IOWA GAMBLING TASK, SOMATIC MARKER HYPOTHESIS, AND NEUROECONOMICS: RATIONALITY AND EMOTION IN DECISION UNDER UNCERTAINTY

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Editorial: Iowa Gambling Task, Somatic Marker Hypothesis, and Neuroeconomics: Rationality and Emotion in Decision Under Uncertainty

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Editorial on the Research Topic

Iowa Gambling Task, Somatic Marker Hypothesis, and Neuroeconomics: Rationality and Emotion in Decision Under Uncertainty

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TWO ANTHOLOGIES ON THE STUDY OF DECISION-MAKING UNDER UNCERTAINTY

This anthology is the second in a series of *Frontiers in Psychology* Research Topics exploring how emotion and rationality interact in decision-making in an uncertain environment. The first anthology, "Twenty Years after the Iowa Gambling Task: Rationality, Emotion, and Decision-Making," comprised 24 papers published separately between August 2012 and December 2015 in *Frontiers in Psychology* (Huang et al., 2018). These 24 articles covered the evolution of the Iowa Gambling Task (IGT) over two decades and included a variety of reviews, theoretical integration, clinical examinations, brain-imaging techniques, and model building, revealing numerous applications of IGT in studies of uncertain decision-making.

While the first anthology shed some light on the current state of IGT applications in decision-making, it raised further issues requiring illumination. These questions include the following: (1) What types of neurological, neuropsychological, and psychiatric dysfunction can be measured by IGT? (2) Can IGT bind to skin conductance responses (SCRs) to represent the critical paradigm of somatic markers? (3) What kind of implicit or explicit learning/decision-making ability does the IGT actually test? (4) Does expected value or gain/loss frequency predominantly influence selection behavior in the IGT? (5) Is it possible to develop a relatively powerful data-analysis scheme that can co-register relatively precise neural responses to specific choice behaviors exhibited in the IGT, such as events of winning, losing, and the switch pattern that occurs when different cards are selected (Chiu et al., 2018)?

To re-examine these fundamental issues generated after the first anthology, we should return to IGT's core foundation, i.e., the somatic marker hypothesis (SMH; Damasio, 1994). The SMH should also be reevaluated alongside other major approaches to the study of choice behavior under uncertainty, e.g., classical rational choice models, bounded rationality (Simon, 1955, 1956), prospect theory (Kahneman and Tversky, 1979), and modern neuroeconomics.

Despite their explanatory power, the traditional behavioral decision theories did not formally integrate emotional components into their human decision-making frameworks. A remarkable portion of emerging neuroeconomic research has focused on the impact of emotion on choice behavior. SMH and IGT could plausibly link traditional behavioral decision theory to emerging neuroeconomic research, highlighting the interplay between emotion and rationality in decision-making under uncertainty. A recent upsurge of interest in modeling emotion in artificial intelligence (AI) or social robotics systems could also be critically evaluated along with these studies: combining SMH and emotion theory within new-generation AI can potentially contribute much to current knowledge.

We therefore proposed a second Research Topic to serve these purposes: "*Iowa Gambling Task, Somatic Marker Hypothesis, and Neuroeconomics: Rationality and Emotion in Decision Under Uncertainty*." To this end, we have anthologized 18 articles published in *Frontiers in Psychology* between 2018 and 2022. As with the first anthology, these articles encompass reviews, theoretical integration, clinical examinations, brain-imaging technology, and model construction. Like the first anthology, they center on the IGT and SMH while covering a range of additional issues as a springboard to further studies of the interaction between emotion and rationality in decision-making under uncertainty.

TWO INSEPARABLE ENTITIES: THE SMH AND THE IGT

In traditional economic theory, rational economic decisions are defined as decisions aimed at maximizing monetary output (von Neumann and Morgenstern, 1947). Nevertheless, behavioral decision studies generally concur that choice behavior does not depend on the decision-maker's ability to calculate long-term overall gains and losses (Kahneman, 2003), fully refuting traditional models such as those of expected value or utility. In contrast to the neglect of emotion in these models, the SMH has stressed the facilitative role of emotion in decision-making under uncertainty (Damasio, 1994). For example, if decision-makers rely on skin conductance (SCR) as an index of somatic markers more than logic or logical reasoning (Bechara et al., 1997), they may increasingly predict long-term benefits, in a sense coming to see and choose good rather than bad decks. Conversely, the dysfunction of somatic marker systems can lead decision-makers to make risky and irrational choices.

For more than two decades, the revolutionary concept of SMH has framed studies of the impact of emotion on decision-making in dynamic-uncertain situations (Dunn et al., 2006). Interestingly, the IGT experiments undertaken by Bechara et al. (1994, 1997) remain a cornerstone of the concept's verifiability. The IGT itself was developed to evaluate realistic decision behavior in a dynamic-uncertain world. Bechara et al. (1994) designed the first dynamic-consecutive four-deck decision game, a significant departure from the descriptive games that preceded it. Participants did not know the outcome, gain-loss probability, or immediate gain-loss of the four decks. SMH shows that the choice patterns of healthy decision-makers can be predicted by eventual returns from the IGT.

As a complex gamble that simulates most types of gamble experience in dynamic-uncertain situations, the IGT thus offers an experimental platform for researchers to study the role of (unconscious) emotion in decision-making under uncertainty. The IGT requires participants to choose from four decks of cards marked A, B, C, and D, which each contain different proportions of "good" and "bad" cards. Whereas the average cost across more than ten trials from the "good" final outcome decks (A and B) will cost the decision-maker 250 USD, the same number of trials from the "bad" final outcome decks C and D will produce gains of 250 USD, on average. Decks C and D provide relatively small instant gains per trial but produce positive long-term consequences; A and B offer relatively large instant gains per trial but lead to negative final consequences in the long run (Bechara et al., 1994). This information is not shared with decision-makers, who therefore have no initial knowledge of the internal gamble structure and final outcomes. This lack of guidance on making the correct choices thus simulates the experience of a dynamic-uncertain world. Bechara et al. (1994) observed that from an initial position of ignorance, healthy participants gradually learned to distinguish between good and bad decks using emotional markers. On the contrary, participants with damage to the ventromedial prefrontal cortex (VMPFC) were powerless to suppress their tendencies to choose the bad decks, losing money consecutively and displaying myopic decision behavior.

However, subsequent findings have been inconsistent, with many IGT-related studies querying whether the IGT provides an adequate verification of SMH (Tomb et al., 2002; Maia and McClelland, 2004, 2005; Lin et al., 2007; Chiu et al., 2008, 2012). SMH assumes that healthy decision-makers will make positive selections that lead to positive final results during the IGT due to alert signals generated by somatic markers, with the reverse also holding for participants with VMPFC. However, additional mechanisms guiding choice behavior during the IGT have since been uncovered. Many researchers stress the importance of immediate gain-loss (as represented by the gain-loss frequency in the gamble) rather than expectations of long-term gains or losses. In these studies, "bad" deck B and "good" deck D appeared to be chosen because they contained higher probabilities of gain and lower probabilities of loss, irrespective of long-term outcomes. Remarkably, game outcomes indicated that SMH was comparable to SCR in healthy decision-makers and VMPFC patients alike.

In particular, the prominent deck B (PDB) phenomenon in which decision-makers prefer the higher frequency of gains but disadvantageous final result of deck B indicates the inability of some decision-makers to consider long-term outcomes/expectations during the IGT (for reviews, see Wilder et al., 1998; Lin et al., 2007; Chiu et al., 2008, 2012, 2018). These developments also resonate with conclusions from behavioral decision theory (Kahneman and Tversky, 1979; Kahneman, 2003) that decision-making under uncertainty is shortsighted, conflicting with the classical SMH understanding that decision-makers are primarily guided by foresight. If the frequency of gains or losses could explain participants' poor performance

in the IGT, or if healthy participants exhibited patterns of shortsighted choice like those with VMPFC lesions (Caroselli et al., 2006), the SMH's basic assumptions would need to be revised. Additional research is therefore required to clarify the interaction between emotion and rationality in decision-making under uncertainty. Hopefully, such studies will highlight the relative strengths and weaknesses of the different approaches and point to a possible resolution of the core hypothesis.

THE ANTHOLOGY

In the light of these considerations and following our second-round call for papers in 2018, this anthology was compiled from 18 published articles, each allocated to one of five categories, as summarized below.

Reviews

Xu and Huang provide a mini-review of the evidence of IGT combined with SCRs, ERPs, and HR, while Lee et al. present cross-cultural evidence that the Prominent Deck B (PDB) phenomenon is widespread.

Clinical Examinations

Na et al. consider the IGT and event-related potentials and demonstrate the net score was correlated with feedback-related negativity (FRN). Singh et al. provide evidence for changes in decision behavior in the IGT among people with left-hemispheric atrophy and hemispherectomy at the pre- and post-operational stages. Buelow and Brunell show that individuals who recalled painful social experiences preferred low-risk choices throughout the IGT, and there was no significant influence of narcissism in the balloon simulation risk task (BART), Columbia card task, Dice Game Task, or IGT. Martínez-García et al. show that eating disorder cases with more distorted body image made more disadvantageous or riskier decisions in the IGT. Gorzelańczyk et al. demonstrate that, compared with healthy control subjects, individuals with gambling addiction made riskier decisions in the IGT, whereas opiate addicts undergoing methadone treatment were less prone to risk-taking behaviors. Hengen and Alpers describe how they utilized the BART to evaluate the correlation between decision-making, social stress, and social anxiety. Xu et al. review research into IGT and schizophrenia and conducted empirical research showing that the PDB phenomenon applied to both schizophrenia and control groups, with the expected value rather less sensitive than gain-loss frequency in differentiating between the decision patterns of each group.

Model Construction

Soshi et al. used empirical data and regression models to show that pre-specified state and anxiety traits forecast future choice behaviors differently. Harada explains how the Q-learning computation model was used to examine the influence of emotion and risk on divergent and convergent thinking. Merchán-Clavellino et al. integrated an unlimited-time version of the IGT, anticipatory skin conductance response, and probabilistic Prospect Valence Learning model to test the correlation of decision behavior and SMH.

Theoretical Integration

In Singh et al.'s study, IGT data from three high, moderate, and low gender parity cultures (Germany, the United States, and India) was collected to test gender differences under the two phases (uncertainty and risk) of IGT. Using IGT and saliva testing, Singh shows that sex (testosterone) and stress (cortisol) hormones may be involved in regulating men's long-term decision-making in IGT. To target third question "(3) What kind of implicit or explicit learning/decision-making ability does the IGT actually test?", Chiu et al., detailly reanalyzed the raw data of Maia and McClelland (2004) study. Chiu et al. found that in Bechara et al. (1997) and Maia and McClelland (2004) IGT studies with variant versions of the questionnaire, however, the IGT performance between both studies was partially different, this revealed both questionnaires might have the different suggestive effect for rational choice in the IGT. Notably, both datasets in Maia and McClelland (2004) study reveal that healthy decision-makers behave myopically, which is against the basic assumption of IGT (Bechara et al., 1994, 1997).

Brain-Imaging Technology

Neo et al. describe research utilizing forced choice and economic tasks while observing right frontal goal conflict-specific EEG rhythms to detect changes in decision-making behavior under conflict, gain, and loss situations. Giustiniani et al. combined IGT and EEG to explore the relationship between motivation level and decision-making ability. Jäger et al. developed an iterative decision-making task in conjunction with fMRI studies and demonstrate that expected valence appears to be the best predictor of repetitive decision-making in the gambling task.

CONCLUSION

The 18 articles summarized above are included in this second *Frontiers in Psychology* anthology of research into the interplay of rationality and emotion on decision behavior under dynamic-uncertain conditions. Overall, several tentative conclusions warranting further investigation can be drawn from the findings. First, some results support those of the previous anthology that the outcomes of the IGT may violate some of the core assumptions of the SMH. Second, the variable of gain and loss frequency in the game is instrumental in the decision-making process under uncertainty, irrespective of whether the uncertain choice settings are implicit or explicit. In this topic, we (Chiu et al.) re-raise the question of "what do IGT participants really know?", which may remain controversial. However, we found that under uncertainty, most participants' decision-making was really behaved based on the gain-loss frequency. Third, the IGT continues to approximate real-life decision-making under uncertainty relatively realistic than the traditional, static, single-trial gambling task (Hastie and Dawes, 2010). This validity is reflected in its extension into clinical investigations and related brain-imaging studies of risk-taking, ensuring the IGT remains a critical experimental paradigm for future decision-making research (Hastie and Dawes, 2010), as this anthology shows. How best to reformulate the revolutionary scheme of the SMH in the

light of increasingly diverse IGT results is a question that deserves our continuing attention (Chiu et al., 2018).

AUTHOR CONTRIBUTIONS

C-HL, Y-CC, and J-TH contributed to this article and finalized the draft after several rounds of detailed discussions. Y-CC and C-HL wrote the first draft. J-TH refined the manuscript. All authors contributed to the article and approved the submitted version.

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Pre-specified Anxiety Predicts Future Decision-Making Performances Under Different Temporally Constrained Conditions

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In real-life circumstances, people occasionally require making forced decisions when encountering unpredictable events and situations that yield socially and privately unfavorable consequences. In order to prevent future negative consequences, it is beneficial to successfully predict future decision-making behaviors based on various types of information, including behavioral traits and/or psychological states. For this prospective purpose, the present study used the Iowa Gambling Task, which simulates multiple aspects of real-life decision-making processes, such as choice preference, selection and evaluation of output feedback, and investigated how anxiety profiles predict decision-making performances under conditions with different temporal pressures on task execution. To conduct a temporally causal analysis, we assessed the trait and state anxiety profiles of 33 young participants prior to the task and analyzed their subsequent decision-making performances. We separated two disadvantageous card decks with high rewards and losses into high- and middle-risk decks, and calculated local performance indexes for decision-making immediately after salient penalty events for the high-risk deck in addition to traditional global performance indexes concerning overall trial outcomes such as final winnings and net scores. For global decision-making, higher trait anxiety predicted more risky choices solely in the self-paced condition without temporal pressure. For local decision-making, state anxiety predicted risk-taking performances differently in the self- and forced-paced conditions. In the self-paced condition, higher state anxiety predicted higher risk-avoidance. In the forced-paced condition, higher state anxiety predicted more frequent choices of the middle-risk deck. These findings suggest not only that pre-specified anxiety profiles can effectively predict future decision-making behaviors under different temporal pressures, but also newly indicate that behavioral mechanisms for moderate risk-taking under an emergent condition should be focused on to effectively prevent future unfavorable consequences when actually encountering negative events.

Keywords: decision-making, Iowa Gambling Task, anxiety, temporal pressure, prospective approach

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INTRODUCTION

People often face various unpredictable events and must decide acts in daily-life situations. In particular, when events are emotionally salient under situational pressure and uncertainty, we may often have difficulty in stably making decisions to obtain positive consequences. To lead a smooth social life, it is advantageous to be able to predict future decision-making performances based on individual behavioral and psychological profiles before actually encountering negative events. Along with the somatic marker hypothesis, which posits that physiological signals anticipatorily affect decision-making under information uncertainty (Damasio, 1996; Bechara et al., 2003; Werner et al., 2013), we hypothesize that decision-making is an adaptive product of the interaction between situational and individual psychological factors, and examine how individual psychological profiles predict future decision-making behaviors.

To examine human decision-making processes in real-life situations in an experimental context, we used the Iowa Gambling Task (IGT), which has been frequently utilized during the past 20 years (Bechara et al., 1994; Chiu et al., 2018). The decision-making process instantiated in the IGT is defined as the executive function that among current lists of choice options that are perceived and/or stored in a short-term memory, people voluntarily select the best option (Bechara et al., 1998). The main characteristics of the IGT consist of the following three factors: (1) probabilistic emotional events of reward and loss, (2) information ambiguity (e.g., ratios between reward and loss) in task execution, and (3) reinforcement learning of an anticipatory decision-making strategy. In each trial of the IGT, participants are required to select one card from advantageous or disadvantageous card decks to maximize the sum of rewards in all trials. Participants are not initially provided with information about the compositions of rewards and losses in each deck nor its probabilities and must learn and anticipate deck types by feedback information about current rewards and penalties. Developing or modifying a decision-making strategy is iteratively based on three sub-processes (Paulus, 2005). The first is assessment of preference for the options, in which an individual assigns advantageous and/or disadvantageous values to behavioral options in an anticipatory manner. The second is execution of selectional action, where individuals must actually select one of the options and inhibit the other options. The third is evaluation of decision-making outcomes by comparing realized outcomes with their anticipation in order to reinforce or modify their preferences and choice patterns. Decision-making in the IGT tends to be distinguished from other executive functions such as cognitive switching and inhibition (Bechara et al., 1998; Bechara, 2004; Toplak et al., 2010); however, there is still controversy regarding whether there is a clear distinction between them (Fellows, 2007; Ouerchefani et al., 2017). As argued by Ernst et al. (2002), because the IGT includes both decision-making *per se*, such as execution of selection (Paulus, 2005), and anticipation of reward and loss as an emotional feedback, it activates not only the dorsolateral prefrontal and anterior cingulate cortices for executive functions such as attention (Ernst et al., 2002) but also the ventromedial prefrontal cortex and amygdala for emotional regulation (Bechara et al., 1998, 2003; Bechara, 2004).

One of the factors affecting decision-making includes temporal parameters (Bowman et al., 2005; Cella et al., 2007; DeDonno and Demaree, 2008; Madan et al., 2015). In real-life circumstances, we often face situations requiring decision-making not only with comfort but also under time constraints of short duration. Because temporal pressure allows limited resources for online psychological processing, it may affect wide aspects of decision-making such as option assessment, action execution, and outcome evaluation (Paulus, 2005). Cella et al. (2007) examined how external temporal pressure affected decision-making processes in the IGT. They divided participants into three groups and externally imposed 2- and 4-s temporal constraints on deck selection in two groups. Compared to the control group without temporal constraints, the participants with the 2-s constraint more frequently selected disadvantageous decks even as trial blocks advanced.

Internal temporal pressure also affects decision-making. DeDonno and Demaree (2008) did not expose participants to external temporal pressure; however, they manipulated the perceived time pressure for the task by presenting the explicit message that the time available for deck selection was not sufficient for successful task execution. Compared to the control group, the pressured group more frequently selected disadvantageous decks. Studies with clinical populations have also shown supportive evidence for the relationship between internal temporal pressure and decision-making. People with obsessive-compulsive disorder (OCD) show behavioral impulsivity (Nielen et al., 2002; Chamberlain et al., 2006; Benatti et al., 2014; Grassi et al., 2015), which is defined as the trait of spontaneously making temporally pressured or rapid responses without considering unfavorable consequences (Moeller et al., 2001). Patients with OCD tend to make risky choices (Cavedini et al., 2002; Starcke et al., 2010; Grassi et al., 2015; but for an opposing perspective, see Glicksohn et al., 2007) because of abnormal functional connections between the basal ganglia and ventromedial prefrontal cortex in the emotional regulation pathway (Rapoport, 1990). Grassi et al. (2015), for example, recruited participants diagnosed with OCD and compared their decision-making in the IGT with that of the control participants. Those with OCD had higher impulsivity scores (in particular, attentional, and non-planning impulsivity) than did the control participants, and they did not modify disadvantageous selections even during later trial blocks, as observed in a previous study (Starcke et al., 2010). Taken together, external and internal temporal pressures change decision-making in diverse populations.

Another influential factor is anxiety, which is evoked by subjective uncertainty to future-oriented negative situations and events (Cannistraro and Rauch, 2003; Mueller et al., 2010) and is occasionally experienced under threat; it is accompanied by autonomic physiological reactions and/or cognitive negativity bias (Robinson et al., 2013; Wiedemann, 2015). Future-oriented uncertainty, in particular, is an important environmental aspect that evokes anxiety and is a fundamental dimension of decision-making processes because of iteratively promoting reinforcement

learning for solving uncertainty in an anticipatory manner (Paulus, 2005). The close relationship between anxiety and decision-making is also supported by neuroimaging findings that the ventromedial prefrontal cortex and amygdala are related to anxiety in an overlapping manner with decision-making (Tian et al., 2016; Brinkmann et al., 2018).

Anxiety is generally sub-divided into trait and state profiles (Spielberger et al., 1970; Spielberger, 1989). Trait anxiety is a stable personality profile characterized by a disposition to easily experiencing anxiety states. State anxiety is a relatively short-term emotional state under stress, consisting of transient feelings of tension and apprehension and an elevated automatic nervous response. Trait and state anxiety adversely or advantageously affect decision-making (Robinson et al., 2013). Starcke et al. (2008) separated participants into two groups with and without a prospective stressful speech task that was scheduled before a decision-making task, but was not actually conducted. The stress group, compared to the control group, reported higher state anxiety scores and attenuated risk-avoidance. That is, long-term stress related to future tasks may trigger intrusive thoughts and reduce memory resources for decision-making, resulting in less risk-avoidance (Ashcraft and Kirk, 2001).

On the other hand, anxiety can reversely promote conservative risk-avoidance (Mather et al., 2009; Clark et al., 2012). Clark et al. (2012) exposed participants to an electrical shock, a threat stimulus (Kuriyama et al., 2011), during each trial of a decision-making task and compared the performances with those in the safe condition without shocks. Participants were more risk-avoidant in the stress condition than in the safe condition, suggesting that aversive shocks were not intrusive and instead enhanced the interoception of physical responses or somatic markers for negative consequences or increased sensitivity to future threats by the automatic activation of emotional neural correlates such as the amygdala (Jiang et al., 2009) to promote risk-avoidance. Such risk-avoidance has also been persistently observed in a specific clinical population. Mueller et al. (2010) recruited individuals with generalized anxiety disorder (GAD), which is characterized by intense future-oriented anxious traits, and compared their decision-making behaviors in the IGT with those of controls. Those with GAD successively increased risk-avoidance performances compared to the controls as the trials advanced. These findings suggest that trait and state anxiety affect decision-making in divergent ways.

The effects of temporal pressure and anxiety may not be independent during decision-making in the IGT. Anxiety tends to be related to speeded-up mental processing such as racing thoughts, where thinking is accelerated subjectively (Pronin and Jacobs, 2008; Keizer et al., 2014; Aho, 2018). Thus, when people with different anxiety traits are exposed to externally temporally pressured conditions, they may respond differently to temporal pressure, yielding different patterns of decision-making processes. As has been initially argued in this chapter, from the prospective standpoint of preventing future negative consequences, it is beneficial to predict individual future decision-making behaviors before actually encountering salient negative events under emergent conditions. Such predictive benefits are more crucial for potential victims in social circumstances, when negative events are socially problematic, such as financial and billing frauds (Deevy et al., 2012).

Trait and state anxiety may predict different aspects of decision-making processes (Bishop, 2007; Tian et al., 2016). The IGT may present a conflicting situation between long- and short-term anxiety because of the alternation of reward and loss in an ambiguous manner. By continuously selecting low-risk decks with low reward and loss, people can effectively avoid high penalty events and enjoy low levels of transient anxiety states. However, compared to adaptive deck selection, which comprises risk-taking with the tendency to successfully avoid losses, persistent low risk-taking may result in earning relatively small amounts of final winnings, which is potentially associated with sustained or less state anxiety due to not realizing one's ideal final winnings. If trait anxiety is more related to sustained future-oriented anxiety during the task, people with higher trait anxiety may more frequently select high-risk decks in particular under information ambiguity without deck information, as observed in previous studies (Miu et al., 2008; Engelmann et al., 2015). On the other hand, when frequently selecting high-risk decks to obtain large gains, people can potentially attenuate sustained anxiety concerning the task mission if high penalty events do not occur. However, people may actually often face high penalty events and strongly and frequently experience transient state anxiety. Thus, people with higher state anxiety may make lower risky choice. If such a trade-off between trait and state anxiety during decision-making in the IGT can be predicted by pre-specified state and trait anxious characteristics, advance information about anxiety profiles and task performances may be useful for people to prevent future negative consequences.

The current study, therefore, assessed participants' state and trait anxiety before the IGT and conducted the IGT under different temporal pressures to make a temporally causal prediction analysis of participants' decision-making behaviors by anxiety profiles. We examined not only overall or global decision-making but also change in local performances immediately after salient penalty events, because coping with salient negative events under temporal pressure, such as post-error recovery, is difficult even in healthy populations (Soshi et al., 2015), although it is important to avoid subsequent negative consequences. We then treated the two disadvantageous decks separately, as suggested by a previous study (Buelow and Suhr, 2013). In the structure of the standard IGT, Deck B includes one maximum penalty card ($ −1,250) randomly ordered in each of the 10-trial blocks (i.e., 10%) (Bechara et al., 1994). The maximum penalty event, therefore, is a probabilistically rare, unpredictable negative event and is suitable for predicting future decision-making performances after saliently negative events by anxiety profiles. To examine global decision-making performances, we calculated popular behavioral indexes of risk-taking such as net scores (advantageous deck minus disadvantageous deck), final winnings, and the total number of maximum penalty events.

We hypothesized the following: (1) pre-specified trait anxiety predicts global decision-making performances differently in the self- and forced-paced conditions, because trait anxiety is likely related to sustained anxiety concerning the flaw in the final mission of the IGT (i.e., maximizing the final winnings);

and (2) pre-specified state anxiety predicts local decision-making performances differently in the self- and forced-paced conditions, because state anxiety is likely related to transient sensitivity to sudden negative events, thereby instantaneously promoting risk-avoidance. Such hypothesized functions of trait and state anxiety may dynamically determine individual decision-making performances in daily social life, and the pre-specification of individual anxiety profiles is likely effective for individuals to develop a strategy for coping with future negative events in daily life.

MATERIALS AND METHODS

Participants

The present study enrolled 33 participants [men: 19 individuals, age (mean ± SD) = 21.4 ± 2.5 years, intelligence quotient (IQ) = 109.5 ± 6.0; women: 14 individuals, age = 22.6 ± 2.0 years, IQ = 113.6 ± 3.9]. They were locally recruited through an advertisement at the Tokyo Institute of Technology and were given 2,000 yen as the baseline reward, and an optional bonus of not more than 3,000 yen depending on their task performance results. All of them had normal or corrected-to-normal visual acuity, and self-reported that they did not have any current and past psychiatric or neurological histories and had not taken medicine for any illness. Their IQ was assessed using the Japanese version of the National Adult Reading Test (Nelson and Wilson, 1991; Matsuoka and Kim, 2007). Written informed consent was obtained from the participants according to the institutional guidelines before conducting the experiment. The study was conducted in accordance with the Declaration of Helsinki, a statement of ethical principles for medical research involving human participants, and was approved by the Ethics Committee of the Tokyo Institute of Technology.

Iowa Gambling Task

We used the IGT task developed by Bechara et al. (1994) to examine change in decision-making performances under temporal pressure. The mission of the task was to maximize the final winnings based on an initial fund of 200,000 yen. Participants selected one of the four advantageous or disadvantageous decks in each of the 100 trials with no information about the total number of trials. Frequent choice of the disadvantageous decks as risk-taking leads to smaller gains at the end of the task. Decks 1 and 2 are disadvantageous decks with constantly high returns of 10,000 yen, but randomly produce high monetary loss. Deck 1 is a deck with frequent penalties and randomly distributes five instances of monetary loss from −15,000 to −35,000 yen, with steps of 5,000 yen in each set of 10 trials, which amounts to a total penalty of −125,000 yen. Deck 2 is a deck with infrequent penalties as well as the highest penalty, randomly including one penalty of −125,000 yen in each set of 10 trials. Decks 3 and 4 are advantageous decks, with lower rewards of 5,000 yen and smaller penalties. Deck 3 frequently and randomly includes five trials of monetary loss ranging from −2,500 to −7,500 yen, with steps of 2,500 yen in each set of 10 trials with a total penalty of −25,000 yen. Deck 4 infrequently dispenses one penalty card of −25,000 yen randomly in each set of 10 trials. Because the participants in the present study performed the IGT in both the self- and forced-paced conditions, the four decks were randomly arranged so as not to appear in the same order for the two conditions. The present study used a modified version of the IGT program implemented in Cognitive Experiments V v1 (Neurobehavioral Systems, Inc., Berkeley, CA, United States) for the Japanese-translated version.

Psychological Assessment

To investigate how pre-specified anxiety characteristics are related to subsequent decision-making behaviors in the self- and forced-paced conditions, we assessed participants' trait and state anxiety using the Spielberger State-Trait Anxiety Inventory (STAI) (Spielberger et al., 1970; Spielberger, 1989). This scale assesses the levels of trait anxiety (STAI-T) and state anxiety (STAI-S) with 40 items; STAI-T measures the stable temperament of behaving anxiously, whereas STAI-S measures individuals' current transient anxious status in response to emotional events and situational changes. The participants completed both scales after arriving at the experimental room and underwent an interview about 1 h before performing the IGT.

Procedure

Participants came to a quiet experimental room to perform the IGT in the self- and forced-paced conditions. They were first provided with instructions concerning the aim and procedure of the experiment on ethical guidelines. As has been argued in the previous study (Bull et al., 2015), task-instruction manners strongly affect participants' ability to build optimal strategies. The original task instructions include the necessary information about deck types (advantageous and disadvantageous) and behavioral preferences for avoiding disadvantageous decks to evade large monetary loss (Bechara et al., 2000b). Such rich and unambiguous information has been important for sophisticated IGT performances (Horne and Lowe, 1993; Balodis et al., 2006; Fernie and Tunney, 2006; Glicksohn and Zilberman, 2010; Bull et al., 2015). The aim of the present study, on the other hand, is to elucidate change in relationships between decision-making behaviors and pre-specified anxiety under intensified ambiguity about the task-structure information in different temporally pressured conditions. Therefore, we minimally instructed participants to maximize the initial fund of 200,000 yen without hints about deck types and a performance strategy, and maximized information ambiguity, which in turn may promote anxious behaviors under information ambiguity (Kalin and Shelton, 1989; Robinson et al., 2013), as in a previous study (Glicksohn et al., 2007). Subsequently, participants faced a 19-inch PC monitor (DELL) placed 0.65 m in front of them and completed a short practice session to learn to manipulate the response pad (RB-740, Cedrus, Corp., San Pedro, CA, United States). The practice session used dummy decks that were randomly assigned rewards and losses to possess indiscriminate patterns of card sequences for purpose to avoid guessing structural information of the decks used in the trials. After understanding the task procedure, participants performed the IGT in the self- and forced-paced conditions, which

were separated by a 5-min rest interval. The task order was counterbalanced across participants. In the self-paced condition, participants were provided with sufficient time to select one of the four decks at their own pace, and the feedback display showed the current gain and loss as well as the total payoff for 2500 ms. The self-paced condition, therefore, provided participants with sufficient time to learn to discriminate between the advantageous and disadvantageous decks. The forced-paced condition, on the other hand, required participants to select a deck as soon as possible after viewing the main deck-selection display under temporal pressure. The forced-paced instruction ("Choose quickly!") always appeared immediately below the decks at the start of each main display and remained until participants selected a deck. The feedback displays appeared for only 500 ms and were soon followed by the main display again. After completing all the tasks, participants self-assessed their deck selection patterns based on five categories: "1" = I intended to select the deck with low rewards and infrequent lower penalty (Deck 4); "2" = I intended to select the deck with low rewards and frequent lowest penalty (Deck 3); "3" = I intended to select the deck with high rewards and infrequent highest penalty (Deck 2); "4" = I intended to select the deck with high rewards and frequent higher penalties (Deck 1); and "5" = others.

Behavioral Indexes for Decision-Making Behavior

Global Deck-Selection Behaviors

We first analyzed global behavioral patterns of the 100 trials overall, using two traditional indexes and eight additional indexes. The first popular index is the final winnings (yen), which indicates that higher risk-taking for disadvantageous decks leads to smaller final winnings. The second traditional index is the net scores of the five trial blocks (Block 1: trials 1–20, Block 2: 21–40, Block 3: 41–60, Block 4: 61–80, Block 5: 81–100), which are calculated by subtracting the number of the selected disadvantageous decks (Decks 1 and 2) from the number of the selected advantageous decks (Decks 3 and 4) for the index of risk-avoidance. More positive scores indicate higher preference for risk-avoidance. The third index is the number of maximum penalty events of −125,000 yen. Participants with a preference for selecting Deck 2 frequently encounter the maximum penalty events. The fourth index is the complexity of deck selection, represented by mean entropy ($H = -\Sigma p_i \times \log_2 p_i$; p = probability of deck choice; i = the number of the deck). Higher entropy (bit) indicates that participants more frequently change their choice of decks throughout the trials overall. For example, when participants who acquired an optimal strategy intend to avoid high risk-taking and establish larger monetary gains in their final winnings, they may tend to continuously choose advantageous decks, consequently yielding lower entropy. The fifth and sixth indexes are related to total and continuous selectivity (%) of the high-risk Deck 2. Total selectivity is the percentage of selected Deck 2 in the overall 100 trials. Continuous selectivity is the percentage of more than one continuously selected Deck 2 in the total number of selected Deck 2. These indexes indicate that higher ratios correspond to a higher preference for high risk-taking. The seventh and eighth indexes are the total and continuous selectivity of the middle-risk Deck 1, which indicates moderate risk-taking. The 9 and 10th indexes are the total and continuous selectivity of the low-risk Decks 3 and 4. Increased ratios for the low-risk decks indicate a preference for risk-avoidance, despite resulting in relatively small monetary gains in each selection but larger final winnings. Response times (RTs) for deck selection were calculated for the self- and forced-paced conditions. We first analyzed mean RTs for all 100 trials under both conditions. Second, along with the net-score analysis for temporal transition of a decision-making pattern, the overall trials were separated into the five blocks, each comprising 20 trials, and a mean RT for each block was calculated for each condition.

Local Deck-Selection Behaviors

Large fluctuation in deck-selection patterns likely occurs after the maximum penalty event in Deck 2 (−125,000 yen) (Buelow and Suhr, 2013). In particular, participants with a preference for low risk-taking may tend to avoid Deck 2 and alternatively select the lower-risk decks after encountering the maximum penalty event. Therefore, we specified the occurrences of maximum penalty events and produced the indexes for local performance changes by calculating the post-event change in the selectivity of the high- (Deck 2) and low- (Decks 3 and 4) risk decks. We also examined the selection change of the middle-risk deck (Deck 1) as the index of change for moderate risk-taking. Although Deck 1 has been traditionally grouped together with Deck 2 as a disadvantageous deck, Deck 1 may be selected differently from not only high- but also low-risk decks after maximum penalty events, because it possesses the same high monetary reward of 10,000 yen and relatively low monetary loss compared to Deck 2 if not being persistently selected. We obtained individual information about the maximum penalty events until the occurrence of the third penalty event because of maintaining over 20 participants in the local performance analyses. First, we calculated the ratios of decks selected before (pre) and after (post) the maximum penalty events (**Figure 1**). The ratio for the pre-event trials is the percentage of selected decks in the total of the five trials immediately before the maximum penalty event. The ratios for the post-event trials consisted of two indexes. The first post-event index (post 1) is represented by the percentage of selected decks in the total of the first-half of the five post-event trials and can be used to obtain information about immediate recovery from high risk-taking. The second post-event index (post 2) is the percentage of decks occupying the five second-half trials, providing information about delayed recovery from high risk-taking. For example, participants with higher negative sensitivity to the maximum penalty might reduce post-1 ratios of the high-risk deck sooner.

Statistical Analysis

We initially summarized participants' self-awareness of deck-selection strategy based on their self-reported scores. We counted the numbers of participants adopting voluntary deck-selection strategies. The answers from "1" to "4" indicate that participants used their preference trend to select one of the four decks.

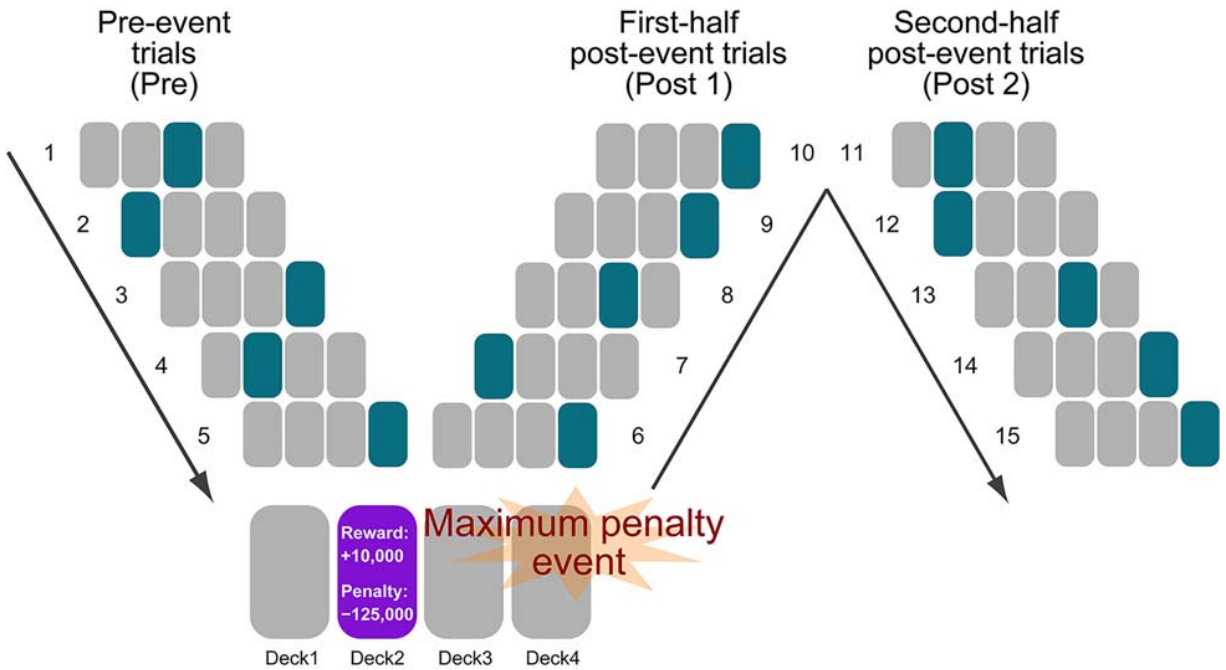

FIGURE 1 | Analysis of local behavioral patterns before and after the maximum penalty event. For the purpose of elucidating local decision-making behavioral characteristics in the Iowa Gambling Task (IGT) under the self- and forced-paced conditions, pre- and post-penalty (–125,000 yen in Deck 2) trials were analyzed for each participant. First, we counted the frequency of the occurrence of the maximum penalty event for each participant. Second, by subtracting the proportions of the selected decks during the post-event trials from those during the pre-event trials, post-event changes in deck selection were examined for the high-, middle-, and low-risk decks. Pre, post 1, and post 2 indicate the five trials immediately before the event, the first-half and second-half post-event trials.

The answer of "5" was counted as a voluntary strategy when participants self-reported that, for example, they selected decks to suppress monetary loss.

For the global performance indexes except the net score, we compared the self- and forced-paced conditions using non-parametric Wilcoxon signed-rank tests, because many index scores violated normality (Anderson-Daring tests: self-paced condition, numbers of maximum penalty events, mean entropy, continuous selectivity of high-risk decks; forced-paced condition: final winnings, numbers of maximum penalty events, mean entropy, continuous selectivity of high-risk decks, total selectivity of low-risk decks). Concerning the net score, almost all of the scores of the five blocks for the self- and forced-paced conditions also violated normality. To test the interaction effect between task (self- and forced-paced conditions) and block, we initially performed z-normalization for all of the data (5 blocks × 2 tasks × 33 participants) and conducted repeated-measures ANOVAs. Response time data for the overall 100 trials were also compared between the self- and forced-paced conditions by a paired *t*-test with normalized data. Subsequently, normalized RTs for the five blocks were analyzed with a two-way repeated-measures ANOVA with the factors of condition (self-paced, forced-paced) and block (Blocks 1–5). When a significant interaction appeared, the block effect was tested separately for each condition by follow-up ANOVAs. Over-one degrees of freedom were corrected for effects related with a trial-block factor using the Greenhouse–Geisser method (ε).

To examine the relations between global performances and anxiety characteristics in each condition, we conducted multiple linear regression analyses using each of the 10 global indexes as a dependent variable (Y) and STAI-T and STAI-S, which were recorded before the IGT, as independent predictive variables (X), controlling for age, sex, IQ, and task order (first = "1," second = "2"). All of the independent and control variables were initially introduced into a regression model, and variables with weak coefficients were successively eliminated in a backward elimination manner. We adopted an explanatory model based on the following criteria: (i) STAI-T and/or STAI-S were significantly included (β: $p < 0.05$), and (ii) explanatory power (adjusted R^2) was the highest among the significant models (F-value: $p < 0.05$). If significant models did not include the STAI variables, we reported the significant model with the highest explanatory power. Multicollinearity between the independent variables was examined by variance inflation factors (*VIF*s) based on the criterion that *VIF*s exceeding 10 indicate severe multicollinearity.

For the local performance indexes, we first compared the three ratios of pre- and post-event trials (pre, post 1, and post 2) with a non-parametric Friedman test. When significant trial-phase effects appeared (χ^2: $p < 0.05$), planned Wilcoxon tests were applied between the pre and post ratios (pre vs. post 1, pre vs. post 2). Multiple regression analyses were also performed to examine the relation between post-event performance changes and anxiety characteristics in a similar manner as in the global performance analysis. The model used the subtraction ratios

between pre- and post-event trials (post 1 or post 2 minus pre) as the dependent variable (Y), STAI-T and STAI-S before the IGT as the independent variable (X), controlling for age, sex, IQ, and task order. We reported significant models based on the criterion adopted in the global performance analysis.

Non-parametric tests for the local performance indexes and regression analyses for both the global and local performances were multiply conducted (non-parametric tests: 3 post-penalty phases × 3 deck types × 2 task conditions = 18 analyses; regression analysis: global, 9 performance indexes × 2 task conditions = 18 analyses; local: 2 post-penalty phases × 3 error events × 3 deck types × 2 task conditions = 36 analyses). This analysis condition allows us to take into consideration both type I errors concerning overestimation of significant explaining models and type II errors involving underestimation of significant effects under intensive correction. Accordingly, to examine the reliabilities of the observed effects under the multiple-testing correction, we performed permutation tests in which samples were randomly and multiply resampled from the original data, and the original results were tested using a *post hoc* permutation distribution of dummy outputs (Nichols and Holmes, 2002), based on the notion that overestimation of significant effects from multiple testing was avoided by data-driven thresholds obtained from at-issue multiple tests.

In the non-parametric permutation tests for the local performance, the raw data of the three trial phases (pre, post 1, post 2) at the maximum penalty events (1st, 2nd, 3rd) in the three deck types (high, middle, low) were transformed into z-scores across participants and combined into a single data set (n = 1,188). All data were randomly reordered and same numbers of samples with participants were chosen for each trial phase (e.g., self-paced: n = 32 for the first post-error phase, n = 30 for the second post-error phase, or n = 24 for the third post-error phase) for Friedman tests. This resampling procedure was repeated 100,000 times with different sample sizes for each penalty event in the two task conditions to obtain dummy p-values. When actual p-values in the original tests (3 penalty events × 3 deck types × 2 task conditions = 18) were within the lower 5% range of the distribution of 100,000 dummy p-values, they were certified as significance-corrected for multiple testing. Similarly, *post hoc* Wilcoxon signed-rank tests used a permutation method to determine a p-value threshold for each pairwise comparison.

In the regression analyses, a similar permutation method was performed as follows: each dependent variable (e.g., final winnings in the global analysis) in the self- and forced-paced conditions was transformed into z-scores across participants. Transformed variables were combined into a single data set separately for each performance analysis, because global and local performance analyses included different dependent variables. Integrated data were randomly reordered and the same numbers of samples as the participants were chosen as a dummy dependent variable (global analysis: n = 33; local analysis for, e.g., the self-paced condition: n = 32 for the first penalty event; n = 30 for the second penalty event; n = 24 for the third penalty event), being regressed by original independent variables including STAI-S and/or STAI-T. Each resampling test was conducted 100,000 times to produce a distribution of dummy p-values. When original p-values were lower than the p-value thresholds (5% borders of the dummy p-value distributions), they were considered significant under correction for multiple testing.

RESULTS

Participants' Voluntary Deck-Selection Strategy

Among the 33 participants, 29 (88%) adopted voluntary strategies. Nine participants answered "1" for Deck 4; four, "2" for Deck 3; seven, "3" for Deck 2; and three, "4" for Deck 1. Among the 10 participants who answered "5," six self-reported using their own strategies. This suggests that the participants felt that they executed the IGT while developing and controlling individual decision-making strategies.

Global Task Behaviors

We initially compared the nine deck-selection indexes except the net score between the self- and forced-paced conditions using the Wilcoxon signed-rank test. No task performances yielded significant differences (final winnings: Z = 0.617, p = 0.537; penalty events: Z = 0.061, p = 0.951; entropy: Z = 0.524, p = 0.600; high-risk deck: total selectivity, Z = 0.804, p = 0.422 and continuous selectivity, Z = 0.253, p = 0.801; middle-risk deck: total selectivity, Z = 0.175, p = 0.861 and continuous selectivity, Z = 0.170, p = 0.865; low-risk deck: total selectivity, Z = 0.751, p = 0.453 and continuous selectivity, Z = 1.108, p = 0.268) (**Supplementary Table S1**).

The results of the net scores are plotted in **Figure 2**. The mean net scores with standard errors of the means are −3.1 ± 0.9, −0.8 ± 0.9, −0.9 ± 1.3, −2.1 ± 1.7, and −0.9 ± 1.7 for the five blocks in the self-paced condition, and −1.5 ± 1.6, 0.9 ± 1.7, 0.5 ± 1.4, 0.8 ± 1.7, and −0.1 ± 1.6 for the five blocks in the forced-paced condition, respectively. The initial ANOVA with normalized data did not indicate a significant difference between the two conditions [condition: $F(1,32)$ = 0.988, p = 0.328; block: $F(4,128)$ = 1.275, p = 0.287; condition × block: $F(4,128)$ = 0.267, p = 0.899]. Although the lack of a significant effect may be surprising in light of previous findings, it is suspected that the current experimental setting increased individual variation in transitions of deck-selection patterns by minimizing task-related instruction without hints about deck types and an optimal deck-selection strategy. Accordingly, we made planned comparisons between Block 1 and Block 2 as a phase transition from exploratory or pre-hunch to predictive phases (Bechara et al., 2000a): actually, net scores changed from Block 1 to Block 2 based on visual inspection. A two-way ANOVA observed a significant block effect across the two task conditions [block: $F(1,32)$ = 4.536, p = 0.041, η_p^2 = 0.124; condition: $F(1,32)$ = 1.067, p = 0.309; condition × block: $F(1,32)$ = 0.003, p = 0.955], indicating that the participants reduced their risk-taking proportions after the initial exploring phase in both task conditions.

Response times for all trials in the self- and forced-paced conditions are 683 ± 92 and 713 ± 110 ms, respectively and

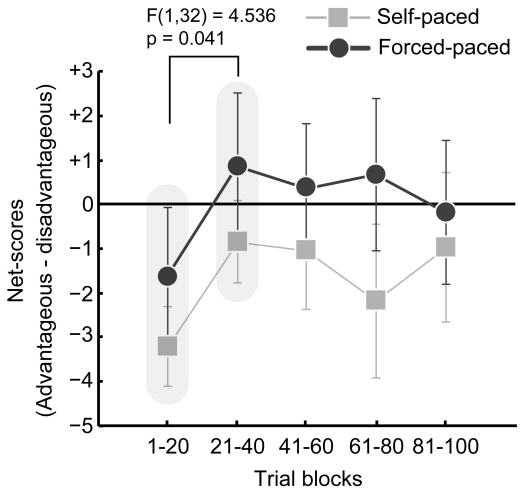

FIGURE 2 | Change in advantageous deck selection patterns in the self- (gray) and forced-paced (black) conditions. The net score for each set of 20 trials was calculated by subtracting the numbers of selected disadvantageous decks (Deck 1 + Deck 2) from the numbers of selected advantageous decks. Larger scores indicate more frequent risk-avoidance. An ANOVA with the factors of condition (self-paced, forced-paced) and block (Block 1, Block 2) showed that net scores significantly increased in the second block in both conditions. Error bars indicate standard errors of the means.

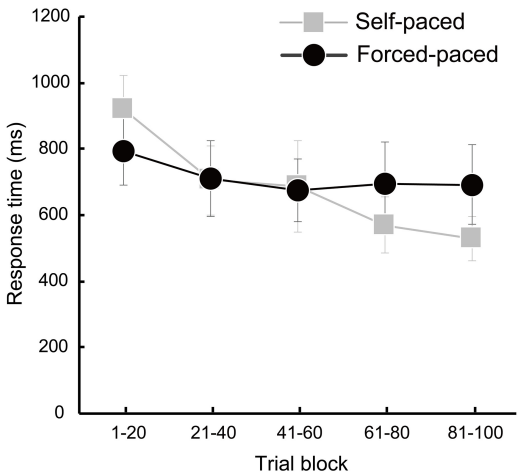

FIGURE 3 | Changes in deck-selection speeds throughout the five trial blocks in the self- (gray) and forced-paced (black) conditions. Mean response time (RT) for each trial block was calculated for the 20 trials in each task condition. A repeated-measures ANOVA was conducted with the factors of condition and block. A significant block effect was observed only in the self-paced condition ($p < 0.0001$).

were not significantly different in a paired t-test [$t(32) = 0.550$, $p = 0.586$]. Response times for the five blocks in the self- and forced-paced conditions are summarized in order as 921 ± 102, 706 ± 105, 687 ± 139, 571 ± 85, and 530 ± 68 ms for the self-paced condition, and 793 ± 102, 711 ± 115, 676 ± 94, 694 ± 128, and 692 ± 120 ms for the forced-paced condition. The summary suggests that the self-paced condition but not the forced-paced condition reduced RTs as progression of the trials (**Figure 3**), which was statistically confirmed. The initial two-way ANOVA indicated the significant interaction of condition × block [$F(4,128) = 3.762$, $p = 0.023$, $\eta_p^2 = 0.105$, $\varepsilon = 0.569$]. The self-paced condition yielded a significant block effect [$F(4,128) = 9.979$, $p < 0.0001$, $\eta_p^2 = 0.238$, $\varepsilon = 0.628$], and the later blocks significantly decreased RTs over the initial block in the planned comparison [Block 1 vs. Block 5: $p < 0.0001$]. The forced-paced condition, on the other hand, did not show a significant block effect [$F(4,128) = 2.811$, $p = 0.060$, $\varepsilon = 0.566$], which indicates that decision-making speed did not alter throughout the overall trials.

The self- and forced-paced conditions showed different relational characteristics between global deck-selection performances and anxiety characteristics. In the self-paced condition, four deck-selection characteristics for risk-taking were significantly predicted by STAI-T (**Table 1**). The numbers of maximum penalty events (**Figure 4Ai**), total and continuous selectivity of the high-risk deck (**Figures 4Aii,iii**), and total selectivity of the low-risk deck (**Figure 4Aiv**) were significantly predicted by STAI-T (maximum penalty events: $\beta = 0.436$, $t = 2.460$, $p = 0.020$, $VIF = 1.153$; high-risk deck: total selectivity, $\beta = 0.426$, $t = 2.541$, $p = 0.017$, $VIF = 1.156$, and continuous selectivity, $\beta = 0.436$, $t = 2.636$, $p = 0.013$, $VIF = 1.155$; low-risk deck: total selectivity, $\beta = -0.411$, $t = 2.242$, $p = 0.033$, $VIF = 1.270$). That is, higher anxiety traits yielded more penalty events, more frequent selection of the high-risk deck, and less frequent selection of the low-risk decks. The total selectivity of the middle-risk deck was predicted by STAI-S ($\beta = -0.426$, $t = 2.468$, $p = 0.019$, $VIF = 1.101$) (**Figure 4Av**). However, in the forced-paced condition (**Table 2**), no deck-selection property was significantly predicted by either STAI-T or STAI-S (**Figures 4Bi–v**). The permutation tests for correction in multiple testing confirmed the observed results: actual p-values of the significant models were below the accidental-level p-value thresholds, set as the border of the lower 5% of dummy p-values (see, for example, **Supplementary Figure S1**) in both the self-paced condition [model with STAI-T (p-value threshold = 0.0506): maximum penalty events, $p = 0.049$; total selectivity in the high-risk deck, $p = 0.025$; total selectivity in the low-risk deck, $p = 0.048$; model with STAI-T and Age (p-value threshold = 0.0503): continuous selectivity in the high-risk deck, $p = 0.012$; model with STAI-S (p-value threshold = 0.0509): total selectivity in the middle-risk deck, $p = 0.044$].

Local Task Behaviors

We specified three earlier maximum penalty events (−125,000 yen) and locally examined post-penalty behaviors. We first calculated the selection rates of the high-, middle-, and low-risk decks immediately before and after the maximum penalty event separately for the self- and forced-paced conditions and compared them using Friedman tests. We then calculated indexes for post-event behavioral change by subtracting the pre-event rates from post-event rates. The difference rate scores, as the dependent variable, were introduced into a regression analysis and were predicted by the independent variables of STAI-T and STAI-S before the IGT.

TABLE 1 | Regression models of overall behavioral patterns in the self-paced condition (n = 33).

Variables	Overall (100 trials)						High-risk deck			
	Final winning		Numbers of maximum penalty events		Mean entropy		Total selectivity		Continuous selectivity	
	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)
STAI-T	−0.351	1.834 (0.077)	0.436*	2.460 (0.020)	0.149	0.797 (0.432)	0.426*	2.541 (0.017)	0.436*	2.636 (0.013)
STAI-S	0.300	1.580 (0.125)	−0.104	0.544 (0.591)	−0.224	1.350 (0.187)	−0.075	0.414 (0.682)	0.019	0.106 (0.916)
Age	−0.179	0.946 (0.352)	0.291	1.641 (0.111)	−0.095	0.508 (0.615)	0.317	1.747 (0.092)	0.381*	2.143 (0.041)
Sex	−0.208	1.223 (0.231)	0.203	1.199 (0.240)	−0.071	0.394 (0.696)	0.194	1.145 (0.262)	0.155	0.923 (0.364)
IQ	−0.105	0.568 (0.574)	0.145	0.807 (0.426)	−0.398*	2.401 (0.023)	0.327	1.845 (0.076)	0.229	1.371 (0.181)
Task order	−0.045	0.263 (0.795)	0.072	0.429 (0.671)	−0.136	0.807 (0.426)	0.146	0.905 (0.374)	0.108	0.673 (0.506)
Regression model										
Adjusted R^2		0.089		0.128		0.133		0.221		0.241
F-value		2.043		3.346		3.458		3.272		4.384
p-value		0.13		0.049*		0.045*		0.025*		0.012*

TABLE 1 | Continued

Variables	Middle-risk deck				Low-risk deck			
	Total selectivity		Continuous selectivity		Total selectivity		Continuous selectivity	
	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)
STAI-T	−0.071	0.363 (0.719)	0.025	0.142 (0.888)	−0.411*	2.350 (0.026)	−0.042	0.253 (0.802)
STAI-S	−0.426*	2.468 (0.019)	−0.022	0.128 (0.899)	0.293	1.598 (0.121)	0.184	1.124 (0.270)
Age	−0.281	1.628 (0.114)	0.069	0.365 (0.718)	−0.153	0.919 (0.366)	0.134	0.743 (0.463)
Sex	0.007	0.041 (0.968)	−0.271	1.481 (0.149)	−0.170	0.967 (0.342)	−0.315	1.792 (0.083)
IQ	−0.044	0.242 (0.811)	−0.353	1.928 (0.063)	−0.309	1.888 (0.069)	−0.448*	2.549 (0.016)
Task order	0.034	0.201 (0.842)	−0.174	1.000 (0.325)	−0.153	0.919 (0.366)	−0.151	0.902 (0.375)
Regression model								
Adjusted R^2		0.134		0.07		0.155		0.143
F-value		3.473		2.205		2.963		3.673
p-value		0.044*		0.128		0.048*		0.037*

*$p < 0.05$.

As observed in **Figure 5**, both the self- and forced-paced conditions showed similar deck-selection trends for the three types of decks. Selection of the high-risk deck generally decreased after the maximum penalty events (post 1, post 2) (**Figure 5A**). Conversely, selection of the low-risk decks tended to increase after the penalty events in both the self- and forced-paced conditions (**Figure 5B**). Although the middle-risk deck has been generally grouped with Deck 2 as a disadvantageous deck, the selectivity showed a flat pattern throughout the overall intervals (**Figure 5C**) that somewhat differed from the selection pattern of the high-risk deck (3 pre and post intervals × 3 penalty events = 9 points: $r = -0.63$) but was relatively similar to that of the low-risk decks ($r = 0.31$).

Non-parametric statistical tests revealed post-penalty behavioral changes in the self-paced condition (**Supplementary Table S2**). Selectivity changes were significant for the first penalty in the low-risk deck and the second penalty in the high- and middle-risk decks in the Freidman tests [low-risk: $\chi^2 = 9.05$, $p = 0.011$; high-risk: $\chi^2 = 7.22$, $p = 0.027$; middle-risk: $\chi^2 = 10.02$, $p = 0.007$]. These *p*-values were below the *p*-value thresholds (the border of the lower 5% *p*-value distributions) in the permutation tests [1st (n = 32): *p*-value threshold = 0.0543; 2nd (n = 30): *p*-value threshold = 0.0482] and were certified as significant after correction for multiple testing. In multiple comparisons, the selection of the high-risk deck significantly decreased during the post-1 trials after the second penalty event [Wilcoxon test: pre (37.3%) vs. post 1 (22.0%), $Z = 2.331$, $p = 0.020$ (<*p*-value threshold, 0.0504)]. Safe-preference after the penalty event was also observed for the low-risk decks: after the first maximum-penalty, selectivity significantly increased during both the post-1 and post-2 trials [pre (33.8%) vs. post 1 (50.0%): $Z = 2.545$, $p = 0.011$; pre vs. post 2 (52.5%): $Z = 2.911$, $p = 0.004$; (<*p*-value threshold, 0.0518)]. On the other hand, the selectivity of the middle-risk deck might have been affected by the increase in the selectivity of the high-risk deck, decreasing after the second penalty event [pre (22.0%) vs. post 2 (13.3%): $Z = 2.124$, $p = 0.034$ (<*p*-value threshold, 0.0504)].

For the forced-paced condition, similar post-penalty preference for risk-avoidance was observed in the selection behaviors for the high- and low-risk decks (**Supplementary Table S3**).

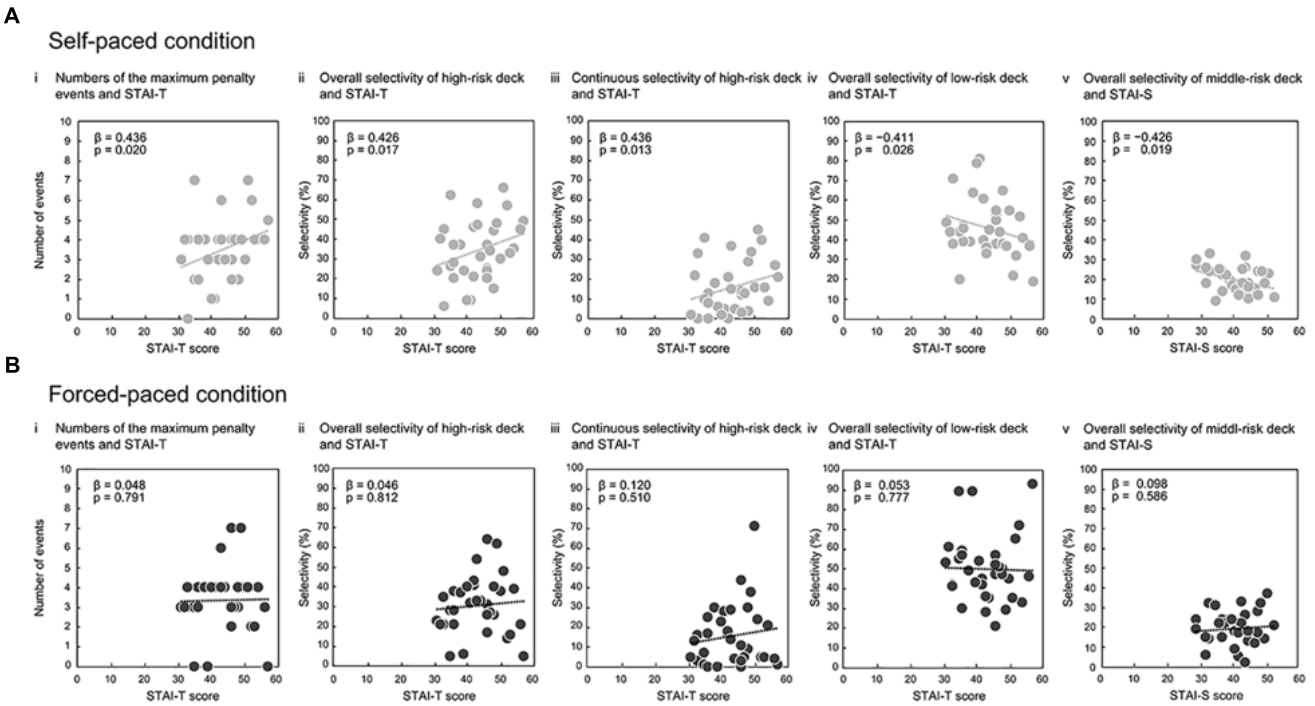

FIGURE 4 | Comparisons of linear relations between global behavioral patterns and trait anxiety between the self- and forced-paced conditions. Scatter plots for the self-paced condition represent significant relations between: the numbers of the maximum penalty events and trait anxiety (STAI-T) **(Ai)**; overall high-risk deck selectivity and STAI-T **(Aii)**; continuous high-risk deck selectivity and STAI-T **(Aiii)**; and overall low-risk deck selectivity and STAI-T **(Aiv)**. The total selectivity of the middle-risk deck was predicted by state anxiety (STAI-S) **(Av)**. Corresponding figures **(Bi–v)** for the forced-paced condition show no significant relation between behavioral patterns and STAI-T. Weighted coefficients (βs) indicate standardized partial coefficients in the multiple regression models.

Friedman tests showed that main effects of selectivity were significant for the second penalty in the high-risk deck and the third penalty in the high- and low-risk decks (high-risk: 2nd, $\chi^2 = 7.67$, $p = 0.022$; 3rd, $\chi^2 = 11.61$, $p = 0.003$; low-risk: 3rd, $\chi^2 = 9.07$, $p = 0.011$). These p-values were below the p-value threshold [2nd ($n = 30$): $p = 0.0482$; 3rd ($n = 24$): $p = 0.0478$] and were certified as corrected for multiple analyses. In subsequent Wilcoxon tests, the selectivity of the high-risk deck significantly decreased [2nd: pre (42.7%) vs. post 1 (24.0%): $Z = 2.502$, $p = 0.012$; 3rd: pre (55.8%) vs. post 1 (23.3%), $Z = 3.090$, $p = 0.002$; pre vs. post 2 (30.8%), $Z = 2.653$, $p = 0.008$]. The selectivity of the low-risk deck significantly increased after the third penalty event [pre (29.2%) vs. post 1 (55.0%): $Z = 2.666$, $p = 0.008$; pre vs. post 2 (51.7%): $Z = 2.388$, $p = 0.017$]. The observed p-values were lower than the p-value thresholds in the permutation tests (2nd: $p = 0.0504$; 3rd: $p = 0.0520$) and were certified as significant under correction for multiple testing. The selectivity of the middle-risk deck, on the other hand, did not show any significant change.

Unlike global decision-making behaviors, local behaviors were well-predicted by STAI-S in the multiple regression analyses. The self- and forced-paced conditions showed contrasted outputs. For the self-paced condition, STAI-S significantly predicted risk-avoidance behaviors (**Table 3**). Although the regression model for the post-1 trials after the second penalty event tended to be significant [adjusted $R^2 = 0.171$, $F(4,25) = 2.493$, $p = 0.069$], higher STAI-S scores predicted more frequent avoidance of the high-risk deck in the model ($\beta = -0.371$, $t = 2.171$, $p = 0.040$, $VIF = 1.019$). Higher STAI-S also predicted higher preference for the low-risk deck during the post-1 trials after the second penalty event [adjusted $R^2 = 0.218$, $F(3,26) = 3.691$, $p = 0.024$; STAI-S: $\beta = 0.493$, $t = 2.786$, $p = 0.010$, $VIF = 1.159$] (**Figures 6A,B**). During the post-1 trials after the third penalty event, higher STAI-T predicted higher frequent avoidance of the high-risk deck [adjusted $R^2 = 0.311$, $F(4,19) = 3.592$, $p = 0.024$; STAI-T: $\beta = -0.525$, $t = 2.308$, $p = 0.032$, $VIF = 1.729$]. The permutation tests showed that the observed p-values for the significant models were below the p-value thresholds [model with STAI-S (p-value threshold = 0.0497): post 1 after the second penalty in the low-risk deck, $p = 0.024$; model with STAI-T (p-value threshold = 0.0504): post 1 after the third penalty in the high-risk deck, $p = 0.024$].

In the forced-paced condition, STAI-S significantly predicted only the selectivity of the middle-risk deck [1st: post 1, adjusted $R^2 = 0.118$, $F(1,28) = 4.885$, $p = 0.035$; 3rd: post 1, adjusted $R^2 = 0.142$, $F(1,22) = 4.813$, $p = 0.039$; post 2: adjusted $R^2 = 0.138$, $F(1,22) = 4.683$, $p = 0.042$] (**Table 4**). Higher STAI-S scores predicted higher selectivity of the middle-risk deck (1st: post 1, $\beta = 0.385$, $t = 2.210$, $p = 0.035$, $VIF = 1.0$; 3rd: post 1, $\beta = 0.424$, $t = 2.194$, $p = 0.039$, $VIF = 1.0$; 3rd: post 2: $\beta = 0.419$, $t = 2.164$, $p = 0.042$, $VIF = 1.0$) (**Figure 6C** for the post-1 trials at the third penalty event). The permutation tests showed that the p-values for the significant models were below the thresholds

TABLE 2 | Regression models of overall behavioral patterns in the forced-paced condition (n = 33).

Variables	Overall (100 trials)						High-risk deck			
	Final winning		Numbers of maximum penalty events		Mean entropy		Total selectivity		Continuous selectivity	
	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)
STAI-T	0.137	0.760 (0.454)	0.048	0.268 (0.791)	−0.195	1.219 (0.233)	0.046	0.240 (0.812)	0.120	0.666 (0.510)
STAI-S	0.030	0.171 (0.866)	0.019	0.108 (0.915)	0.016	0.086 (0.932)	−0.045	0.239 (0.812)	0.018	0.102 (0.920)
Age	0.201	1.108 (0.277)	−0.159	0.840 (0.407)	−0.019	0.100 (0.921)	−0.196	1.035 (0.309)	−0.137	0.746 (0.462)
Sex	0.226	1.259 (0.218)	0.018	0.092 (0.927)	−0.267	1.569 (0.128)	0.007	0.038 (0.970)	0.179	1.012 (0.319)
IQ	−0.340	−1.772 (0.087)	0.247	1.420 (0.166)	0.232	1.340 (0.191)	0.293	1.550 (0.132)	0.035	0.183 (0.856)
Task order	0.299	1.766 (0.088)	−0.151	0.847 (0.404)	−0.352*	2.181 (0.038)	−0.088	0.485 (0.631)	0.097	0.543 (0.591)
Regression model										
Adjusted R^2	0.123		0.031		0.202		0.019		0.001	
F-value	2.125		2.015		3.024		1.317		1.024	
p-value	0.104		0.166		0.034*		0.283		0.319	

TABLE 2 | Continued

Variables	Middle-risk deck				Low-risk deck			
	Total selectivity		Continuous selectivity		Total selectivity		Continuous selectivity	
	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)	β	*t*-Value (*p*-value)
STAI-T	−0.198	1.196 (0.242)	−0.176	0.896 (0.377)	0.053	0.286 (0.777)	0.027	0.155 (0.878)
STAI-S	0.098	0.551 (0.586)	0.226	1.304 (0.202)	0.023	0.127 (0.900)	0.156	0.917 (0.367)
Age	−0.345	1.922 (0.065)	0.091	0.494 (0.625)	0.298	1.633 (0.114)	0.267	1.524 (0.138)
Sex	−0.446*	2.684 (0.012)	−0.139	0.798 (0.431)	0.218	1.204 (0.239)	0.131	0.739 (0.466)
IQ	0.211	1.187 (0.246)	0.022	0.121 (0.904)	−0.354	1.834 (0.077)	−0.492**	−2.810 (0.009)
Task order	−0.319	2.024 (0.053)	−0.218	1.259 (0.218)	0.228	1.337 (0.192)	0.027	0.158 (0.875)
Regression model								
Adjusted R^2	0.25		0.04		0.11		0.161	
F-value	3.129		1.661		1.993		4.069	
p-value	0.024*		0.207		0.123		0.027	

*$p < 0.05$; **$p < 0.01$.

of corrected p-values [model with STAI-S for the first penalty (p-value threshold = 0.0502) and the third penalty (0.0499): 1st: post 1, p = 0.035; 3rd: post 1, p = 0.039; post 2, p = 0.042]. These results suggest that pre-specified state anxiety is related to intermediate risk-taking in the forced-paced condition.

DISCUSSION

The present study conducted a decision-making experiment using the IGT to examine how trait and state anxiety profiles predict future decision-making performances under different temporal pressure conditions. Because negative events may occur unpredictably in our daily life, the prospective approach is beneficial for minimizing unfavorable consequences by predicting decision-making behaviors when actually encountering events based on psychological factors, such as anxious profiles in the present research. We assumed that pre-specified trait and state anxiety would differently predict decision-making performances, because trait anxiety may be sensitive to relatively remote, final decision-making outcomes concerning the overall task mission of maximizing final winnings, whereas state anxiety would likely be sensitive to decision-making immediately after negative events, specifically the maximum penalty events. To test the prediction, global and local behavioral indexes were calculated and regressed by the trait and state anxiety profiles assessed before the IGT was performed. Trait anxiety predicted global decision-making behaviors only in the self-paced condition without temporal pressure: higher trait anxiety predicted higher preference for overall high risk-taking in the self-paced condition. On the other hand, pre-specified state anxiety differently predicted local decision-making behaviors between the self- and forced-paced conditions: higher state anxiety predicted higher preference for risk-avoidance after the maximum penalty events in the self-paced condition, and on the other hand, predicted higher preference for moderate risk-taking in the forced-paced condition. These findings suggest that pre-specified trait and state anxiety work differently as predictors of future decision-making performance under different temporal pressure conditions.

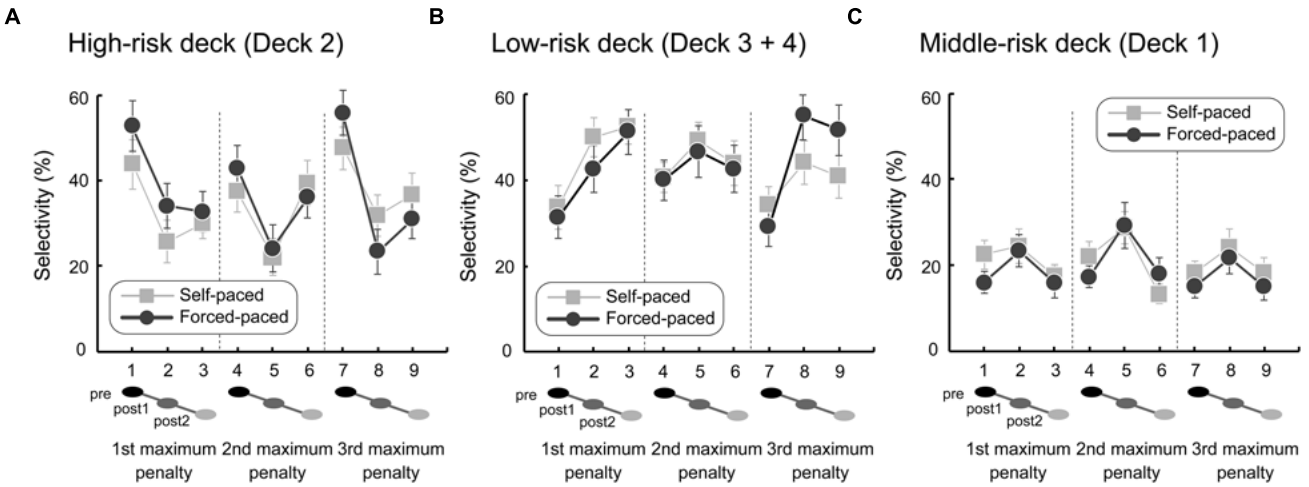

FIGURE 5 | Local behavioral patterns of high, middle, and low risk-taking in the self- and forced-paced conditions. We locally examined the high-risk-taking behavioral characteristics immediately before and after the maximum penalty event (–125,000 yen in Deck 2). The high-risk-taking property **(A)** was calculated with the pre- and first-half (post 1) and second-half (post 2) post-event proportions of Deck 2 selection for the total of each five-trial interval. The low-risk-taking property **(B)** was also calculated for the combined Decks 3 and 4. The middle-risk-taking property **(C)** was similarly calculated for Deck 1. Error bars indicate standard errors of the means.

TABLE 3 | Regression models of local deck-selection changes (post minus pre) after maximum penalty events in the self-paced condition.

	Selectivity changes (post minus pre)											
	1st (*n* = 32)				**2nd (*n* = 30)**				**3rd (*n* = 24)**			
	Post 1		**Post 2**		**Post 1**		**Post 2**		**Post 1**		**Post 2**	
	β	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**
High-risk deck												
STAI-T	0.049	0.266 (0.792)	0.06	0.339 (0.737)	−0.130	0.605 (0.551)	−0.098	0.516 (0.610)	−0.525*	2.308 (0.032)	−0.055	0.266 (0.793)
STAI-S	−0.141	0.778 (0.443)	−0.272	1.659 (0.108)	−0.371*	2.171 (0.040)	0.004	0.023 (0.982)	0.482	2.075 (0.052)	−0.098	0.476 (0.639)
Age	−0.132	0.728 (0.472)	−0.144	0.765 (0.451)	−0.192	0.960 (0.347)	0.324	1.863 (0.073)	0.457*	2.314 (0.032)	0.166	0.816 (0.423)
Sex	−0.114	0.628 (0.535)	−0.131	0.738 (0.467)	−0.261	1.408 (0.171)	−0.127	0.688 (0.497)	0.416*	2.209 (0.040)	−0.173	0.852 (0.404)
IQ	−0.053	0.289 (0.774)	−0.259	1.555 (0.131)	−0.418*	2.189 (0.038)	0.003	0.016 (0.988)	−0.021	0.095 (0.925)	−0.084	0.399 (0.694)
Task order	−0.107	0.587 (0.562)	−0.342	2.070 (0.048	0.226	1.302 (0.205)	−0.279	1.605 (0.120)	−0.090	0.510 (0.616)	0.315	1.558 (0.133)
Middle-risk deck												
STAI-T	−0.296	1.425 (0.166)	−0.086	0.387 (0.702)	0.113	0.641 (0.527)	0.056	0.300 (0.766)	0.357	1.406 (0.176)	−0.025	0.116 (0.909)
STAI-S	0.349	1.681 (0.104)	0.194	1.083 (0.288)	0.021	0.014 (0.989)	0.119	0.648 (0.523)	−0.494	1.907 (0.072)	−0.064	0.302 (0.766)
Age	0.040	0.198 (0.845)	0.073	0.355 (0.726)	−0.011	0.115 (0.909)	−0.270	1.455 (0.158)	−0.415	1.882 (0.075)	0.000	0.000 (1.000)
Sex	−0.033	0.180 (0.859)	0.072	0.369 (0.715)	0.360	1.899 (0.068)	0.267	1.423 (0.167)	−0.373	1.722 (0.092)	−0.131	0.618 (0.543)
IQ	0.350	2.025 (0.053)	0.240	1.341 (0.190)	0.430	2.270 (0.031)	0.548**	2.841 (0.009)	−0.095	0.395 (0.698)	0.062	0.290 (0.774)
Task order	−0.236	1.376 (0.180)	0.091	0.494 (0.625)	0.026	0.142 (0.888)	0.054	0.304 (0.763)	−0.010	0.051 (0.960)	0.062	0.289 (0.775)
Low-risk deck												
STAI-T	0.055	0.324 (0.749)	0.077	0.446 (0.659)	0.049	0.227 (0.822)	0.213	1.175 (0.250)	0.231	1.115 (0.277)	0.139	0.661 (0.516)
STAI-S	0.030	0.176 (0.862)	0.165	0.967 (0.341)	0.493**	2.786 (0.010)	−0.034	0.147 (0.885)	0.135	0.640 (0.529)	0.189	0.904 (0.376)
Age	0.103	0.591 (0.559)	0.076	0.439 (0.664)	0.232	1.312 (0.201)	−0.175	0.835 (0.411)	−0.145	0.686 (0.500)	−0.190	0.906 (0.375)
Sex	0.299	1.789 (0.084)	0.053	0.306 (0.762)	−0.012	0.069 (0.946)	0.187	0.944 (0.354)	−0.057	0.267 (0.792)	0.097	0.457 (0.652)
IQ	−0.212	1.156 (0.257)	0.125	0.719 (0.478)	0.004	0.022 (0.983)	−0.256	1.412 (0.170)	0.078	0.369 (0.715)	0.155	0.734 (0.471)
Task order	0.318	1.903 (0.067)	0.364*	2.139 (0.041)	−0.271	1.651 (0.111)	0.180	0.970 (0.341)	0.107	0.506 (0.618)	0.014	0.066 (0.948)

*1st: the first maximum penalty event; 2nd: the second maximum penalty event; 3rd: the third maximum penalty event; pre: five trials before the penalty event; post 1: the first-half five trials after the penalty event; post 2: the second-half five trials after the penalty event; *$p < 0.05$; **$p < 0.01$.*

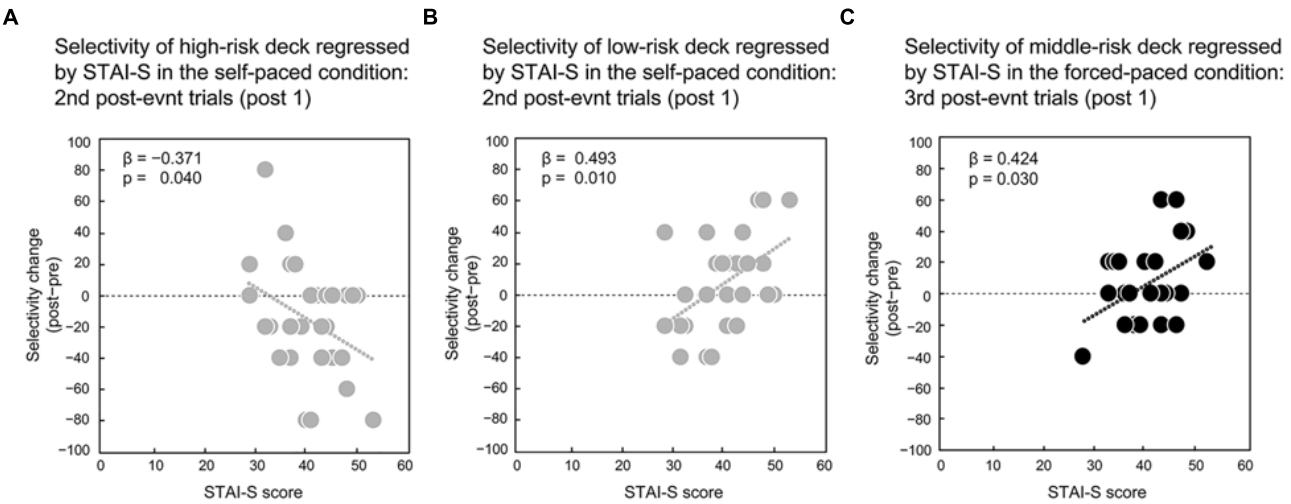

FIGURE 6 | Linear relations between deck selectivity after the maximum penalty events and mood characteristics for the self- and forced-paced conditions. Change in high-risk-deck selectivity after the second maximum penalty was negatively correlated with state anxiety (STAI-S) in the self-paced condition **(A)**. Change in low-risk-deck selectivity after the second maximum penalty event was positively correlated with STAI-S in the self-paced condition **(B)**. Change in middle-risk-deck selectivity after the third maximum penalty event was positively correlated with STAI-S in the forced-paced condition **(C)**. Post-event selectivity change was calculated by subtracting pre-event proportions of the given deck from post-event counterparts. Post 1 and post 2 indicate the first-half and second-half post-event trials, respectively.

TABLE 4 | Regression models of local deck-selection changes (post minus pre) after maximum penalty events in the forced-paced condition.

	Selectivity changes (post minus pre)											
	1st (*n* = 30)				**2nd (*n* = 30)**				**3rd (*n* = 24)**			
	Post 1		**Post 2**		**Post 1**		**Post 2**		**Post 1**		**Post 2**	
	β	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**	**β**	***t*-Value (*p*-value)**
High-risk deck												
STAI-T	0.107	0.545 (0.590)	0.121	0.627 (0.536)	−0.219	1.179 (0.249)	−0.156	0.815 (0.422)	−0.307	1.412 (0.174)	−0.020	0.096 (0.924)
STAI-S	−0.297	1.702 (0.100)	−0.256	1.493 (0.147)	0.122	0.616 (0.544)	−0.088	0.469 (0.643)	−0.375	1.882 (0.075)	−0.050	0.244 (0.809)
Age	−0.173	−0.929 (0.361)	0.119	0.646 (0.524)	−0.379	1.978 (0.059)	−0.322	1.698 (0.101)	−0.317	1.523 (0.144)	−0.093	0.438 (0.666)
Sex	−0.296	1.700 (0.101)	−0.366*	2.130 (0.042)	−0.225	1.212 (0.237)	−0.221	1.167 (0.253)	−0.002	0.011 (0.991)	0.292	1.481 (0.154)
IQ	−0.014	0.073 (0.942)	0.162	0.883 (0.385)	−0.136	0.650 (0.522)	−0.158	0.777 (0.444)	0.023	−0.106 (0.917)	0.042	0.182 (0.857)
Task order	0.066	0.367 (0.717)	0.128	0.734 (0.469)	0.215	1.200 (0.241)	0.149	0.805 (0.428)	0.369	2.035 (0.056)	0.314	1.592 (0.126)
Middle-risk deck												
STAI-T	0.072	0.367 (0.717)	−0.308	1.552 (0.133)	−0.051	0.243 (0.810)	−0.394*	−2.145 (0.041)	−0.166	0.777 (0.446)	0.093	0.429 (0.672)
STAI-S	0.385*	2.210 (0.035)	0.207	1.048 (0.304)	−0.209	1.118 (0.273)	0.345	1.892 (0.070)	0.424*	2.194 (0.039)	0.419*	2.164 (0.042)
Age	0.064	0.356 (0.725)	−0.118	0.621 (0.540)	0.016	0.078 (0.938)	0.136	0.746 (0.463)	0.176	0.866 (0.396)	−0.066	0.317 (0.754)
Sex	−0.005	0.028 (0.978)	0.169	0.927 (0.363)	−0.183	0.927 (0.362)	−0.329	1.978 (0.059)	−0.219	1.137 (0.268)	−0.043	0.215 (0.832)
IQ	0.061	0.230 (0.820)	−0.099	0.512 (0.613)	−0.194	1.039 (0.308)	0.012	0.068 (0.947)	0.174	0.898 (0.380)	0.154	0.790 (0.439)
Task order	0.078	0.439 (0.664)	−0.332	1.846 (0.076)	0.113	0.572 (0.572)	0.107	0.631 (0.534)	0.102	0.519 (0.609)	0.076	0.388 (0.702)
Low-risk deck												
STAI-T	−0.087	0.465 (0.646)	0.020	0.101 (0.920)	0.280	1.607 (0.121)	0.306	1.534 (0.138)	0.291	1.543 (0.138)	0.087	0.150 (0.882)
STAI-S	0.051	0.272 (0.788)	0.242	1.369 (0.182)	0.052	0.276 (0.785)	−0.304	1.564 (0.130)	0.028	0.132 (0.896)	−0.052	0.406 (0.689)
Age	0.098	0.506 (0.617)	−0.134	0.702 (0.489)	0.298	1.567 (0.130)	0.281	1.470 (0.154)	0.235	1.095 (0.287)	0.210	1.083 (0.292)
Sex	0.261	1.428 (0.164)	0.304	1.717 (0.097)	0.349	1.955 (0.062)	0.307	1.675 (0.106)	0.053	0.275 (0.786)	−0.363	1.876 (0.075)
IQ	−0.030	0.153 (0.879)	−0.118	0.616 (0.543)	0.320	1.651 (0.112)	0.085	0.425 (0.675)	0.013	0.064 (0.949)	−0.055	0.242 (0.811)
Task order	−0.098	0.525 (0.604)	0.007	0.039 (0.969)	−0.290	1.644 (0.113)	−0.119	0.657 (0.518)	−0.417*	2.213 (0.038)	−0.329	1.786 (0.089)

*1st: the first maximum penalty event; 2nd: the second maximum penalty event; 3rd: the third maximum penalty event; pre: five trials before the penalty event; post 1: the first-half five trials after the penalty event; post 2: the second-half five trials after the penalty event; *$p < 0.05$.*

Trait anxiety predicted global risk-taking behaviors in the self-paced condition: participants with higher trait anxiety more frequently selected the high-risk deck (Deck 2) and more frequently deselected the low-risk decks (Decks 3 and 4), thus encountering more maximum penalty events (−125,000 yen in Deck 2). These findings seemed to be counterintuitive at first glance, because trait anxiety tends to promote cognitive bias toward occurrences of negative events and risk-avoidance behaviors, as observed in people with elevated trait anxiety (Miu et al., 2008; Mueller et al., 2010). One of possible interpretation of the findings may be that participants with higher anxiety traits more frequently selected high-risk decks for recovering large losses even after facing to maximum penalty events. If they were provided with the instruction of the deck types and optimal strategies before the task, they might recognize that they should find out and continuously choose the advantage decks. Although participants might develop their own assumptions about the deck types even under information ambiguity as shown by self-reports of their deck-selection after the tasks, the procedure was likely different from confirmation or confidential decision-making (Vickers and Packer, 1982), in which participants are provided with prior information about the deck types and become confidentially convinced of it throughout the task. Poorer amounts of prior knowledge possibly induce higher anxiety with less confidence, as observed in, for example, verbal learning contexts (Yang and Quadir, 2018). Upon the present experimental context without the prior knowledge, participants might develop their own assumption about the deck types, which is indicated by the finding that the maximum penalties induced immediate risk-avoidance, as observed in **Figures 5A,B**. However, participants with, in particular, higher anxiety traits might be less confident of their strategic assumptions, and yield anxiety toward future, uncertain monetary gains, selecting high-reward decks for monetary recovery. This is suggested by the fact that the average net-scores in the self-paced condition did not gradually increase as represented by **Figure 2**, and actually, about 30% participants self-reported that they used the strategies to actively select high-reward decks to rapidly recover the largest loss or earn rewards as much as possible. It is speculated in summary that under information ambiguity, participants with higher trait anxiety were more anxious for future failure in maximizing final rewards and more frequently selected the high-reward decks even if they developed the assumption that the decks might sometime impose high penalties.

As revealed by comparing local deck-selections between the pre- and post-penalty events, post-penalty risk-avoidance was similarly promoted in both the self- and forced-paced conditions (**Figures 5A,B**). However, state anxiety predicted local decision-making performances differently in the self- and forced-paced conditions, which indicates that state anxiety profiles specified before the IGT are not irrelevant but continuous to future decision-making. In the self-paced condition, higher state anxiety predicted more frequent risk-avoidance after maximum penalty events: higher state anxiety was related to lower selectivity of the high-risk deck as well as higher selectivity of the low-risk decks, particularly after the second penalty event. As has been argued for global decision-making outcomes, the present participants, distinguished from individuals with abnormal emotional assessment and decision-making (Bechara et al., 2000a), could likely appropriately assess a somatic marker emotionally evoked by the maximum penalty events (Damasio, 1996) and regulate emotional response accordingly, thereby engaging in local risk-avoidance behaviors under no temporal pressure. Although decision-making in the IGT tends to be differentiated from general executive functions (Bechara et al., 1998; Bechara, 2004; Toplak et al., 2010), it requires suppressing emotional disturbance caused by the penalty events and monitoring deck selection by inhibiting the other options (Paulus, 2005), which may be related to dorsolateral prefrontal functions outside the ventromedial prefrontal areas (Ernst et al., 2002). Therefore, in the present study, the participants with higher state anxiety were sensitive to the maximum penalty events and appropriately drove executive functions without emotional disturbance, thereby transiently avoiding risk-taking more frequently. Considering the global behavioral findings together, the dynamic nature of decision-making without temporal pressure may be comprehensible as a function of the interaction between trait and state anxiety. Global decision-making behaviors were predicted by trait anxiety, which indicates that higher trait anxiety is related to higher risk-taking overall. However, local decision-making was sensitive to state anxiety and higher anxious states were related to higher risk-avoidance in an opposite manner. That is, participants with normal decision-making may have switched risk-taking and risk-avoidance adaptively under no temporal pressure according to changes in their anxiety profiles in a conflicting situation between the current penalty events and the remote task mission in the course of the IGT under information uncertainty without hints of deck types and an optimal strategy. Although the trait and state anxiety scores of the present participants yielded significant positive correlation ($r = 0.458$, $p = 0.007$), its strength was not prominently high, suggesting that trait and state anxiety possess multidimensionality and may not be strongly correlated because the current situation was not completely compatible with ordinary-life anxious conditions that the participants tend to face (Endler et al., 1991; Leal et al., 2017). Such mild correlation between the two anxiety profiles may in turn leave a margin for partial dissociation between them, consequently yielding a dynamism of global and local decision-making.

Under the forced-paced condition, state anxiety predicted intermediate risk-avoidance behaviors. That is, higher state anxiety was related to more frequent selection of the middle-risk deck. Similar to the self-paced condition, the forced-paced condition showed low selectivity of the high-risk deck and high selectivity of the low-risk decks as shown in **Figures 5A,B**. The participants, whether with high or low state anxiety, tended to locally avoid high risk-taking, but the participants with higher pre-specified state anxiety more frequently engaged in moderate risk-taking even after the maximum penalty under temporal pressure. There are two possible interpretations of the local decision-making pattern under temporal pressure based on different psychological backgrounds. The first interpretation

concerns automatic emotional dysregulation. Decision-making in the IGT is related to two stages in the processing of somatic states (Bechara et al., 2003). In the first stage, the primary inducer is an external event and situation that automatically evokes a somatic state, such as the maximum penalty event in the present study. The secondary inducer includes psychological entities, such as thoughts and memories of emotional events and situations evoking primary somatic states. When facing the maximum penalty events under temporal pressure, the participants might have experienced somatic states through primary as well as secondary inducers in a complex manner and escaped from the current high risk-taking; however, they may not have completely regulated their emotional reactions, thereby automatically selecting the middle-risk deck as a consequence. The second interpretation is related to controlled compensation. Decision-making in the IGT generally comprises three stages: anticipatory option assessment, action execution, and outcome evaluation (Paulus, 2005). In particular, the latter two are related to the cognitive inhibition of competitive options and post-action monitoring as a general executive function (Fellows, 2007; Ouerchefani et al., 2017). The participants regulate emotional reactions to the maximum penalty events under temporal pressure to avoid selecting the high-risk deck; however, they might dare to actively select the middle-risk deck under attentional control to recover monetary loss as soon as possible. Because subsequent decision-making behaviors depend on monitoring response feedback (Yi et al., 2012), selecting the middle-risk deck under temporal pressure is possibly highly adaptive under behavioral monitoring for simultaneously coping with elevated anxiety states caused by the current penalty and sustained less-state anxiety concerning final winnings during the IGT, which would induce the negative consequences of larger monetary loss. At present, our findings cannot completely determine which mechanism is plausible for decision-making under the forced-paced condition because participants' self-reports indicate that they voluntarily selected card decks based on control of their own developing strategy. On the other hand, unlike the self-paced condition, RTs under temporal pressure did not show a gradual reduction over the progress of trials likely based on an adaptive effect by learning the task (Visser et al., 2007). The suggestion is that salient penalty events implicitly promote cautious attitudes and does not fasten decision-making even in later trials under temporal pressure. The relation between conscious self-reports and RTs, which are not necessarily controlled-behavioral indexes, likely provides information about the adaptive aspects of decision-making in interactions between our internal and external states.

The implications of the present findings may be relevant to social problems such as billing frauds. In Japan, for example, the incidence of billing frauds has grown annually (the number of incidents in 2017 was 18,212, with an increase rate of about 30% compared to the previous year[1]), and the amount of monetary damage per incident was about 2,300,000 yen. Prevention measures for a billing fraud, therefore, are required not only at the public social level but also at the personal psychological level. The present findings for the IGT in the forced-paced condition may provide potential information for psychological prevention measures. The state anxiety of people who are vulnerable to future billing frauds may easily fluctuate under subjectively perceived temporal pressures that are externally evoked by defrauders, and these individuals may tend to falter in their emotional regulation, consequently transferring money to the defrauders' bank accounts. Noticeably, the requested amounts of billing money are not too large to be paid (e.g., 2,300,000 yen in 2017 in Japan, a decrease compared to the previous year), that is, not high but moderate risk requirements. Therefore, we should focus on the psychological mechanisms of not only high risk-taking but also moderate risk-taking for exploring prevention measures.

Finally, the limitations of the present study should be discussed. State and trait anxiety were recorded on the same day as the IGT. Although trait anxiety is related to chronic anxiety properties observed in ordinary life, state anxiety is related to a current transient state of anxiety. Therefore, assessment of state anxiety might have occurred too soon before the IGT for prediction analysis of decision-making. A stricter methodology would have had participants undergo the IGT and STAI assessments multiple times on separate days. If the predictability of IGT performances was established via anxiety profiles collected on separated days, the reliability of the present results would be increased.

To conclude, the present study used the IGT to simulate several aspects of real-life decision-making processes and examined how anxiety profiles differently predicted future decision-making performances under different temporal pressure conditions. The prospective approach predicts decision-making performances based on the pre-specified psychological profiles of individuals and applying it may be beneficial for people to avoid socially and privately negative consequences. Pre-specified trait and state anxiety differently predicted future decision-making behaviors. The present study showed that under temporal pressure, moderate risk-taking rather than high risk-taking was enhanced after negative events by high sensitivity to state anxiety. The psychological mechanism for moderate risk-taking should be examined in future research, bearing in mind that "a small leak will sink a great ship."

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the **Supplementary Files**.

ETHICS STATEMENT

Written informed consent was obtained from the participants according to the institutional guidelines before conducting the experiment. The study was conducted in accordance with the Declaration of Helsinki, a statement of ethical principles for medical research involving human participants, and was approved by the Ethics Committee of the Tokyo Institute of Technology.

[1] https://www.npa.go.jp/publications/statistics/sousa/sagi.html

AUTHOR CONTRIBUTIONS

TS, MN, and AT designed the study. MN and EF performed data collection. TS and MN analyzed the data and wrote the initial version of the manuscript. TS, MN, EF, and AT revised the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01544/full#supplementary-material

DATA SHEET S1 | Data analyzed for participants' global and local performances of the Iowa Gambling Task under the two different temporally pressured conditions.

FIGURE S1 | Cumulative histogram of dummy *p*-values in the permutation regression analyses for the model with the independent variable STAI-T for the numbers of maximum penalty events (n = 100,000). Cumulative frequencies of dummy *p*-values gradually increase from zero to one in the horizonal *p*-value axis. The actual *p*-value of the significant model was $p = 0.049$ in the self-paced condition. The values was within the lower 5% of the distribution ($p < 0.0506$) and was certified as significance-corrected for multiple testing.

TABLE S1 | Comparisons of global decision-making outcomes between the self- and forced-paced conditions (n = 33).

TABLE S2 | Comparisons of selectivity (%) of the high-, middle-, and low-risk decks between pre- and post-penalty events in the self-paced condition.

TABLE S3 | Comparisons of selectivity (%) of the high-, middle-, and low-risk decks between pre- and post-penalty events in the forced-paced condition.

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Decision Making Profile of Positive and Negative Anticipatory Skin Conductance Responders in an Unlimited-Time Version of the IGT

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Based on the somatic marker hypothesis (Damasio, 1994), many studies have examined whether or not physiological responses are "somatic markers" that implicitly guide the decision making process. Vegetative or motor reactions that are produced by negative or positive stimuli generate a series of somatic markers. So, when a similar stimuli is encountered in the future, these somatic marks will facilitate favorable decisions and inhibit the disadvantageous ones (Martínez-Selva et al., 2006). The most widely studied physiological responses, as indicators of these markers, are heart rate and the skin conductance response (Damasio, 1994; Bechara et al., 1996). The Iowa Gambling Task (IGT) has been the most widely used tool in this research. The common IGT protocol for psychophysiological studies comprises limited inter-trial intervals, and does not distinguish participants as a function of relevant physiological traits, such as the anticipatory skin conductance response (aSCR). The objectives of this work were to determine whether "somatic markers" guide the decision making process without time restrictions and to examine the effects of opposite aSCR profiles on this process. Participants were 29 healthy subjects, divided into two groups according to positive (+) and negative (−) aSCR. Two different data analysis strategies were applied: firstly, gambling indices were computed and, secondly, we examined the parameters of the probabilistic Prospect Valence Learning (PVL) model in three versions: maximum likelihood estimation (MLE), PVL-Delta and PVL-Decay simulations with Hierarchical Bayesian analysis (HBA) for parameter estimation. The results show a significant group effect in gambling indices, with the aSCR+ group presenting lower risk in the decision making process than the aSCR− group. Significant differences were also observed in the Utility parameter of MLE-PVL, with the aSCR− group have low sensitivity to feedback outcomes, than aSRC+ group. However, data from the PVL simulations do not show significant group differences and, in both cases, the utility value denotes low sensitivity to feedback outcomes.

Keywords: decision– making, iowa gambling task, prospect valence learning model, positive anticipatory skin conductance, negative anticipatory skin conductance

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INTRODUCTION

Damasio (1994) attempted to explain through the somatic marker hypothesis why patients with brain damage (ventromedial prefrontal cortex) have poor social functioning, despite achieving adequate scores on other cognitive processes, as assessed by typical neuropsychological tests. This hypothesis argues that decisions are not only determined by rational processes, but also by emotional ones. Thus, a deficit in decision making might be due to difficulties in properly using emotional information from body signals. These body signals, that Damasio called "somatic markers", would allow regulating or guiding actions toward "good" decisions and they are particularly important in situations of uncertainty, where the exact result of a decision is not known in advance, such as deck selection in the Iowa Gambling Task (IGT).

Vegetative or motor reactions that are produced by negative or positive stimuli generate a series of somatic markers. So, when a similar stimulus is encountered in the future, these somatic marks will facilitate favorable decisions and inhibit the disadvantageous ones (Martínez-Selva et al., 2006). The most widely studied physiological responses, as indicators of these markers, are heart rate and the skin conductance response (Damasio, 1994; Bechara et al., 1996).

The IGT, designed by Bechara et al. (1994), has been consolidated as an assessment instrument of decision making processes under uncertainty. This task consists of four decks of cards (ABCD), with different gains and losses that the subject discovers across the trials. The aim of the "game" is to win as much money as possible, but participants are not informed that there is a hidden strategy. This strategy involves the presence of two advantageous decks (with long-term gains, but each card has a gain or a loss of a smaller magnitude) and two disadvantageous decks (with long-term losses, but each card has a gain or loss of a greater magnitude). The authors propose that decision making can be assessed by computing the Gambling Index (GI), which is calculated by subtracting the choices of the advantageous decks from the disadvantageous ones, that is, GI = (C+D)−(A+B).

The first set of studies based on this task revealed differences between brain-damaged patients and healthy adults, in the sense that healthy people made fewer unfavorable decisions, associated with higher skin conductance in the disadvantageous decks. This was interpreted in the sense that somatic signals intervene in healthy subjects to guide the process of decision making and favor the advantageous decks. On the contrary, higher skin conductance was not observed before choosing the disadvantageous decks in people with brain lesions, indicating the absence of somatic markers that guide the decision making process and leading to worse outcomes on the IGT (Bechara et al., 1996, 1997; Tomb et al., 2002; Carter and Pasqualini, 2004).

In later studies, it has been observed that healthy subjects may also differ in their anticipatory responses, as these may be more or less intense. The "high risk-takers" are defined as having minor anticipatory responses and a poorer performance on the IGT. It is argued that their low physiological responses do not allow the development of appropriate somatic markers (Bechara and Damasio, 2002). However, many questions remain to be solved because various studies report inconclusive results. Differences in physiological responses were not found in all cases: only in individuals with good performance on the IGT (Crone et al., 2004), only in the last moves of the task (Akiyama and Hasegawa, 2014), or only in some decks (Jenkinson et al., 2008). Some researchers rejected the thesis that decision making is guided by somatic markers or emotions (e.g., Maia and McClelland, 2004; Evans et al., 2005), whereas other studies cast doubts on the ecological validity of the IGT (Steingroever et al., 2013). In any case, the inconsistencies in the literature may be due, at least in part, to methodological artifacts.

Concerning the administration time of the task, studies measuring skin conductance responses (SCR) during IGT stipulate inter-trial intervals (ITI) from 7 to 10 s, so finishing the game involves approximately 17 min (Bechara et al., 1996; Bechara and Damasio, 2002; Carter and Pasqualini, 2004; Crone et al., 2004; Jenkinson et al., 2008; Starcke et al., 2009; Fonfría et al., 2015; Ottaviani and Vandone, 2015). However, some studies focused solely on behavioral measures (i.e., no physiological records) in a variety of healthy and clinical samples have not established fixed intervals between the cards, making the IGT a less tedious and more dynamic task (Bechara et al., 1994; Sevy et al., 2007; Buelow and Suhr, 2009; Fridberg et al., 2010; Alameda-Bailén et al., 2014). Considering that both types of studies obtain similar results and are framed within the somatic marker hypothesis, we think that these markers must appear in short temporal intervals controlled by the experimenter, but that it is also important to examine the performance of physiological indices in a more natural process of decision making without time constraints.

In addition, while recording skin conductance provides information about whether emotions play a role in the decision making process, it specifically does not allow us to determine individual sensitivity to the frequency or magnitude of reinforcements and punishments (Bull et al., 2015). Therefore, performance on the IGT can be analyzed by computational probabilistic models, such as (PVL, Ahn et al., 2008, 2011, 2014), complementarily to the Gambling Index. This model, based on Bayesian logic, is based on three general assumptions (Ahn et al., 2008):

- the evaluation of the positive/negative results can be represented by a one-dimensional utility function.
- expectancies about each deck are learned by what is experienced in each trial.
- these expectancies determine the choice probabilities of each deck on each trial.

The PVL model has been applied to different clinical samples and has allowed the identification of distinct decision-making patterns in the IGT (Ahn et al., 2008, 2011, 2014; Alameda-Bailén et al., 2014, 2015, 2017, 2018).

Ultimately, the aim of this study is to investigate whether higher SCR before card selection from disadvantageous decks is associated with better results in the task, and vice versa, with no restrictions concerning maximum response times, as a means to make the decision-making process more natural. In fact, following Bechara et al. (1997), we forced a minimum interval of 1 s before the selection of each card. We also intended to compare the performance patterns of participants with higher and lower SCRs in anticipation of choosing cards from disadvantageous decks using PVL parameters, and to observe possible group differences. In order to better characterize their decision-making styles, we applied the maximum likelihood estimation (MLE), and PVL-Delta and PVL-Decay simulations with Hierarchical Bayesian analysis (HBA) for parameter estimation.

MATERIALS AND METHODS

Participants

Twenty-nine young adults (22 women), aged between 18 and 35 (M = 22.31, SD = 4.34) participated voluntarily in the study. Participants were recruited among students of the University of Huelva and did not receive any compensation for their participation. We do not keep any personal information of the participants, and we only record their gender and age. This study was carried out in accordance with the Declaration of Helsinki and the recommendations of the Bioethics Committee Guidelines of the University of Huelva, following the protocols established by the university and the Portal of Ethics of Biomedical Research of Andalusia (Portal de Ética de la Investigación Biomédica de Andalucía: PEIBA), although, ethical approval was not required in line with national legislation and institutional guidelines. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

After performing the task, participants were further divided into two groups, according to their anticipatory SCR: (a) the aSCR− group comprised 14 participants (9 women), with an average age of 21.43 (SD = 3.65) and a baseline mean SCR of 4.82 μS (SD = 3.25); (b) in the aSCR+ group, there were 15 participants (13 women), with an average age of 23.13 (SD = 4.88) and a baseline mean SCR of 6.66 μS (SD = 4.46). In order to compute individual aSCR values, skin conductance preceding each card (1250 ms time-window) was averaged, and the inverse GI formula was applied (Carter and Pasqualini, 2004), that is, SCR in anticipation of disadvantageous choices (A+B) minus the responses to advantageous choices (C+D): aSCR (A+B) – aSCR (C+D). Results of this formula are either positive or negative, with positive aSCR values representing higher conductance responses in anticipation of disadvantageous decks, and negative values meaning higher responses in anticipation of advantageous decks.

No significant group differences were observed for age, $t_{(27)} = -1.06$, $p = 0.299$, sex, $\chi^2 = 1.98$, $p = 0.159$, and skin conductance during the period of no stimulation (baseline), $t_{(27)} = -1.26$, $p = 0.217$.

TASK

We used the *Cartas* software (Palacios et al., 2010), a computerized version of Bechara et al. (1994) IGT, "ABCD" version. The task consists of presenting four decks of cards (A, B, C, and D), from which the subject must choose one card in every trial for a total of 100 choices. Each deck has a total of 40 cards displaying a certain gain or loss. The participant starts with the amount of €2000, displayed on the screen, which is updated with the gains or losses after each trial.

For every 10 cards selected from the disadvantageous decks (A and B), the subject loses a total of €250. In deck A, gains are always €100, but losses range between €150 − 350 in 5 out of 10 elections, whereas in deck B, there is a single loss of €1250 for each cycle of 10 cards.

For every 10 cards selected from the advantageous decks (C and D), participants gain €250. Losses in deck C range between €25 – 75, whereas in deck D, there is a single loss of €250, occurring once every 10 cards. The aim for participants is to win as much money as possible, although the best strategy is concealed when giving the instructions.

After selecting one card, participants had to wait at least 1 s before choosing the next one, but they had no time limit for their responses.

Procedures

Data gathering sessions were performed individually, with an approximate duration of 45 min, in a room with adequate lighting and acoustics. All participants were informed about the objectives of the study and gave informed consent before starting the experiment.

Afterward, the participant was seated comfortably in front of a computer and prepared for physiological recording. Skin conductance (SC) was measured using MC-6SY cable and compatible electrodes (range 5–100 μS) connected to an I-330-C2+ 12-channel polygraph, synchronized with USE3 Physiolab data processing software (all from J & J Engineering, Inc., Washington, DC, United States).

Electrodes were placed on the middle phalanges of the index and middle finger of the non-dominant hand (JE-26 gel was employed). Participants were instructed not to move the hand and to remain silent during the experiment. A baseline acquisition (1 min) was performed before starting the IGT, and the SC recording was run simultaneously with the task thereafter. Markers were manually inserted in the recordings each time participants selected a card.

In order to examine the decision-making processes, measures from two analytical procedures were computed. Firstly, we obtained the GI, as described above, and other classical IGT measures. Partial GIs were also calculated for blocks of 20 trials each, that is: B1 (cards 1–20), B2 (cards 21–40), B3 (cards 41–60), B4 (cards 61–80), and B5 (81–100). Thus, we analyzed the following measures: total GI, partial GIs, number of choices per deck (ABCD) and number of choices per type of deck (advantageous vs. disadvantageous). Secondly, we determined the following PVL parameters: utility, loss aversion, recency, and consistency (see **Table 1**).

TABLE 1 | Summary of prospect valence learning model (PVL).

	Interval of values				
Parameter	**Maximum likelihood**	**Decay Rule**	**Delta Rule**	**Minimum value**	**Maximum value**
Utility (α)	$0 < \alpha < 1$	$0 < \alpha < 2$		Sensitivity to feedback outcomes	
				Lower	Higher
Loss aversion (λ)	$0 < \lambda < 5$	$0 < \lambda < 10$		Sensitivity to losses relative to gains	
				Higher	Lower
		$0 < A < 1$			
Recency (A)	Decay Rule	Decay Rate	Learning Rate	Recent outcomes	Past outcomes
Consistency (c)		$0 < c < 5$		Random	Deterministic

The equations to calculate the parameters of PVL are:

To rate a card:

$$u(t) = \begin{cases} x(t)x^{a} \rightarrow \text{if } X(t) \geq 0 \\ -\lambda\,|x(t)|^{\alpha} \rightarrow \text{if } X(t) < 0 \end{cases} \quad (1)$$

where:

α = **Utility or Reward sensitivity**. This regulates the shape of the utility (power) function. High values of α indicate more sensitive to feedback outcomes, whereas low values of α indicate low sensitivity to feedback outcomes.

λ = **Loss aversion**. This determines sensitivity to losses compared to gains. A value of λ less than 1 indicates more sensitivity to gains than to losses whereas a value of λ greater than 1 indicates more sensitivity to losses than to gains.

To create deck expectancy, E, for deck *j* on trial *t*, the equation for decay-reinforcement rule is:

$$E_j(t) = A \cdot E_j(t-1) + \delta_j(t) \cdot u(t) \quad (2)$$

and the equation for delta rule is:

$$E_j(t) = E_j(t-1) + A\delta_j(t).[u(t) - E_j(t-1)] \quad (3)$$

Where *j* refers to deck A, B, C, or D. $\delta j(t)$ is a dummy variable equal to 1 if deck j was chosen on trial t, and otherwise is 0. A is the recency or learning rate parameter.

***A* = Recency parameter/learning rate.** In PVL-Delta the expected value is updated with a learning rate parameter and a prediction error term. Where *A* close to 1 places more weight on recent outcomes, and where *A* close to 0 places more weight on past outcomes. The difference between predicted and experienced outcomes is the prediction error. In PVL-Decay A is used for value updating. The recency parameter indicates how much the expected values of all decks are discounted on each trial.

In the delta rule (Rescorla–Wagner rule, Rescorla and Wagner, 1972), only the expectancy of the selected deck is updated while the expectancies of other decks remain unchanged. In the decay rule (Erev and Roth, 1998), A is used for value updating. It indicates how much the expected values of all decks are discounted on each trial. The decay rule permits the expectancies of all the alternatives to change on each trial, thus is more flexible than the delta rule but high model flexibility may over-fit the data and lead to poor generalizability.

The equation to calculate the probability of choosing Deck *j* is:

$$Pr\left[D(t+1) = j\right] = \frac{e^{\theta(t)\cdot e_j(t)}}{\sum_{k=1}^{4} e^{\theta(t)\cdot E_k(t)}} \quad (4)$$

and, finally, to calculate the consistency between choices and expectancies, the equation is:

$$\theta(t) = 3^{c} - 1 \quad (5)$$

where: ***c* = Consistency or Response Sensitivity**. This is a consistency parameter (choice sensitivity), it reflects how deterministically individual choices are made in relation to alternative choices. High values represent more deterministic choices and low values random choices.

We applied the (MLE, Ahn et al., 2008), and PVL-Delta and PVL-Decay simulations with HBA for parameter estimation (Ahn et al., 2008, 2014, 2016).

The MLE has been performed with the decay rule (Erev and Roth, 1998), as it consistently shows better models of *post hoc* fit than the delta rule in the IGT (Yechiam et al., 2005). For the MLE estimation of PVL parameters we follow a scrip in R programmed by Ahn et al. (2008).

Hierarchical bayesian analysis simulation method uses the parameters estimated from the IGT task as seed to make predictions. It is not an individual level analysis. To perform HBA, we used a R packages hBayesDM (Ahn et al., 2016) and RStan (Stan Development Team, 2014), which uses Markov chain Monte Carlo (MCMC) sampling Hamiltonian Monte Carlo (HMC) algorithms, that allows efficient sampling for complex models and with highly correlated parameters. The individual parameters were obtained from the normal distributions at the group. On the websites:

- https://www.rdocumentation.org/packages/hBayesDM/versions/0.4.0/topics/igt_pvl_delta
- https://www.rdocumentation.org/packages/hBayesDM/versions/0.4.0/topics/igt_pvl_decay

you can see the commands used for both HBA simulations: PVL-Delta and PVL-Decay. The HBA simulations were performed based on of each group data, thus, we performed

for the aSCR− group the corresponding HBA simulations (PVL-Delta and PVL-Decay), and equally, the HBA simulation, PVL-Delta and PVL-Decay, for aSCR+ group (using the procedure in Appendix B of Ahn et al., 2008).

Statistical analyses comprised: (a) *t*-test for independent samples to examine possible group differences in decision making (aSCR+ vs. aSCR−) in the total test (GI); (b) repeated measures ANOVA followed by planned contrasts to analyze group differences in partial GIs (B1, B2, B3, B4, B5) to observe task evolution across the blocks; (c) repeated measures ANOVA followed by planned comparisons of groups (aSCR+ vs. aSCR−) to examine differences in the number of choices depending on the deck type (advantageous vs. disadvantageous) and deck (A, B, C, D); (d) Student's *t*-test for independent samples on PVL parameters; (e) repeated measures ANOVA of SRC activation (anticipatory/post-election) by bloks, for the positive (aSCR+) and negative (aSCR−) anticipatory skin conductance response groups for advantageous and disadvantageous desk; and (f) repeated measures ANOVA of the deck choice times by block for the positive (aSCR+) and negative (aSCR−) anticipatory skin conductance response groups for advantageous and disadvantageous deck (see **Supplementary Data Sheet S1**).

RESULTS

The results showed significant differences between the aSCR+ group (M = 12.00, SD = 18.99) and the aSCR− group (M = −2.29, SD = 13.38) for total GI, $t_{(27)} = -2.33$, $p = 0.028$, $d = 0.41$. Concerning the partial GIs, the results show a group effect, $F_{(1,27)} = 5.58$, $p = 0.026$, $\eta^2 = 0.17$, with the planned contrast analyses revealing significant differences in block B2, $t_{(20.4)} = -2.42$, $p = 0.025$, $d = 0.47$, and a marginally significant difference in B3, $t_{(27)} = -1.98$, $p = 0.058$), $d = 0.36$, with higher partial GI scores for the aSCR+ group in both cases (see **Figure 1**).

Regarding the effects of group (aSCR+, aSCR−) and deck type (advantageous, disadvantageous) on the number of choices, the repeated measures ANOVA did not show any main effect ($F < 1$) but we found a significant interaction effect of Group*Type of Deck, $F_{(1,\ 27)} = 5.41$, $p = 0.028$, $\eta 2 = 0.17$. Specifically, whereas the aSCR+ group chose more cards from the advantageous decks (M = 56.00, SD = 9.49) than from the disadvantageous ones (M = 44.00, SD = 9.49, $p = 0.009$) the aCSR- group chose similarly from both types of decks, with a non-significant tendency ($p > 0.05$) to select more cards from the disadvantageous decks (M = 51.14, SD = 6.69) over the advantageous ones (M = 48.86, SD = 6.69).

Planned comparisons revealed significant group differences both for the advantageous and disadvantageous decks, $t_{(27)} = -2.33$, $p = 0.028$, $d = 0.41$.

In a further analysis of the effects of group (aSCR+, aSCR−) and deck (A, B, C, D) on the number of choices, the repeated measures ANOVA yielded a main effect of deck, $F_{(3,\ 81)} = 25.27$, $p < 0.001$, $\eta^2 = 0.48$, and a marginal interaction effect was also obtained, $F_{(3,\ 81)} = 2.58$, $p = 0.059$, $\eta^2 = 0.08$. *Post hoc* analyses within the aSCR− group revealed significant differences between decks A–B ($p < 0.01$), A–D ($p < 0.05$), and B–C ($p < 0.05$), whereas the aSCR+ Group showed differences between decks A–B ($p < 0.01$), A–C ($p < 0.01$), and A–D ($p < 0.001$).

Planned comparisons revealed a significant group difference only for deck A, $t_{(27)} = 3.19$, $p = 0.004$, $d = 0.59$, which was more frequently selected by the aCSR- group (see **Figure 2**).

Regarding to the parameters of the PVL model, as can be seen in **Table 2**, there were no significant differences between aSCR− and aSCR+, in PVL-decay and PVL-delta simulations, the parameter utility (α: $t = 2.432$, $p = 0.006$) presented significant differences using MLE.

We have analyzed the anticipatory and post-election SCR activation by block for the positive (aSCR+) and negative (aSCR−) anticipatory skin conductance response groups for advantageous and disadvantageous desk (**Figures 3**, **4** and **Table 3**).

We can see how the activation levels of the aSRC+ group are higher than those of the aSRC− group, however, the activation levels between advantageous and disadvantageous choices are

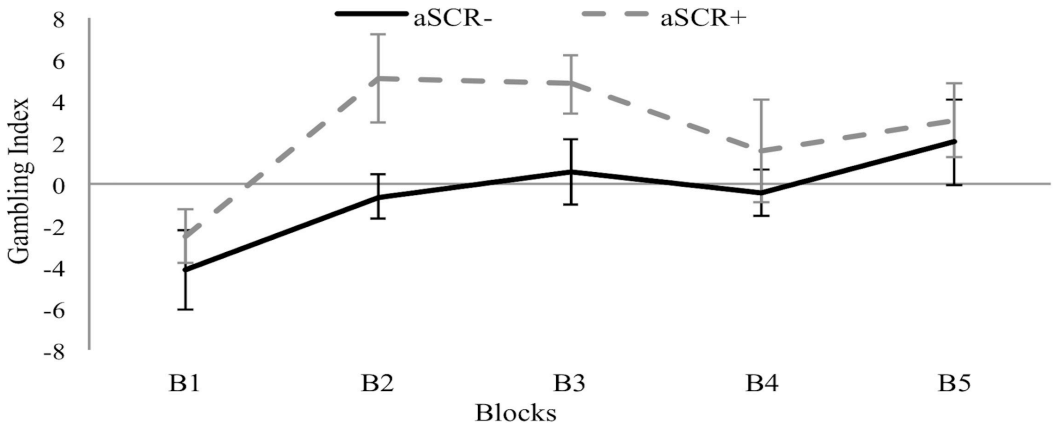

FIGURE 1 | Means of the Gambling Index by block for the positive (aSCR+) and negative (aSCR–) anticipatory skin conductance response groups (error bars represent standard error of the mean).

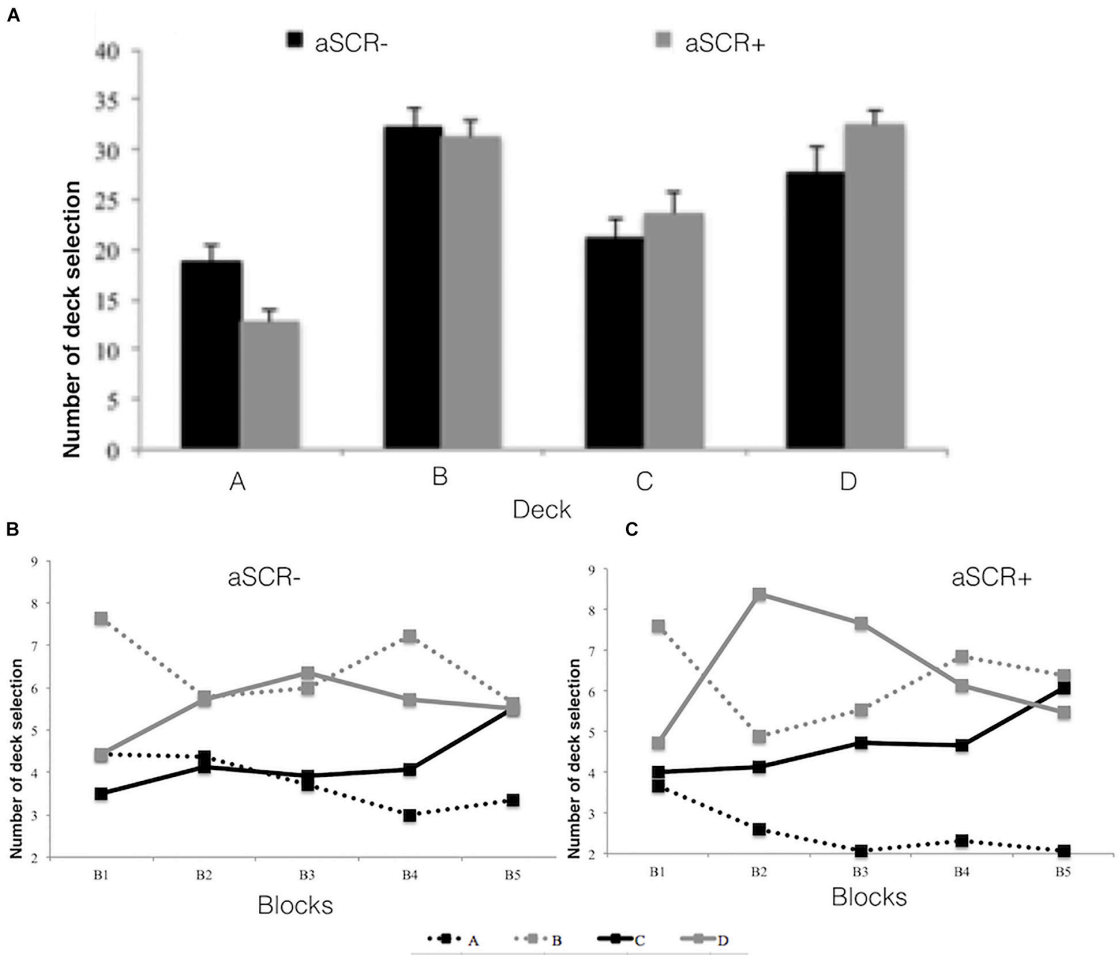

FIGURE 2 | Number of deck selections (ABCD) for the positive (aSCR+) and negative (aSCR–) anticipatory skin conductance response groups (error bars represent standard error of the mean), for total task **(A)** and by blocks **(B)** for (aSCR– and **C** for aSRC+).

TABLE 2 | Descriptive and statistical analysis of the PVL parameters.

	MLE: PVL			HBA: PVL-Decay			HBA: PVL-Delta		
	aSCR−	aSCR+		aSCR−	aSCR+		aSCR−	aSCR+	
	M (SD)	M (SD)	Sig.	M (SD)	M (SD)	Sig.	M (SD)	M (SD)	Sig.
A	0.495 (0.31)	0.458 (0.32)		0.918 (0.05)	0.919 (0.05)		0.093 (0.06)	0.092 (0.06)	
α	0.557 (0.41)	0.165 (0.26)	0.006	0.529 (0.26)	0.534 (0.25)		0.680 (0.21)	0.681 (0.21)	
c	0.365 (0.36)	0.998 (1.16)		0.430 (0.98)	0.431 (0.98)		2.008 (0.68)	2.010 (0.68)	
λ	3.00 (2.17)	2.57 (2.22)		1.369 (0.53)	1.358 (0.52)		1.001 (0.40)	1.001 (0.39)	

A (recency); α (utility); c (consistency), and λ (loss aversion).

similar in both groups. Also note that there are no differences between anticipatory and post-election activation. Perhaps it should be noted that while we can observe a downward trend in the aSCR+ group in the aSCR− group is upward.

The analysis of variance of repeated measures does not show significant effects of any main effect. Two interactions are significant, those obtained between SCR (anticipatory/post-election) and group (aSCR+/aSCR−) $F_{(2,24)} = 9.348$; $p = 0.005$, and between SCR (anticipatory/post-election) and blocks [$F_{(4,24)} = 3.065$; $p = 0.036$]. In the first interaction, we observe that there are no significant differences between anticipatory and post-election activation in the aSCR− group, while in the aSRC+ group if there are significant differences, anticipatory activation

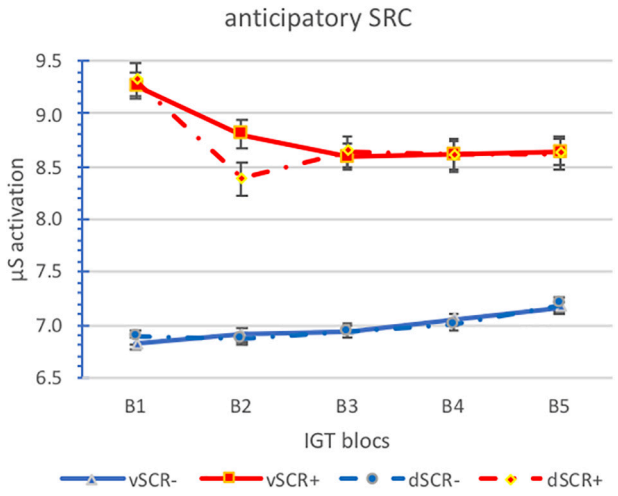

FIGURE 3 | Means of the anticipatory SCR activatión by block for the positive (aSCR+) and negative (aSCR–) anticipatory skin conductance response groups for advantageous and disadvantageous desk (error bars represent standard error of the mean).

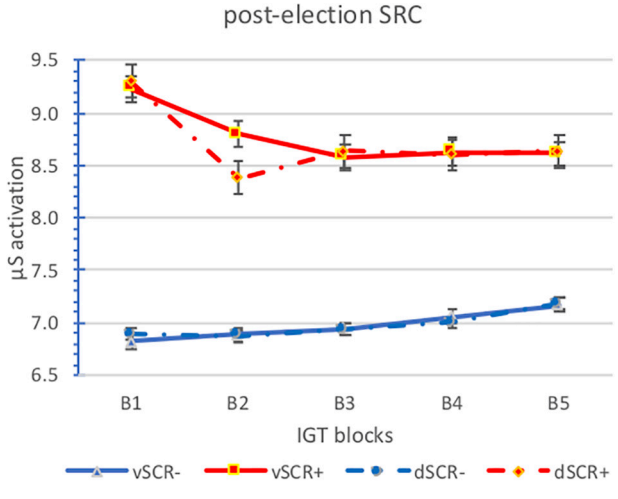

FIGURE 4 | Means of the post-election SCR activation by block for the positive (aSCR+) and negative (aSCR–) anticipatory skin conductance response groups for advantageous and disadvantageous desk (error bars represent standard error of the mean).

is slightly higher (p = 0.004). As for the relationship between the activation (anticipatory/post-election) along the blocks we obtain slightly lower levels in the post-election activation and in both cases (anticipatory and post-election activation) there is a slight downward trend.

Finally, in relation to response times, we have analyzed the deck choice times by block for the positive (aSCR+) and negative (aSCR−) anticipatory skin conductance response groups for advantageous and disadvantageous deck (**Figure 5** and **Table 4**). We can observe, both groups present descending election times, especially between the first and the second block. The aSRC+ group has the lowest response times in the advantageous elections.

The analysis of variance of repeated measures shows us only one main effect in the task blocks [$F_{(4.24)}$ = 9.049; p = 0.000] confirming the observed downward trend, especially between the initial blocks (B1 and B2) and the rest.

DISCUSSION

The aim of this study was to determine whether healthy community-dwelling individuals would manifest a significantly distinct behavioral pattern in the IGT based on their SCRs prior to card selection, with the novelty that we did not establish a limited time interval between trials as a means to enhance the ecological validity of the task. Also, participants' decisions were analyzed both with classical methods and a computational model.

Taken altogether, our results suggest that participants with higher anticipatory SCRs to the disadvantageous decks (aSCR+) perform better in the IGT than participants not showing such anticipatory responses (aSCR−). These results are similar to previous studies that apply limited time intervals between trials (Bechara et al., 1996, 1997, 2002; Bechara and Damasio, 2002; Carter and Pasqualini, 2004; Crone et al., 2004; Jenkinson et al., 2008; Starcke et al., 2009; Fonfría et al., 2015; Ottaviani and Vandone, 2015), suggesting that free time to deliberate responses does not change the decision-making process.

More important, it must be noted that the total GI of the aSCR− group, despite being healthy, is below the cut-off score (10) established by Bechara et al. (2001, 2002) and Bechara and Damasio (2002) for impaired decision making, and other studies have confirmed this criterion in different types of patients (Alameda et al., 2012; Cavedini et al., 2012). Although some studies have shown that different factors may explain this variability in healthy population, such as age (Denburg et al., 2009), level of education (Davis et al., 2008), gender (De Visser et al., 2010), certain personality characteristics (Glicksohn and Zilberman, 2010), anxiety (Fonfría et al., 2015), and the time or number of movements (Bull et al., 2015), our results reveal that special care must be taken regarding galvanic response profiles when selecting participants for control groups.

In addition, our results are consistent with the idea that the initial phase of the IGT is used to explore and learn how the task works (Damasio, 1994; Dunn et al., 2006). The aSCR+ and aSCR− groups start choosing differently only in the second block, indicating that participants with higher prior activation to the disadvantageous decks determine a better strategy in the decision process, resulting in a better performance in the IGT. The performance of the aSCR− group also improved across the task, with both groups behaving similarly in the last blocks, but at a different learning rate. Therefore, aSCR− participants may need more time to develop the appropriate strategy, as suggested by Bull et al. (2015) or Marin et al. (2019), they suggest that low SCR is related with hypoactivation of brain regions involved in fear learning. This being said, it would be interesting to see whether the group differences found would definitely disappear by extending the duration of the task.

TABLE 3 | Mean and S.D. of anticipatory and post-election SCR activation for advantageous and disadvantageous decks by blocks.

	Anticipatory SCR								Post-election SCR							
	Advantageous (C + D)				Disadvantageous (A + B)				Advantageous (C + D)				Disadvantageous (A + B)			
	SCR-		SCR+		SCR-		SCR+		SCR-		SCR+		SCR-		SCR+	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
B1	6.821	3.914	9.263	7.629	6.880	3.910	9.314	7.714	6.820	3.904	9.235	7.562	6.888	3.897	9.301	7.684
B2	6.902	3.903	8.806	7.489	6.860	3.896	8.388	7.639	6.887	3.888	8.793	7.511	6.875	3.911	8.382	7.674
B3	6.942	3.926	8.591	7.521	6.930	3.912	8.638	7.476	6.943	3.934	8.581	7.502	6.930	3.905	8.635	7.490
B4	7.047	3.981	8.607	7.742	6.996	3.936	8.611	7.750	7.057	3.979	8.625	7.769	7.005	3.938	8.602	7.758
B5	7.162	4.073	8.634	8.357	7.192	4.105	8.626	8.529	7.174	4.087	8.610	8.319	7.185	4.097	8.637	8.550

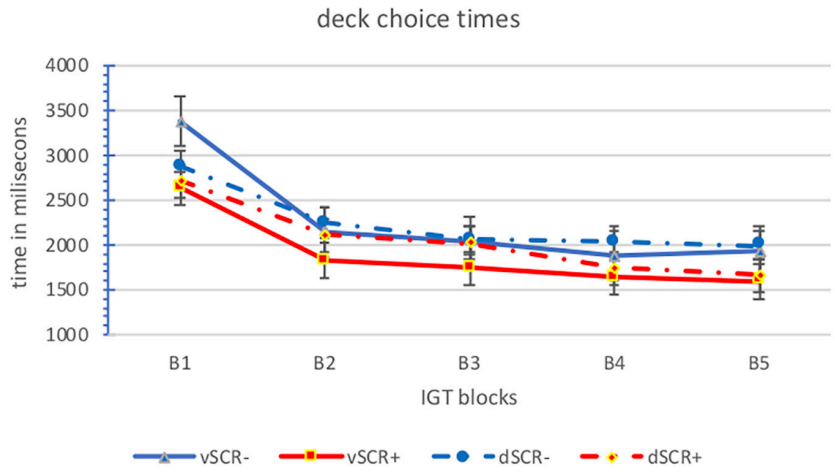

FIGURE 5 | Means of the deck choice times by block for the positive (aSCR+) and negative (aSCR–) anticipatory skin conductance response groups for advantageous and disadvantageous deck (error bars represent standard error of the mean).

TABLE 4 | Mean and S.D. of deck choice times for advantageous and disadvantageous decks by blocks.

	Advantageous (C+D)				Advantageous (A+B)			
	SCR–		SCR+		SCR–		SCR+	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
B1	3368.642	1769.784	2632.038	1425.076	2876.044	930.469	2710.814	1010.941
B2	2152.657	889.514	1826.366	892.939	2246.659	996.518	2105.207	978.937
B3	2048.194	862.381	1741.432	717.125	2058.854	925.146	2022.747	916.060
B4	1875.548	708.558	1643.454	697.875	2033.633	878.071	1741.174	684.998
B5	1931.274	741.325	1593.584	604.072	1998.761	689.776	1667.924	645.841

Although the aSCR+ group prefers favorable decks, and participants with less activation to the disadvantageous decks select more unfavorable decks, when choices are analyzed in detail, we observe that the aSCR+ group prefers D, B, and C, ordered from highest to lowest preference. This means that these individuals could not establish B as a deck involving long-term losses (probably because they are focused on the frequency of the losses, which is one per 10 cards). This effect has been previously described in studies with non-clinical samples (e.g., Lin et al., 2007; Lee et al., 2014), and it underlines the importance of analyzing all four decks (ABCD), as argued by Steingroever et al. (2013). These decision-making problems are due to the inability to establish stimulus-reward relationships or to eradicate previously learnt responses (Maia and McClelland, 2004; Rolls, 2004). The choices of the disadvantageous decks offer gains at the beginning but losses in the long term. This shows that participants either did not adequately identify the characteristics of the decks (Fernie and Tunney, 2006; Lin et al., 2007, 2009) or they had problems eradicating their initial preference for the disadvantageous decks (A-B).

Not surprisingly, the aSCR− group prefers deck B, which may reveal hypersensitivity to reward (Bechara et al., 2002), but the next option is for deck D, which was less expected and would be consistent with punishment-avoidance interpretations (González et al., 2010). This is when PVL (maximum likelihood) parameters become useful. Analysis of the utility (α) parameter yields α-values near 0 in the aSCR+ group, showing that these participants are less sensitive to feedback outcomes than the aSCR− group. Similar results have been found in other studies (e.g., Alameda et al., 2012; Alameda-Bailén et al., 2014). However, data from the PVL simulations do not show significant group differences and, in both cases, the α-value denotes low sensitivity to feedback outcomes.

Regarding consistency (*c*), both groups score low on MLE and PVL-Decay, groups selects cards randomly, which is consistent with previous findings by Fridberg et al. (2010), although these authors focused on a different group comparison. The group differences are more evident in maximum likelihood than in simulation data but, in this case, the *c* values of both groups are similar.

Both groups are more sensitive to losses than to gains, although λ-values are higher with maximum likelihood than with PVL-Decay simulation. Finally, we observed the greatest difference between the maximum likelihood data and the simulation data in parameter A, which had lower values with no significant differences in the former and values close to 1 with significant group differences in the latter, and, although both groups grant more weight to recent outcomes.

CONCLUSION

Summing-up, regardless of using unlimited inter-trial intervals, our results suggest that aSRCs to disadvantageous decks are indicating a somatic marker that guides the decision-making process toward more favorable choices, leading to a better score on the IGT. Furthermore, even in healthy participants, the decision-making process is qualitatively different in people who are well equipped to develop somatic markers (aSCR+) from people who are not (aSCR−). According to the PVL model parameters, decisions of participants who do not benefit from aSCRs to the disadvantageous decks are more random, and show low sensitivity to feedback outcomes. These findings are relevant for researchers using the IGT, as they highlight the potential effects of individual aSCR differences even in healthy control groups, and the failure to control for these differences, or at least to consider them in the data analysis, may lead to inaccurate behavioral results.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

AUTHOR CONTRIBUTIONS

All authors contributed equally to the development of the manuscript, substantially to the design and planning, or analysis and interpretation of the data, significantly in drafting or critically reviewing the content, and participated in the approval of the final version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02237/full#supplementary-material

DATA SHEET S1 | Database.

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An Event-Related Potential Study of Decision-Making and Feedback Utilization in Female College Students Who Binge Drink

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This study investigated the ability to use feedback for decision-making in female college students who binge drink (BD) using the iowa gambling task (IGT) and event-related potentials (ERPs). Twenty-seven binge drinkers and 23 non-binge drinkers (non-BD) were identified based on scores on the Korean version of the Alcohol Use Disorder Test and the Alcohol Use Questionnaire. The IGT consists of four cards, including two cards that result in a net loss, with large immediate gains but greater losses in the long term, and two cards that result in a net gain, with small immediate gains but reduced losses in the long term. Participants were required to choose one card at a time to maximize profit until the end of the task while avoiding losses. The BD group showed a significantly lower total net score than the non-BD group, indicating that the BD group chose more disadvantageous cards. The BD group showed significantly smaller ΔFRN amplitudes [difference in amplitudes of feedback-related negativity (FRN) between gain and loss feedback] but not in P3 amplitudes. Additionally, ΔFRN amplitudes in the fronto-central area were positively correlated with the total net score and net scores for sectors 4 and 5. Thus, total net scores and later performance on the IGT increased as ΔFRN amplitudes from the fronto-central area increased. FRN is known to reflect early feedback evaluation employing a bottom-up mechanism, whereas P3 is known to reflect late feedback processing and allocation of attentional resources using a top-down mechanism. These results indicate that college students who binge drink have deficits in early evaluation of positive or negative feedback and that this deficit may be related to decision-making deficits.

Keywords: binge drinking, decision-making, feedback-related negativity, feedback utilization, event-related potentials, P3

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INTRODUCTION

Binge drinking (BD) is defined as a repeated pattern of excessive alcohol consumption and abstinence over a short period of time (Wechsler and Nelson, 2001; Parada et al., 2012; Maurage et al., 2013). BD is most prevalent among young adults, especially college students (Wechsler and Nelson, 2001; Chun et al., 2003; Stephens and Duka, 2008), and is associated with various problems including assault, drunk driving, unguided or unsafe sexual behavior,

and academic underachievement (Wechsler and Nelson, 2001; Chun, 2002; Naimi et al., 2003; Cha, 2005). Additionally, binge drinkers exhibit similar structural and functional brain abnormalities and neuropsychological deficits to patients with alcohol use disorder (AUD) (Crego et al., 2010; Lopez-Caneda et al., 2012; Campanella et al., 2013; Kanny et al., 2013; Maurage et al., 2013; Mota et al., 2013), and BD predicts the development of AUD in the future (O'Neill et al., 2001; Tucker et al., 2003; Jennison, 2004; Kanny et al., 2013).

Patients with AUD cannot stop drinking alcohol even though they suffer from its negative consequences [American Psychiatric Association (APA), 1994, 2013]. Such behaviors reflect inefficient decision-making among patients with AUD, as they continue to seek immediate rewards and ignore future consequences (Mazas et al., 2000; Bechara et al., 2001). In other words, they not only underestimate the negative consequences of alcohol consumption (Mallett et al., 2006) but also emphasize immediate rewards over long-term consequences (MacKillop et al., 2010; Amlung et al., 2014). Decision-making deficits have been observed in patients with AUD (Bechara et al., 2001; Bechara, 2003; Fein et al., 2004; Goudriaan et al., 2005; Mitchell et al., 2005; Noel et al., 2007) and in binge drinkers (Goudriaan et al., 2007; Johnson et al., 2008; Xiao et al., 2009, 2013; Yoo and Kim, 2016).

Decision-making is defined as a process of forming a preference for an option, making a choice based on the preference, executing the choice, and evaluating the consequences of the choice (Ernst and Paulus, 2005). Decision-making is a complex process including both cognitive and non-cognitive processes (i.e., emotions) (Bechara et al., 1999), and various brain areas, such as the orbitofrontal, ventromedial prefrontal, anterior cingulate cortices, and amygdala, are involved in decision-making (Bechara et al., 2000; Bush et al., 2002; Ernst et al., 2002; Kennerley et al., 2006; Wallis, 2007). The iowa gambling task (IGT) (Bechara et al., 1994; Bechara, 2004) is widely used to measure decision-making ability. Participants are asked to choose one of four cards on every trial to maximize profit while avoiding loss. The chosen card results in gains on every trial, but also results in intermittent losses. The cards differ in feedback magnitude and probability. Two cards (A and B) result in large immediate gains but greater losses, causing a net loss (disadvantageous cards), whereas the other two cards (C and D) lead to small immediate gains and smaller losses, resulting in a net gain (advantageous cards). Participants must evaluate feedback such as valence (gain or loss), magnitude (large or small), and the probability of encountering losses to learn the contingency between the card and its consequences (Dunn et al., 2006; Webb et al., 2014). Studies investigating decision-making ability in patients with AUD using the IGT found that patients with AUD performed poorly compared to normal controls, choosing significantly more disadvantageous cards and significantly fewer advantageous cards compared with the controls (Bechara et al., 2001; Fein et al., 2004; Goudriaan et al., 2005; Dom et al., 2006; Noel et al., 2007). Additionally, positive correlations were observed between IGT performance and gray matter volume in the dorsal and ventromedial prefrontal cortices, which are crucial for decision-making (Le Berre et al., 2014). Poor IGT performance has also been observed in individuals with BD (Goudriaan et al., 2007; Johnson et al., 2008; Moreno et al., 2012; Yoo and Kim, 2016). For example, adolescents (Moreno et al., 2012) and college students with BD (Yoo and Kim, 2016) performed significantly worse on the IGT than did non-BD groups.

Feedback utilization, a process of identifying whether an action induces positive or negative consequences and evaluating those consequences, is crucial to making efficient decisions (San Martin, 2012). Considerable improvement in our understanding of the neurological basis of feedback utilization has revealed that the orbitofrontal, ventromedial prefrontal, and anterior cingulate cortices as well as the ventral striatum are involved in feedback utilization (Delgado et al., 2000; Elliott et al., 2000; Knutson et al., 2000; O'Doherty et al., 2001; Rogers et al., 2004). The ventral striatum is involved in prediction errors, i.e., how actual feedback differs from personal expectations, whereas the orbitofrontal cortex is involved in evaluating feedback based on prediction errors (Elliott et al., 2000; Pagnoni et al., 2002; McClure et al., 2003; O'Doherty et al., 2003). Additionally, the anterior cingulate cortex evaluates rewards in situations where contingencies are uncertain and then relays the evaluation of the reward to motor areas for response execution (Bush et al., 2002).

Studies, which have used event-related potentials (ERPs) to investigate feedback utilization, reported two components, feedback-related negativity and P3, as the electrophysiological indices of feedback utilization (Gehring and Willoughby, 2002; San Martin, 2012). Gehring and Willoughby (2002) used a simple gambling task to observe a negative peak approximately 265 ms post feedback whose amplitude was larger in response to negative than to positive feedback. This peak is known as feedback-related negativity (FRN) or outcome-related negativity (ORN) (Kamarajan et al., 2009). FRN is sensitive to feedback valence (gain or loss) (Yeung and Sanfey, 2004) and is associated with activation of the midbrain dopaminergic system (Tobler et al., 2005). Additionally, reinforcement-learning theory suggests that FRN reflects prediction errors, i.e., the difference between actual feedback and personal expectation (Wu and Zhou, 2009; Bellebaum et al., 2010; San Martin, 2012). P3, another ERP component related to feedback utilization, is a positive peak observed in central-parietal areas at 275–700 ms post feedback (Kamarajan et al., 2009; San Martin, 2012). P3 is known to be sensitive not only to feedback valence but also to feedback magnitude and probability (Yeung and Sanfey, 2004; Hajcak et al., 2007; Wu and Zhou, 2009; Polezzi et al., 2010; Xu et al., 2011). It has been suggested that P3 reflects activation of the locus coeruleus-norepinephrine system and processing of task-relevant information to maximize decision-making efficiency (Nieuwenhuis et al., 2005). In other words, P3 reflects, unlike FRN, a top-down mechanism that processes and evaluates feedback-related information in detail (Wu and Zhou, 2009; San Martin, 2012).

The effects of alcohol consumption on feedback utilization are reflected on the FRN and P3 amplitudes. For example, a study that used a gambling task and measured ERPs found

that the alcohol consumption group exhibited significantly lower FRN amplitudes in response to both gain and loss feedback, especially to loss feedback, than did a placebo group, indicating that alcohol consumption affects feedback utilization (Nelson et al., 2011). Deficits in feedback utilization are also observed in patients with AUD. For example, Fein and Chang (2008) using the Balloon Analogue Risk Task, observed that patients with AUD and a family history of AUD exhibited significantly smaller FRN amplitudes than did those without a family history. Kamarajan et al. (2010) used a gambling task and reported that patients with AUD exhibited lower P3 amplitudes in response to both gain and loss feedback and smaller FRN amplitudes to loss feedback than did normal controls. Additionally, they observed increased activation in primary sensory and motor areas during the FRN time window and decreased activation in the cingulate gyrus during the P3 window in patients with AUD relative to normal controls. These results indicate that the sensory and motor areas of patients with AUD are hyper-excited during early feedback evaluation, and areas involved in feedback evaluation are hypo-activated compared to normal controls (Kamarajan et al., 2010).

To our knowledge, only one study has investigated feedback utilization deficits in binge drinkers using ERPs. That study, which used the IGT, found that the BD group tended to exhibit smaller FRN amplitudes ($p = 0.06$) than the non-BD group (Wahlstrom, 2013). However, that study used the original computerized IGT (Bechara et al., 1994; Bechara, 2007), which had two limitations: first, the original IGT consisted of 100 trials, which is not suitable for an ERP study where a sufficient number of trials are needed (Schuermann et al., 2011). Second, the original IGT displays gains in every trial and subsequently displays losses according to each card's probability. When multiple stimuli are displayed in succession, the ERPs to loss feedback might be contaminated by previous gain feedback.

The present study investigated feedback utilization ability during decision-making in BD female college students using the IGT and ERP. Specifically, this study examined whether decision-making deficits in BD female students are related to feedback utilization deficits, and if so, how they are reflected in feedback-related ERP components, FRN, and P3. Based on previous findings, we hypothesized that the BD group would perform significantly worse than the non-BD group on the IGT; that the BD group would show significantly smaller FRN and P3 amplitudes than the non-BD group; and that IGT performance and feedback-related ERPs would be positively correlated. Gender differences are observed in BD (O'Malley and Johnston, 2002; Wechsler et al., 2002; Weitzman et al., 2003), decision-making (Bolla et al., 2004), and ERP amplitudes (Larson et al., 2011). For example, females tend to drink less (O'Malley and Johnston, 2002), perform poorer on the IGT (Bolla et al., 2004) than males, and exhibit different neural activities with regard to the N2 and P3 components (Larson et al., 2011). For these reasons, only female college students were included in this study.

MATERIALS AND METHODS

Participants

The details of the participant screening procedures have been described in previous studies by our research group (Yoo and Kim, 2016; Park and Kim, 2018). The Korean version of the Alcohol Use Disorder Identification Test (AUDIT-K) (Barbor et al., 1992; Lee et al., 2000), Alcohol Use Questionnaire (AUQ) (Mehrabian and Russell, 1978), and a questionnaire inquiring about binge drinking episodes in the last 2 weeks were administered to 435 female college students. The BD and non-BD groups were defined based on (1) alcohol-related problems and drinking habits, (2) the number of BD episodes, and (3) drinking speed. The BD group included those who (1) scored at least 12 but less than 26 on the AUDIT-K, (2) had consumed four or more glasses at one sitting in the last 2 weeks, and (3) drank two or more glasses per hour. Although the World Health Organization (WHO) recommends using a score >8 as the cutoff point for problem drinking (Barbor et al., 1992), the cutoff score of 12 was applied because a cutoff point of 8 includes those who do not have apparent drinking problems but may display problem drinking in the future (Conigrave et al., 1995; Kim et al., 1999). In contrast, those who received scores >26 on the AUDIT-K were also excluded, as AUD was suspected. The non-BD group included those who (1) scored less than 8 on the AUDIT-K, (2) had not drunk four or more glasses in one sitting in the last 2 weeks, and (3) drank 1 glass or less per hour.

The Structured Clinical Interview of the Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition (SCID-NP) (First et al., 1995) was administered to ensure that no participants had a psychiatric disorder. Additionally, the Self-Rating Depression Scale (SDS) (Zung et al., 1965), the State-Trait Anxiety Inventory (STAI) (Speilberger et al., 1983), and Barratt Impulsivity Scale (BIS) (Patton et al., 1995) were administered to evaluate depression, anxiety, and impulsivity, respectively. To control for the influence of alcohol-related genes and family history, the Korean version of the Children of Alcoholics Screening Test (CAST-K) (Jones, 1983; Kim et al., 1995) was administered, and those who scored 6 or more were excluded. Last, those who were left-handed or ambidextrous were also excluded to control for the effect of brain lateralization.

In the end, 50 students participated in this study (27 in the BD group and 23 in the non-BD group). This study was approved by Sungshin Women's University Institutional Review Board (SSWUIRB 2017-040). The participants provided written informed consent after receiving a description of the study, and they were paid for their participation.

The Korean Version of the Alcohol Use Disorder Identification Test (AUDIT-K)

The AUDIT (Barbor et al., 1992), a self-administered questionnaire designed to measure the presence of AUD and drinking problems, consists of 10 items. The total score ranges from 0 to 40. Three items inquire about frequency and quantity of alcohol consumption, three about symptoms related to alcohol

dependence, and four about psychosocial problems related to alcohol consumption. The Korean version was administered in this study (Lee et al., 2000).

Alcohol Use Questionnaire

The AUQ (Mehrabian and Russell, 1978) is a self-administered questionnaire measuring dinking patterns. Items 10, 11, and 12 evaluate drinking speed, frequency of being drunk within the last 6 months, and the rate of being drunk when consuming alcohol, respectively. These three items were used to calculate a BD score (Townshend and Duka, 2002). The binge score was calculated using the following equation:

$$\text{AUQ Binge score} = \left(\text{Item } 10 \times 4 + \text{Item } 11 + \text{Item } 12 \times 0.2\right)$$

The Iowa Gambling Task

This study employed a modified version of the original computerized IGT (Bechara, 2007) to make the task suitable for measuring ERPs (**Figure 1A**). Four cards were displayed on a computer monitor, and participants were asked to maximize profits until the end of the game by choosing a card during each trial. Gain or loss feedback was displayed after each choice, with gain feedback consisting of a green smiling emoticon with points earned and loss feedback consisting of a red crying emoticon with the points lost (**Figure 1B**).

The magnitude and probability of gain and loss for each card were set as for the original computerized IGT (Bechara, 2007). The cards consisted of two disadvantageous cards (A and B), which provided large gains and larger losses, resulting in a net loss, and two advantageous cards (C and D), which provided small gains but smaller losses, resulting in a net gain. Cards A and C each had a 50% chance of causing losses, whereas cards B and D had a 10% chance of causing losses.

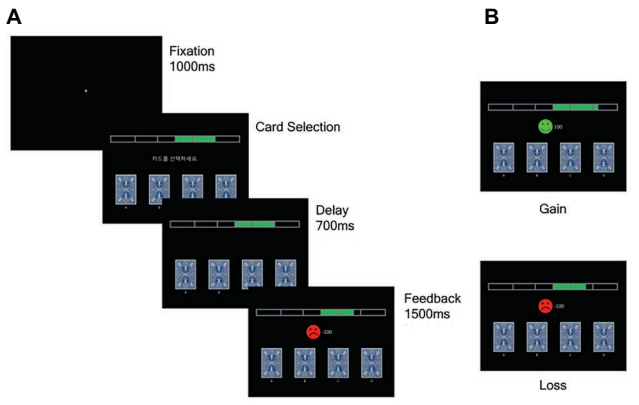

FIGURE 1 | The modified IGT. **(A)** A fixation point will be displayed for 1,000 ms and then four cards will be displayed till the participants make their choice. At 700 ms after a card is chosen, feedbacks will be displayed for 1,000 ms. **(B)** The feedback stimuli consist of gain conditions and loss conditions. In gain conditions, green smiling emoticon and the earned points will be displayed whereas red crying emoticon and the lost points will be displayed in loss conditions.

The task consisted of three blocks; the locations of the cards were changed at the beginning of each block to keep participants motivated. Each block comprised 100 trials; a total of 320 trials, including 20 practice trials, were administered. Decision-making ability was measured by the net score, which was calculated by subtracting the frequency of choosing the disadvantageous cards (A and B) from the frequency of choosing the advantageous ones (C and D).

E-Prime software (version 2.0; Psychological Software Tools, Inc., Sharpsburg, PA, USA) was used to administer the modified IGT. A fixation point (+) was displayed for 1,000 ms, and the cards were then displayed until the participants made their choice by pressing a button. The feedback, either a gain or loss, was displayed for 1,000 ms at 700 ms after a card was chosen.

Electrophysiological Recording Procedure

Electroencephalography (EEG) was measured using a 64-channel Geodesic sensor net connected to a 64-channel, high-input impedance amplifier (Net Amp 300; Electrical Geodesics, Eugene, OR, USA) in a shielded and soundproofed room. All electrodes were referenced to Cz, and impedance was maintained at 50 kΩ or less (Tucker et al., 2003). EEG activity was recorded continuously using a 0.3–100 Hz bandpass filter at a sampling rate of 500 Hz. The recorded EEG data were digitally filtered using a 0.3–30 Hz bandpass and re-referenced to the average reference. The continuous EEG was then segmented into 800 ms epochs (from 100 ms pre- to 700 ms post-feedback). Additionally, epochs contaminated by artifacts such as eye blinks were removed based on the threshold of a peak-to-peak amplitude of ± 70 μV from the eye channels. The remaining data were averaged according to feedback valence, i.e., gain and loss feedback.

Statistical Analysis

Demographic variables were analyzed with independent *t*-tests. The total net scores on the modified IGT were analyzed with independent *t*-tests. Additionally, each block was subdivided into five sectors, and scores for each sector were averaged across the three blocks to calculate sector net scores to measure performance improvement across trials. The sector net scores were analyzed with mixed-design analysis of variance (ANOVA), where group (BD or non-BD) was a between-subjects factor, and sector (1–5) was a within-subject factor.

ERP components and time windows were determined based on grand averaged ERPs and individual ERP waveforms. FRN was defined as the most negative peak observed at 200–275 ms after feedback-onset, and P3 was defined as the most positive peak followed by FRN, i.e., observed 275–600 ms after feedback. Because the FRN and P3 time windows overlapped and because the FRN is a negative and P3 is a positive peak, it is possible that latent components representing FRN and P3 independently might be distorted on the ERP waveforms due to the overlapping windows where the amplitudes and latencies do not clearly represent the differences by feedback

valence (Luck, 2014). To overcome this problem, it is necessary to isolate ERP components; difference waves have been recommended for this purpose (Luck, 2014). Therefore, ΔFRN (FRN effect) and ΔP3 (P3 effect) were defined as the amplitude difference between gain and loss feedback (Holroyd, 2004; Hajcak et al., 2007; Carlson et al., 2009; Holroyd et al., 2009; Walsh and Anderson, 2011; Xu et al., 2011).

Amplitudes and latencies of each component were analyzed by mixed ANOVA. Electrode site (FC3, FCz, FC4, C3, Cz, C4, P3, Pz, and P4) and valence (gain or loss) were within-subject factors, and group was a between-subjects factor. The electrode sites for ΔFRN and ΔP3 were a within-subject factor, and group was a between-subjects factor. Greenhouse-Geisser corrections were used in cases of violation of sphericity, and corrected p are reported when appropriate. The mean numbers of trials included in the FRN/P3 analysis for the BD and non-BD groups were 105.57 (gain = 161.89, loss = 51.26) and 111.33 (gain = 17.48, loss = 52.17), respectively. The two groups did not differ in terms of trials for averaging FRN/P3 in the gain feedback [$F(1,48) = 0.62$, $p = 0.44$], the loss feedback [$F(1,48) = 0.04$, $p = 0.85$] or both feedbacks [$F(1,48) = 0.57$, $p = 0.46$]. The relationships of the ΔFRN and ΔP3 amplitudes with performance on the IGT, i.e., total net scores and sector net scores, were analyzed using Pearson's correlation coefficient analysis. A $p < 0.05$ was considered significant.

RESULTS

Demographic Characteristics

The BD and non-BD groups did not differ in terms of age [$t(48) = -1.08$, $p = 0.29$], educational level [$t(48) = -1.07$, $p = 0.29$], SDS [$t(48) = 0.80$, $p = 0.43$], or trait anxiety on the STAI [$t(48) = 1.05$, $p = 0.30$]. However, the BD group exhibited significantly higher state anxiety on the STAI [$t(48) = 5.49$, $p < 0.001$], BIS [$t(48) = 6.92$, $p < 0.001$], AUDIT-K total score [$t(48) = 16.81$, $p < 0.001$], drinking speed [$t(48) = 12.56$, $p < 0.001$], frequency of being drunk within the last 6 months [$t(48) = 5.63$, $p < 0.001$], percentage of being drunk when consuming alcohol [$t(48) = 3.73$, $p < 0.01$], and AUQ binge score [$t(48) = 9.94$, $p < 0.001$] compared to the non-BD group. The demographic characteristics of the BD and non-BD groups are presented in **Table 1**.

As significant differences in state anxiety and impulsivity were detected, mixed analysis of covariance was performed with state anxiety and impulsivity as covariates to control their effect on the IGT and ERP components. However, the analysis revealed that state anxiety as a covariate was not significantly associated with the IGT ($p = 0.086$), FRN ($p = 0.565$), or P3 ($p = 0.634$) and that impulsivity as a covariate was not significantly associated with the IGT ($p = 0.464$), FRN ($p = 0.295$), or P3 ($p = 0.631$).

The Modified Iowa Gambling Task

The BD group exhibited a significantly lower total net score than the non-BD group [$t(48) = -2.61$, $p < 0.05$]. In terms of sector net scores, a main effect of sector was observed [$F(4,192) = 2.45$, $p < 0.05$]. A further *post hoc* analysis revealed a trend toward a lower net score for sector 2 than for sector 4 ($p = 0.09$). Additionally, a main effect of group was observed [$F(1,48) = 7.28$, $p < 0.05$], with the BD group exhibiting significantly lower sector net scores than the non-BD group. However, the sector × group interaction was not significant [$F(4,192) = 1.23$, $p = 0.30$]. Mean total and sector net scores of the BD and non-BD groups are presented in **Table 2** and **Figure 2**.

Electrophysiological Measures

The grand-averaged ERPs elicited by gain and loss feedback at fronto-central (FCz), central (Cz), and parietal midlines (Pz) for the BD and non-BD groups are displayed in **Figure 3**. The BD and non-BD groups exhibited the largest FRN and P3 amplitudes at Cz. The topographical distribution of FRN and

TABLE 1 | Demographic characteristics of the non-BD and BD groups.

	Non-BD (n = 23)	BD (n = 27)	t
	Mean (SD)	Mean (SD)	
Age (years)	22.04 (1.92)	21.44 (1.99)	−1.08
Education (years)	15.09 (1.08)	14.74 (1.20)	−1.07
SDS	39.61 (5.39)	41.15 (7.83)	0.80***
STAI state	38.57 (8.10)	56.93 (14.16)	5.49**
STAI trait	38.70 (7.56)	41.26 (9.37)	1.05
BIS	63.48 (10.95)	83.26 (9.29)	6.92**
AUDIT-K	2.39 (1.80)	17.37 (4.20)	16.81***
Speed of drinking (drinks/h)	0.65 (0.57)	4.22 (1.34)	12.56***
Times drunk in the last 6 months	0.13 (0.34)	5.07 (4.55)	5.63***
Percentage of times became drunk when drinking (%)	11.87 (23.37)	39.44 (28.83)	3.73**
AUQ binge drinking score	5.11 (5.17)	29.85 (11.66)	9.94***

***p < 0.01; ***p < 0.001. SDS, self-rating dpression scale; STAI, Spieberger's state-trait anxiety inventory; BIS, Barratt impulsivity scale; AUDIT-K, the Korean version of alcohol use disorder identify test; AUQ, alcohol use questionnaire.*

TABLE 2 | Performance of the modified IGT in the non-BD and BD groups.

	Non-BD (n = 23)	BD (n = 27)
	Mean (SD)	Mean (SD)
Sector 1	–0.03 (4.16)	–1.73 (3.04)
Sector 2	0.72 (5.73)	–3.04 (4.14)
Sector 3	0.93 (5.53)	–1.63 (3.49)
Sector 4	2.23 (5.75)	–1.41 (4.35)
Sector 5	1.25 (5.14)	–1.93 (4.08)
Total	5.10 (23.43)	–9.73 (15.11)

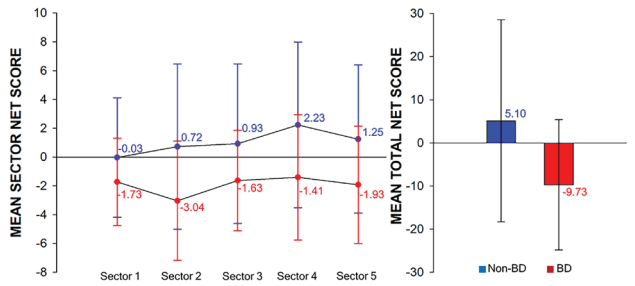

FIGURE 2 | Performance of the modified IGT. Sector net scores (left) and total net scores (right) of the modified IGT in the non-binge drinking and binge drinking groups.

P3 measured at all electrodes when the largest FRN and P3 amplitudes were observed are displayed in **Figures 4, 5**, respectively.

Main effects of valence [$F(1,48) = 62.17$, $p < 0.001$] and electrode site [$F(8,384) = 18.52$, $p < 0.001$] were observed in terms of FRN amplitudes. FRN amplitudes in response to loss feedback were significantly larger than those in response to gain feedback, and the largest and smallest FRN amplitudes were observed at Cz and FC4, respectively. Additionally, a valence × group interaction was observed [$F(1,48) = 8.06$, $p < 0.01$]. A simple effect analysis revealed that while the BD and non-BD groups exhibited comparable FRN amplitudes in response to both gain [$F(1,48) = 0.84$, $p = 0.36$] and loss feedback [$F(1,48) = 1.81$, $p = 0.19$], the magnitude of difference between the valences for each group was different. In other words, both groups exhibited larger FRN amplitudes in response to loss than to gain feedback, and the difference in the FRN amplitudes between the gain and loss feedback was larger in the non-BD group (mean difference = 2.32, $p < 0.001$) than in the BD group (mean difference: 1.09, $p < 0.01$). In addition, an electrode site × valence interaction was observed [$F(8,384) = 12.32$, $p < 0.001$] such that FRN amplitudes in response to the loss feedback were larger than those to the gain feedback in all electrodes except FC3. The main effect of group was not significant [$F(1,48) = 0.08$, $p = 0.78$]. The mean FRN amplitudes of the BD and non-BD groups are presented in **Table 3**.

Main effects of group [$F(1,48) = 6.67$, $p < 0.05$] and electrode site [$F(8,384) = 12.32$, $p < 0.001$] were observed for ΔFRN. The BD group exhibited a significantly smaller ΔFRN compared to the non-BD group. The greatest ΔFRN amplitude was observed at Cz, and the smallest was detected at FC3. The electrode site × group interaction was not significant [$F(8,384) = 0.70$, $p = 0.70$].

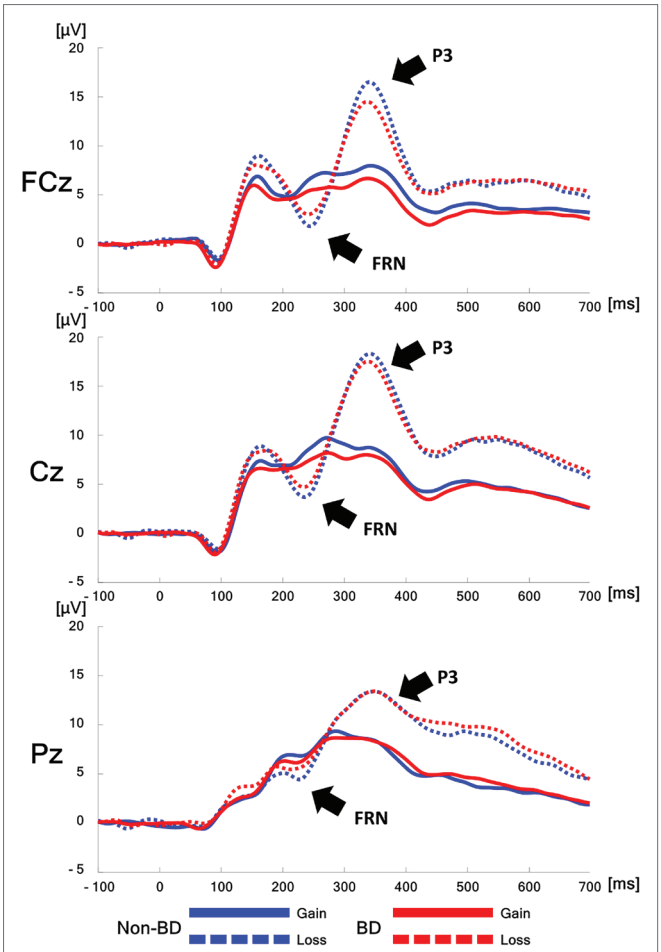

FIGURE 3 | The grand-averaged ERPs. The grand-averaged ERPs elicited by gain (solid line) and loss (dotted line) feedbacks at FCz, Cz, and Pz for the non-binge drinking (blue) and binge drinking groups (red).

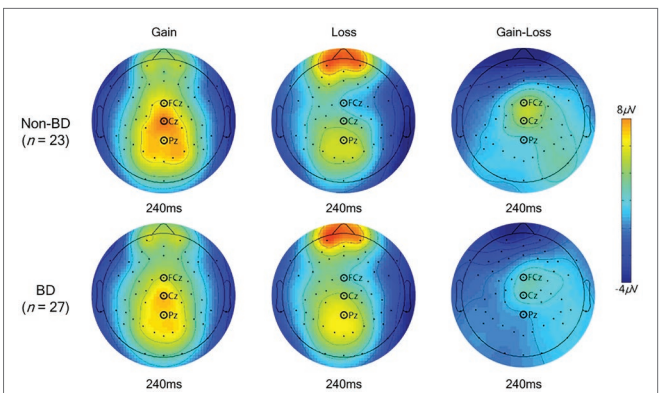

FIGURE 4 | Topographical distribution of FRN. The topographical distribution of FRN measured at all electrodes when the maximum FRN amplitudes were observed.

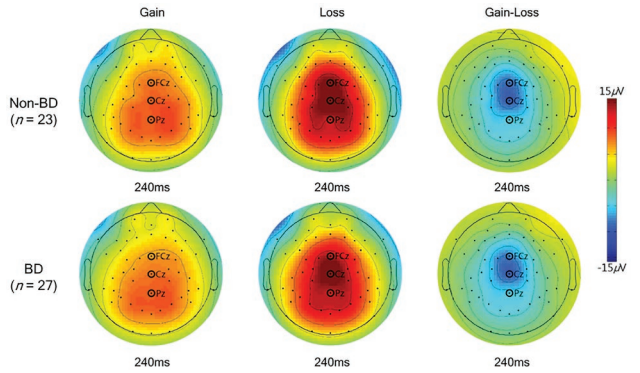

FIGURE 5 | Topographical distribution of P3. The topographical distribution of P3 measured at all electrodes when the maximum P3 amplitudes were observed.

TABLE 3 | Mean FRN amplitudes (μV) in the non-BD and BD groups.

	Non-BD (*n* = 23)		BD (*n* = 27)	
	Gain	Loss	Gain	Loss
FC3	3.41 (2.27)	2.79 (2.75)	3.44 (2.02)	3.43 (2.54)
FCz	4.94 (3.50)	1.53 (3.84)	4.51 (2.59)	3.13 (3.50)
FC4	3.32 (2.35)	0.62 (2.56)	3.38 (1.88)	1.87 (2.68)
C3	3.98 (2.60)	2.80 (2.73)	3.73 (1.88)	3.40 (1.97)
Cz	7.11 (4.07)	3.72 (4.24)	6.88 (2.65)	4.67 (3.37)
C4	4.03 (2.42)	1.51 (2.48)	3.48 (1.87)	1.78 (2.46)
P3	4.49 (2.50)	2.96 (2.68)	3.39 (1.88)	3.12 (1.82)
Pz	7.04 (3.45)	4.18 (3.73)	6.04 (2.65)	5.33 (2.90)
P4	4.30 (2.56)	1.63 (3.11)	3.50 (2.18)	1.77 (3.08)

() – Standard deviation.

Main effects of valence [$F(1,48) = 12.85$, $p < 0.01$] and electrode site [$F(8,384) = 3.46$, $p < 0.05$] were observed in terms of FRN latencies. Thus, FRN latencies in response to gain feedback were shorter than those in response to loss feedback ($p < 0.01$). In addition, the shortest latency was observed at Pz, and the longest was observed at P4. The valence × electrode site interaction was also significant [$F(8,384) = 10.25$, $p < 0.001$]. The latencies in response to gain feedback were significantly shorter than those in response to the loss feedback at FCz, FC3, FC4, Cz, C3, and C4 but not at the other electrode sites. The valence × group interaction was not significant [$F(1,48) = 2.75$, $p = 0.10$]. Mean FRN latencies of the BD and non-BD groups are presented in **Table 4**.

Main effects of valence [$F(1,384) = 180.72$, $p < 0.001$] and electrode site [$F(8,384) = 35.58$, $p < 0.001$] were observed in the P3 amplitudes. The P3 amplitudes in response to loss feedback were larger than those in response to gain feedback, and the largest and smallest P3 amplitudes were observed at Cz and C3, respectively. A valence × electrode site interaction was also observed [$F(8,384) = 84.46$, $p < 0.001$], with the largest difference in P3 amplitudes between the gain and loss feedback at Cz and the smallest at P4. However, the main effect of group [$F(1,48) = 0.64$, $p = 0.43$], the interaction effect of valence × group [$F(1,48) = 0.15$, $p = 0.70$], and the

TABLE 4 | Mean FRN latencies (ms) in the non-BD and BD groups.

	Non-BD (*n* = 23)		BD (*n* = 27)	
	Gain	Loss	Gain	Loss
FC3	218.96 (22.23)	244.17 (22.19)	228.07 (28.63)	235.93 (23.10)
FCz	218.70 (23.68)	244.17 (17.18)	229.19 (28.19)	240.07 (19.77)
FC4	226.61 (20.22)	236.70 (19.58)	228.07 (21.99)	238.30 (8.53)
C3	216.96 (16.48)	234.52 (23.45)	227.85 (24.95)	228.89 (23.09)
Cz	218.35 (20.64)	238.09 (17.71)	225.41 (28.07)	234.67 (17.59)
C4	228.96 (21.11)	235.39 (17.95)	230.52 (19.55)	234.15 (17.51)
P3	230.26 (25.20)	228.96 (24.55)	221.85 (18.68)	218.59 (20.49)
Pz	228.26 (23.96)	220.43 (17.44)	224.15 (19.99)	223.11 (21.48)
P4	236.17 (21.23)	231.48 (18.67)	236.22 (16.14)	230.96 (15.77)

() – Standard deviation.

TABLE 5 | Mean P3 amplitudes (μV) in the non-BD and BD groups.

	Non-BD (*n* = 23)		BD (*n* = 27)	
	Gain	Loss	Gain	Loss
FC3	5.86 (2.90)	10.49 (4.87)	5.44 (2.40)	10.11 (3.46)
FCz	8.4 (4.49)	16.65 (7.60)	6.74 (2.90)	14.63 (5.00)
FC4	7.19 (3.47)	10.92 (5.53)	6.42 (2.10)	9.97 (4.16)
C3	6.02 (2.71)	10.14 (4.43)	5.95 (2.25)	10.05 (3.27)
Cz	9.08 (4.68)	19.10 (7.69)	8.18 (3.25)	17.80 (5.43)
C4	7.95 (3.42)	10.75 (4.58)	7.14 (2.10)	10.14 (3.58)
P3	6.80 (3.03)	10.14 (3.65)	6.71 (2.22)	9.98 (3.13)
Pz	8.71 (4.04)	13.93 (4.22)	8.96 (2.70)	12.67 (4.67)
P4	8.42 (3.43)	10.62 (4.17)	7.62 (2.45)	10.01 (4.04)

() – Standard deviation.

electrode site × group interaction [$F(8,384) = 0.59$, $p = 0.79$] were not significant. The mean P3 amplitudes of the BD and non-BD groups are presented in **Table 5**.

A main effect of electrode site was observed in ΔP3 [$F(8,384) = 73.33$, $p < 0.001$]. The largest ΔP3 amplitude was observed at Cz and the smallest at P4. No main effect of group [$F(1,48) = 0.23$, $p = 0.63$] or group × electrode site interaction [$F(8,384) = 1.08$, $p = 0.38$] was observed.

Main effects of valence [$F(1,48) = 51.89$, $p < 0.001$] and electrode site [$F(8,384) = 11.65$, $p < 0.001$] were observed for the P3 latencies. The P3 latencies in response to loss feedback were significantly shorter than those in response to gain feedback ($p < 0.001$); the shortest latency was observed at Pz and the longest at FC4. An interaction effect of valence × electrode site was also significant [$F(8,384) = 7.49$, $p < 0.001$]. P3 latencies elicited by loss feedback were shorter than those by gain feedback at all electrode sites except FCz and Cz. The group × valence interaction was not significant [$F(1,48) = 2.93$, $p = 0.09$]. The mean P3 latencies of the BD and non-BD groups are presented in **Table 6**.

Correlations Between Performance on the Modified IGT and ΔFRN/ΔP3

Positive correlations were observed between ΔFRN amplitudes at FCz and total net scores ($r = 0.298$, $p < 0.05$), sector 4

TABLE 6 | Mean P3 latencies (ms) in the non-BD and BD groups.

	Non-BD (n = 23)		BD (n = 27)	
	Gain	Loss	Gain	Loss
FC3	336.70 (35.14)	324.17 (22.20)	334.89 (28.16)	315.93 (23.10)
FCz	329.57 (32.75)	324.17 (17.18)	328.00 (30.47)	320.07 (19.77)
FC4	334.70 (31.24)	316.70 (19.58)	342.30 (25.59)	318.30 (18.53)
C3	339.39 (35.19)	314.52 (23.45)	346.30 (30.74)	308.89 (23.09)
Cz	317.83 (32.79)	318.09 (17.71)	324.30 (36.81)	314.67 (17.59)
C4	336.43 (29.55)	315.39 (17.95)	346.37 (24.51)	314.15 (17.51)
P3	334.26 (33.27)	308.96 (24.55)	337.26 (33.62)	298.59 (20.49)
Pz	311.13 (29.54)	300.43 (17.44)	316.37 (35.65)	303.11 (21.48)
P4	329.48 (29.67)	311.48 (18.67)	348.74 (27.94)	310.96 (15.77)

() – Standard deviation.

net scores (r = 0.333, $p < 0.05$) and sector 5 net scores (r = 0.357, $p < 0.05$) of the IGT. Thus, larger ΔFRN amplitudes at FCz were associated with better IGT performance, especially in the later sectors of the IGT. On the other hand, no significant association was detected between the ΔP3 amplitudes and IGT performance.

DISCUSSION

This study investigated feedback utilization ability for decision-making in BD college students using the modified IGT and ERP data. The BD group exhibited significantly lower total net IGT scores and lower ΔFRN amplitudes than did the non-BD group. Additionally, the ΔFRN amplitude at the fronto-central area was positively correlated with the total net scores, sector 4 net scores and sector 5 net scores on the IGT.

The BD group exhibited significantly lower total net scores than the non-BD group did, and performance of the non-BD group tended to increase as the task progressed (mean sector 1 = −0.03; sector 2 = 0.73; sector 3 = 0.93; sector 4 = 2.23; sector 5 = 1.25), whereas the BD group persistently chose disadvantageous cards over advantageous ones (mean sector 1 = −1.73; sector 2 = −3.04; sector 3 = −1.63; sector 4 = −1.41; sector 5 = −1.93). These results are consistent with those of previous studies (Johnson et al., 2008; Xiao et al., 2009, 2013; Yoo and Kim, 2016) and suggest that individuals with BD have deficits in decision-making. To maximize gains on the IGT, one must choose more advantageous cards that provide small initial gains but result in a net gain over disadvantageous cards that provide a large initial gain but result in a net loss. Johnson et al. (2008) suggested that poor performance on the IGT in individuals with BD reflects their failure to consider consequences, i.e., tendency to pursue immediate rewards, disregarding the larger potential risk.

The statistical analyses of FRN, one of the ERP components elicited by feedback, revealed that the BD group exhibited significantly lower ΔFRN amplitudes than the non-BD group did. The non-BD group exhibited larger FRN amplitudes in response to loss feedback than to gain feedback, whereas the FRN amplitude differences in the BD group between gain and loss feedback were significantly smaller than those in the non-BD group. These results are consistent with previous studies on patients with AUD and male BD college students (Fein and Chang, 2008; Kamarajan et al., 2010; Wahlstrom, 2013). The present study also revealed that both groups exhibited larger FRN amplitudes in response to loss feedback than to gain feedback, which is consistent with many previous studies (Gehring and Willoughby, 2002; Holroyd and Coles, 2002; Goyer et al., 2008; Gu et al., 2011) and suggests that FRN is sensitive to feedback valence. FRN is known to reflect an early evaluation of feedback provided by the environment (Yeung and Sanfey, 2004; Gu et al., 2011; San Martin, 2012). For example, Yeung and Sanfey (2004) suggested that FRN and P3 reflect early and late stages of feedback processing, respectively. Gu et al. (2011) reported that FRN reflects early feedback evaluation based on the salience of the feedback information.

Insensitivity to future consequences (IFC) in patients with AUD and substance use disorder (SUD) has been consistently reported (Bechara and Damasio, 2002; Mallett et al., 2006; Cantrell et al., 2008). For example, Cantrell et al. (2008), using a modified version of the IGT, measured the preference for larger versus smaller rewards (PLvS), the difference between frequencies of choosing the cards that provide large gains and cards with small gains, and IFC, the difference between frequencies of choosing cards that result in a net loss and cards that result in a net gain in patients with AUD. The results showed that although patients with AUD did not exhibit significantly different PLvS scores, they exhibited significantly higher IFC scores than the control group. Additionally, a study of patients with SUD, including AUD, using the IGT and the prospect valence model analysis observed a consistent lack of sensitivity to losses in patients with SUD (Baitz, 2016). Therefore, significantly smaller ΔFRN amplitudes in the BD group compared to the non-BD group observed in the present study suggest that the BD group has deficits in early feedback evaluation and that they are less sensitive to loss feedback than are members of the non-BD group.

In this study, no significant difference in the P3 amplitudes was observed between the BD and non-BD groups, which was not consistent with previous studies reporting reduced P3 amplitudes in patients with AUD (Porjesz et al., 1987; Kamarajan et al., 2010). The generators of P3 are known to be located in the temporo-parietal junction or locus coeruleus-norepinephrine system (Nieuwenhuis et al., 2005). On the other hand, alcohol is known to affect frontal areas of the brain (Curtin and Fairchild, 2003; Nelson et al., 2011). For example, those who consume alcohol exhibit reduced N450 amplitudes in frontal areas, whereas P3 amplitudes in the parietal and occipital areas are not affected by alcohol consumption (Curtin and Fairchild, 2003). Nelson et al. (2011) also reported that alcohol consumption reduces both theta and delta band activities, which are known major components of FRN and P3, respectively, affecting theta band activity more severely. Whereas alcohol consumption affects the frontal area, overall gray and white matter volume reductions, including those in frontal areas, are observed in patients with AUD (Fein et al., 2002; Buhler and Mann, 2011;

Le Berre et al., 2014). For example, one study observed reduced whole-brain network cluster coefficients in patients with AUD and reported that longer AUD duration was associated with a global decrease in the efficiency of the brain network (Sjoerds et al., 2017). These results suggest that alcohol consumption affects frontal areas first and then spreads over the whole area as drinking duration increases. Taking together, our results imply that BD of relatively short duration (the mean drinking duration in the BD group was 33.33 months) may affect later feedback evaluation and attentional resource allocation relatively less severely than does BD with a long drinking history.

Both groups exhibited larger P3 amplitudes with loss feedback than with gain feedback. Studies on feedback-related ERPs using tasks other than the IGT have reported larger P3 amplitudes in response to gain feedback than to loss feedback (Toyomaki and Murohashi, 2005; Hajcak et al., 2007; Bellebaum and Daum, 2008; Wu and Zhou, 2009), whereas studies using the IGT observed larger P3 amplitudes in response to loss feedback than to gain feedback (Carlson et al., 2009; Cui et al., 2013). Feedback-related P3 is known to be sensitive to different feedback information, not just to feedback valence but also to feedback magnitude and probabilities as well (Yeung and Sanfey, 2004; Goyer et al., 2008; Hajcak and Simons, 2008; Wu and Zhou, 2009; Polezzi et al., 2010; Gu et al., 2011; Xu et al., 2011). This suggests that P3 reflects feedback processing with a top-down mechanism that allocates attentional resources to the information relevant to the task at hand (Nieuwenhuis et al., 2005; Gu et al., 2011). The loss magnitudes of each card must be understood to maximize profit on the IGT. Thus, participants need to understand that disadvantageous cards (A and B) result in large gains, but losses will soon accumulate over gains, and thus shift their preference or attention progressively toward advantageous cards (C and D) (Webb et al., 2014). These results suggest that both groups allocated their attentional resources to feedback valence, especially to loss feedback, while taking the modified IGT.

Although the importance of feedback utilization for decision-making has been emphasized (Ernst and Paulus, 2005; San Martin, 2012), only one study has investigated the association between IGT performance and feedback-related ERPs (Carlson et al., 2009). Carlson et al. (2009) investigated how children responded to gain/loss feedback using P3 and evaluated how anticipation prior to the response was related to behavioral adjustment using stimulus-preceding negativity (SPN). That study found that the difference in children's SPN amplitude between advantageous and disadvantageous decks was positively correlated with behavioral adjustment. In the present study, ΔFRN amplitudes at FCz were positively correlated with total net scores and sectors 4 and 5 net scores on the IGT. Thus, larger differences between FRN amplitudes with gain and loss feedback were associated with improved performance on the modified IGT. No previous study has reported an association between FRN and IGT performance; studies using the reversal learning task have reported associations between FRN and behavioral adjustments (Frank et al., 2005; Bellebaum and Daum, 2008). For example, Frank et al. (2005) compared negative learners, who learn stimulus-result contingencies by avoiding negative feedback, with positive learners, who learn these contingencies by pursuing positive feedback; they found significant positive correlations between the tendency to avoid negative feedback and error-related negativity (ERN) amplitudes, which is the ERP component known to share some neural sources with FRN (Holroyd, 2004). To perform successfully on the IGT, participants must learn the contingencies between the cards and their consequences implicitly during the task (e.g., gain or loss feedback) (Bechara, 2004). Therefore, these results suggest that early feedback evaluation in the fronto-central area is associated with the implicit learning process during decision-making.

No significant associations between ΔP3 amplitudes and IGT performance were observed in this study. Previous results for P3 amplitudes and behavioral adjustments using the reversal learning task are inconsistent (Frank et al., 2005; Chase et al., 2011). For example, Frank et al. (2005) reported that FRN amplitudes, not P3 amplitudes, predicted behavioral adjustment, whereas Chase et al. (2011) reported that P3 amplitudes, not FRN amplitudes, predicted behavioral adjustment. The differences between these two studies lay in the task instructions. Frank et al. (2005) did not provide any information regarding contingency shifts during the task and requested that participants make decisions based on their internal judgment, whereas Chase et al. (2011) told the participants that the contingency would shift during the task and requested that participants adjust their responses when they were certain that the contingency had shifted. Thus, the latter study reflected decision-making based more on a set of rules provided prior to the task than on the actual feedback during the task. San Martin (2012) suggested that the importance of FRN and P3 in behavioral adjustment varies depending on which information is more important when performing the given task. In our study, participants were only instructed regarding the goal and process of the task. Therefore, the rules of the task (probability of loss and magnitude of cards) must be learned solely through feedbacks. Such a task design is closer to the study by Frank et al. (2005). These results suggest that both the BD and non-BD groups relied more on early feedback evaluation of valence than on late evaluation with a top-down mechanism as they performed the modified IGT.

This study has several limitations. First, the feedback evaluation investigated here focused mainly on feedback valence. The magnitudes of the cards on the modified IGT increased, as was the case in the original IGT (Bechara, 2007). Although this may keep participants motivated, the increasing magnitude forbids examination of how feedback-related ERPs respond differently to feedback of small or large magnitude. Additionally, the probabilities of encountering losses from cards B and D were too low (10%) to secure enough trials to investigate how ERPs differ based on the probability of losses. However, as this study focused on how BD differs from non-BD in response to feedback during decision-making, the card properties of the original IGT

were adopted in order to simulate everyday decision-making environment where various feedback information is combined. Second, this study measured feedback utilization using time-based ERPs. However, the time windows for FRN and P3 are close to each other, and they may distort each other in ERP waveforms. Difference waves were measured to isolate ERP components and prevent such distortion, but other techniques, such as time-frequency analysis (Zhu et al., 2019) or functional connectivity analysis, may reveal more detailed information, such as how different neural waves interact and communicate during feedback processing. Third, only female college students participated in this study to control gender differences. Future studies which include both male and female participants would provide more valuable information on how BD affects feedback utilization and decision-making ability depending on different genders.

In conclusion, the BD group exhibited significantly lower total net scores on the modified IGT and significantly lower ΔFRN amplitudes. On the other hand, no differences were observed in ΔP3 or P3 amplitudes between the groups. Additionally, positive correlations were observed between ΔFRN amplitudes in the fronto-central area and IGT performance. These results imply that the BD group had deficits in decision-making and early feedback evaluation, with a tendency to pursue immediate large gains even at greater potential risks, revealing deficits in early evaluation regarding feedback valence.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Sungshin Women's University Institutional Review Board (SSWUIRB 2017-040). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

M-SK helped in conceptualization. EN and K-MJ helped in formal analysis. M-SK helped in funding acquisition. EN and K-MJ helped in methodology. M-SK helped in supervision. EN, K-MJ, and M-SK helped in writing, reviewing, and editing.

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Country and Sex Differences in Decision Making Under Uncertainty and Risk

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Whether males and females differ in decision-making remains highly debatable. However, a male advantage in decision making is observed in animal as well as human models of the iowa gambling task (IGT), and, in case of the latter, the difference is observed across a wide range of age groups. It is unclear if these sex differences on the IGT are malleable to environmental influences such as sociocultural factors. We tested sex differences during the uncertainty and risk phases of the IGT in data pooled from three countries that reflected high, moderate, to low gender-equity (Germany, United States, and India: N = 531, female = 269). Comparing the net scores in uncertainty vs. risk blocks (first two vs. last two blocks) confirmed the male-advantage on the IGT across the three countries, specifically in the risk blocks, with the highest male-advantage observed for Germany. Results are discussed in terms of sex differences in reaction to uncertainty vs. risk, and the counter-intuitive effect of gender-equitable environment suggesting that national/environmental factors might influence advantageous decision making, but in ways that accentuate rather than abate sex differences.

Keywords: sex differences, gender, iowa gambling task, decision making, risk, uncertainty

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INTRODUCTION

Sex differences on the iowa gambling task (IGT) are well-documented in human and animal models, suggesting sex-specific decision making processes (van den Bos et al., 2012, 2013). Further, the female decision-making deficit is prominent in the early task phase that is associated with uncertainty/ambiguity (Bolla et al., 2004) while the male-advantage is characterized by higher advantageous decision making in the last phase of the task, when the decision payoffs are known (i.e., decision making under risk; van den Bos et al., 2013). The authors of the IGT proposed neurobiological differences in anatomy of the prefrontal cortex (PFC), specifically right-PFC engagement in males (Tranel et al., 2005) and left-dorsolateral PFC engagement in females (Bolla et al., 2004) contributing to sex differences on the task. However, age-related improvements due to PFC-maturation is reported for both males and females, specifically in the last phase of the task (Crone and van der Molen, 2004; Hooper et al., 2004). It remains unknown whether sex-differences on the IGT, specifically phase-specific male-advantage in advantageous decision making, will be observed in countries that differ in sociocultural environment.

In spite of efforts toward cultural adaptation of the task (e.g., Rutz et al., 2013), potential sex-differences in phase-specific IGT performance across countries that differ in sociocultural and gender-equitable environment remain unexplored. For instance, decision making in the risk phase of IGT differed between two culturally different countries but showed no effect of age or gender (e.g., Brazil and United States) (Bakos et al., 2010). Compared to American participants, Israeli participants performed poorly on the IGT, and the authors pointed out that country-differences might become prominent when American vs. non-American population is compared; however, in the absence of the sex composition of the Israeli sample and phase-specific analysis of IGT, it is unclear whether between-country differences in gender-equity and socioeconomic status between America and Israel influenced sex- and phase-specific decision making (Ekhtiari et al., 2009). Our previous work (within/single-country analysis) pointed toward phase-specific sex-differences in the IGT. For instance, IGT performance declined after the uncertainty blocks for strongly right-handed Indian females (Singh, 2016), presence of female-dominant sample in the United States was linked with poor deck choice (deck B) in the uncertainty phase of the IGT (Okdie et al., 2016), and stress-induced IGT deficit was high in German males whereas the non-stressed males continued to show male-advantage in the task (Starcke et al., 2017). Even though the IGT is a non-linguistic measure of neuropsychological assessment, authors have cautioned that country and cultural differences should be considered in task interpretation (Fasfous et al., 2013; Daugherty et al., 2017). These observations, combined with reports of sociocultural factors potentially influencing the IGT (Ekhtiari et al., 2009; Bakos et al., 2010), or cultural variation in the IGT as a part of neuropsychological assessment (Fasfous et al., 2013; Daugherty et al., 2017), prompted us to analyze potential country and sex interactions in two distinct phases of IGT decision making (i.e., uncertainty and risk phases).

Sex and country-based comparisons of performance on widely used cognitive tasks of risk and decision making might reflect the effect of socioeconomic environment, such as gender-equity, on task performance, and additionally might explain societal outcomes such as female underrepresentation in fields that are cognition-intensive, working memory dependent, and male-dominated, such as math (Reilly, 2012). Further, decision making in the last phase of the IGT implicates PFC-governed executive functions (Brand et al., 2007), whereas the first two blocks of the uncertainty phase are least affected by working memory demands (Bagneux et al., 2013). Less is known about male advantage and country-level variation in executive functions; however, working memory shows a male-advantage that is independent of ethnicity (Silverman et al., 2007) and gender-related attitude (Lippa et al., 2010). On the other hand, country-variation in gender equity influenced sex differences in working memory (Miller and Halpern, 2014). We selected three countries that reflect a gradation in gender-equity – Germany representing the high gender-equitable country, United States representing moderate gender-equity, and India representing the low gender equitable country (Germany ranked 10th, United States ranked 53rd, and Indian ranked 112th, World Economic Forum, 2019). Therefore, the aim of the present study was to investigate whether sex differences on the IGT are phase and/or country-specific.

MATERIALS AND METHODS

Data were pooled from unpublished datasets from three countries: India, United States, and Germany. The sample (N = 531) consisted of 269 (50.7%) female and 262 (49.3%) male participants between 18 and 35 years of age (M = 22.62, SD = 3.74). The Indian sample was collected from the city of New Delhi (n = 177, 85 females) and contained participants with a maximum age of 35 years (M = 23.31, SD = 2.99). From originally 184 subjects from Germany (city of Duisburg) and 743 subjects from the United States (city of Newark, OH), one sub-sample each was selected that matched the sample from India in terms of size (i.e., n = 177), age distribution (with a maximum of 35 years), and gender distribution (i.e., similar number of males and females). The selected sample from Germany (n = 177) contained 96 females and 81 males aged between 18 and 33 years (M = 24.25, SD = 3.84). The selected sample from the United States consisted of 177 participants (88 females) between 18 and 34 years (M = 20.29, SD = 3.13). The United States data were skewed in terms of age and gender distribution. Therefore, participants were selected to represent age (median-based groups) and sex in the following manner. First, an all-male United States sample was created taking all male participants ages 20–35 years (21 cases), then 51 male 19-year-old participants, then 17 male 18-year-old participants. The same procedure was used to select the 88 female participants.

The data from each country were collected as a part of research protocols approved by institutional ethics committees where the studies were conducted. Informed consent of the participants for research participation and for publication of its results was collected as a part of the protocols. Participants had more than 12 years of formal education (post-secondary level), and were students enrolled in an education program in the public/national institute where the studies were carried out. We assumed that the three countries reflect the place of education of the participant, and of data collection, rather than a measure of cultural and national identity of the participant. Information regarding age, gender, and block-wise net score was pooled from the three datasets. The datasets from the three countries did not differ regarding gender distribution [$\chi^2(2) = 1.46$, $p = 0.482$], but regarding age [$F(2,531) = 67.86$, $p < 0.001$, $\eta_p^2 = 0.204$], which is why we controlled for age in all of the following analyses. The IGT performance was represented by block-wise (i.e., five blocks of 20 trials each) net scores as per the standard scoring approach: number of cards drawn from decks C′ and D′ minus the number of cards drawn from decks A′ and B′. Additionally, net scores on blocks 1 and 2 (trials 1–40) were totaled to reflect decision making under uncertainty (early phase) and net scores on blocks 4 and 5 (trials 61–100) were totaled to reflect decision making under risk (late phase).

Measures

Computerized version of the IGT was used with progressive reward variant (A′, B′, C′, D′) and standard task instructions in the respective local language. Task performance was non-incentivized for all the participants (there were no performance-contingent incentive provided to the participants).

Analysis

A mixed model ANOVA was used to first address net scores for task progression across the five blocks of trials, and then to address phase-specific net scores (blocks: uncertainty vs. risk) as the within-subject variable and gender (male vs. female), and country (India vs. United States vs. Germany) as between-subject variables with age as a covariate.

RESULTS

Results revealed a main effect of the five blocks suggesting that advantageous decision making improved as the task progressed, $F(3.47, 1816.87) = 3.73$, $p < 0.01$, $\eta_p^2 = 0.007$ (mean net score: block 1 = −2.45, block 2 = 1.92, block 3 = 2.96, block 4 = 3.19, and block 5 = 3.29) (Greenhouse-Geisser corrected values, **Table 1**). The interaction of sex and block was not significant, $F(3.47, 1816.87) = 1.50$, $p = 0.21$, $\eta_p^2 = 0.003$, and neither was that of age and block, $F(3.47, 1816.87) = 1.37$, $p = 0.243$, $\eta_p^2 = 0.003$. Task progression and improvement in long-term decision making was observed independent of sex and age. As expected, the interaction of country and block was significant, $F(6.93, 1816.87) = 8.75$, $p < 0.001$, $\eta_p^2 = 0.032$, suggesting that participants from the three countries differed in advantageous decisions made as the task progressed with participants from Germany making the most advantageous decisions (**Figure 1**) (mean net scores: Germany = 2.51, India = 1.61, and United States = 1.23). The three-way interaction of block, country, and sex was significant, $F(6.94, 1800.19) = 2.24$, $p = 0.029$, $\eta_p^2 = 0.009$, suggesting that both sex and country had a small influence on improvement in advantageous decision making (**Figure 2**) (mean net scores: Germany male = 3.27 vs. female = 1.74, United States male = 1.94 vs. female = 0.53, and India male = 1.97 vs. female = 1.24), with the greatest difference between the net scores of males and females for Germany.

TABLE 1 | Summary of the mixed ANOVA including the factors IGT block (within), sex (between), and country (between) on IGT net score.

Main effects and interaction effects	*F*	*p*	η_p^2
Block (five levels)*	3.73	0.008	0.007
Sex (two levels)	5.25	0.022	0.010
Country (three levels)	1.71	0.182	0.006
Block × sex	1.50	0.206	0.003
Block × country	8.75	<0.001	0.032
Block × sex × country*	2.24	0.029	0.009

*IGT, iowa gambling task. Effects are controlled for age. *Greenhouse-Geisser corrected.*

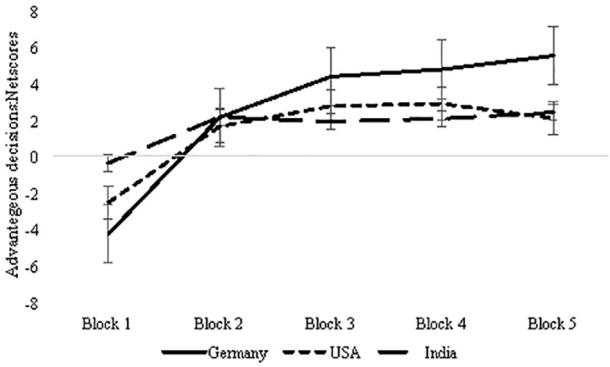

FIGURE 1 | Three-country comparison of advantageous decision making as the task progresses over 100 trials. Error bars represent standard error.

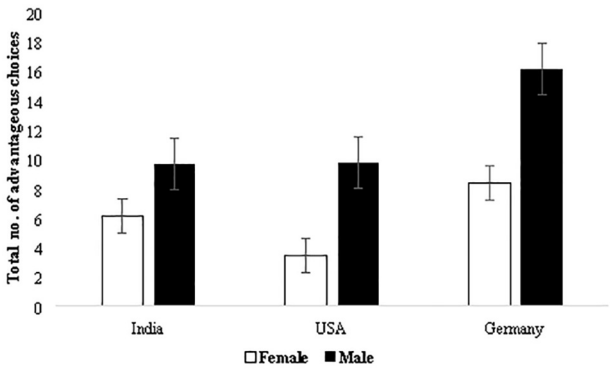

FIGURE 2 | Country and sex-specific comparison of advantageous decision making in 100 trials of the IGT. Error bars represent standard error.

Results of decision making in the uncertainty trials (early phase) and risk trials (late phase) showed no main effect of block, $F(1,524) = 1.93$, $p = 0.166$, $\eta_p^2 = 0.004$, and no main effect of country, $F(2, 524) = 1.16$, $p = 0.313$, $\eta_p^2 = 0.004$, but a significant main effect of sex, $F(1,524) = 4.97$, $p = 0.026$, $\eta_p^2 = 0.009$ (**Table 2**). Looking at the interactions, there was no effect of sex and block, $F(1,524) = 2.82$, $p = 0.094$, $\eta_p^2 = 0.005$. The interaction of age and block was also not significant, $F(1,524) = 0.002$, $p = 0.962$, $\eta_p^2 = 0.001$. The interaction between country and block was significant, $F(2,524) = 15.76$, $p < 0.001$, $\eta_p^2 = 0.057$ (mean net scores: Germany uncertainty blocks = −2.20 vs. risk blocks = 10.24, United States uncertainty blocks = −1.10 vs. risk blocks = 4.81, and India uncertainty blocks = 1.71 vs. risk blocks = 4.39). The three-way interaction between block, sex, and country was significant, $F(2,524) = 4.18$, $p = 0.016$, $\eta_p^2 = 0.016$, suggesting that male and female participants from the three countries differed in advantageous decisions made in the under uncertainty and under risk portions of the task with the highest improvements in decision making from uncertainty to risk phase being observed for Germany (**Figures 3**, **4**).

In order to analyze the reported three-way interaction in more detail, we ran additional analyses split by sex, country, and

TABLE 2 | Summary of the mixed ANOVA including the factors IGT phase (within), sex (between), and country (between) on IGT net score.

Main effects and interaction effects	*F*	*p*	η_p^2
IGT phase (two levels)*	1.93	0.166	0.004
Sex (two levels)	4.97	0.026	0.009
Country (three levels)	1.16	0.313	0.004
IGT phase × sex	2.82	0.094	0.005
IGT phase × country	15.76	<0.001	0.057
IGT phase × sex × country	4.18	0.016	0.016

*IGT, iowa gambling task. Effects are controlled for age. *Greenhouse-Geisser corrected.*

block respectively. Age was again included as a covariate. *Post hoc* ANOVA separated by sex showed that the block × country interaction was more pronounced in males [$F(2, 258) = 15.00$, $p < 0.001$, $\eta_p^2 = 0.104$] compared to females, $F(2, 265) = 3.02$, $p = 0.050$, $\eta_p^2 = 0.022$ (see **Figures 3**, **4** for a visualization). *Post hoc* ANOVA split by country showed the effects of block and sex were significant only in the case of Germany, $F(1,174) = 7.53$, $p = 0.007$, $\eta_p^2 = 0.041$, as these were not significant for United States, $F(1,174) = 2.58$, $p = 0.110$, $\eta_p^2 = 0.015$, or for India, $F(1,174) = 1.63$, $p = 0.203$, $\eta_p^2 = 0.009$. Separate comparisons for the uncertainty and risk phases of the IGT showed no effect of sex in the (early) uncertainty phase, $F(1, 224) = 1.26$, $p = 0.262$, $\eta_p^2 = 0.002$, but an effect in the (later) risk phase, $F(1, 224) = 5.70$, $p = 0.017$, $\eta_p^2 = 0.011$, with males performing better than females, especially in the sample from Germany (see **Figures 3**, **4**).

This three-country comparison was based on participants drawn from large/national educational institutions that are representative of the diverse population of their country. To rule out the possibility that the results might be affected due to non-representativeness of the sub-sample drawn from the United States sample, we carried out the same set of analysis on another age and gender matched sub-sample from the United States sample. We found support for the results obtained in the earlier iteration suggesting consistency in our findings reported herewith, that is, there were country, and sex-differences in phase-specific IGT performance, with high long-term decision-making and high male-advantage observed for Germany. Additionally, to check whether sampling variation was under control, we used retrospective power analysis (G*Power) and confirmed that the values obtained in *F* tests were well within the limits of the critical *F*, and that the beta error (type II error) were within the acceptable limits (Banerjee et al., 2009).

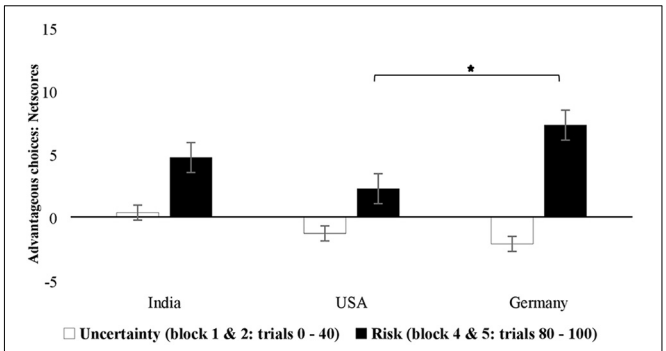

FIGURE 3 | Country-specific advantageous decision making of female participants under uncertainty (trials 0–40) and risk phase of the IGT (trials 80–100). Error bars represent standard error.

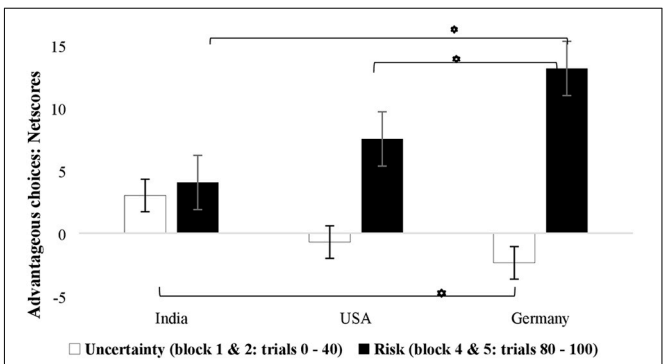

FIGURE 4 | Country-wise advantageous decision making of male participants under uncertainty (trials 0–40) and risk phase of the IGT (trials 80–100) suggests greater change in advantageous decision making from uncertainty to the risk phase occurred in case of Germany. Error bars represent standard error.

DISCUSSION

The present investigation aimed to explore sex and country-wise differences in long-term decision making; analysis of the five blocks showed improvement in long-term decision making and, even though the change was independent of sex, the task progression varied across country, showing the highest task improvement for Germany. We observed that advantageous decision-making improved as the task progressed, and this varied by country and the combined effect of country and sex. There was a country-wise difference in advantageous decision making; however, the effect size was small. High net scores in Germany could be because the male advantage in working memory is high in Germany compared to other countries (Janssen and Geiser, 2012; Jansen et al., 2016).

We specifically explored whether the male advantage occurred in the uncertainty phase (early phase) or in the risk phase (later phase) and whether the phase-specific male advantage varied with age and countries with gender-favorable environment. Age had no effect on decision making on the IGT, and its interactions with sex and country also failed to influence decision making. These results are in line with others who observed that the male advantage on the IGT was consistent in adolescents and older adults (Overman and Pierce, 2013). Further, age-related improvement in IGT was unaffected by cultural differences in an 11-country comparison of western and Asian countries (including United States and India) (Icenogle et al., 2017), suggesting that the effect of age and maturation on IGT decision making might be the same across the three countries.

Sex had a significant effect on advantageous decision making on the IGT, beyond the effects of country, age, and IGT phase, illustrating an overall male advantage. Furthermore, sex and country jointly influenced decision making on the IGT and differed during the decision making under uncertainty vs. risk phases of the task. This finding is in line with others who found that advantageous decision making among males and females differed between the under risk and uncertainty trials (Bolla et al., 2004; van den Bos et al., 2013). Further, advantageous decision making differed between uncertainty and the risk phase of the task, and the interaction of country and sex contributed to this difference. Males outperformed females in advantageous decision making and the male advantage was most prominent in the risk-phase of the task. Further, the male advantage during the risk phase was higher in Germany, a country with high gender-equitable environment compared to the other two countries that rank lower in gender-equity (World Economic Forum, 2016). These results are aligned with a counter-intuitive observation that cognitive sex differences are accentuated in nations that have high gender equity and are economically developed (Lippa et al., 2010; Stoet et al., 2016). Others have also found that sex-differences in personality measures tend to be largest in countries that have more gender-equitable environment (Mac Giolla and Kajonius, 2018). Why would sex differences be larger in a country that has macro environment that facilitates gender equity?

Studies have suggested that highly industrialized and gender-equitable countries have higher male-advantage in working memory (Lippa et al., 2010; Janssen and Geiser, 2012; Jansen et al., 2016). It is possible that high male-advantage in working memory contributed to country and sex-differences in phase-specific IGT performance. Further, the prominent male-advantage in Germany could also reflect population-level variation in testosterone, the male sex hormone. Testosterone is unaffected by race/ethnicity (Alvarado, 2010) and is higher in Western or industrialized/developed countries (e.g., United States) (Ellison et al., 2002); however, male testosterone decline is higher in the United States than it is in Germany (Anaissie et al., 2017). Since testosterone drives risk taking in the IGT (Reavis and Overman, 2001) and high male advantage in working memory in Germany is testosterone-linked (Jansen et al., 2019), it is possible that country-level differences in testosterone resulted in accentuated phase-specific sex differences in the IGT performance in Germany.

A second possible explanation for such results might be that female participants from countries that have low gender equity probably worked harder and put more efforts toward reducing the gender-gap to reach the level of higher education. Operating in challenging environment (i.e., low gender equitability) might have altered decision making of these females to match that of the males from these countries. Introducing effortful deliberation through moral dilemmas improved IGT decision making of females to the level of male participants, with additional evidence suggesting this increased deliberation led to engagement of the dorsolateral PFC with subsequent improvement of working memory and advantageous decision making of females (Overman et al., 2006). Since males engage dorsolateral PFC (as compared to the medial orbital frontal cortex engaged by females), the group used an olfactory task to engage the medial orbital frontal cortex and found it to reduce advantageous decision making of males to equal that of females (Overman et al., 2011). Previous studies have shown that the dorsolateral PFC is especially relevant for advantageous decisions under risk (Labudda et al., 2008), and therefore might have played a critical role in the later phases of the IGT that is marked with risk (Brand et al., 2007). In line with the former, the results of the current study showed that the gender differences were more pronounced in the later phase of IGT. Further, everyday stressors in low industrialized and developed countries might influence working memory differentially for males and females as stress-induced impairment is prominent in males (Preston et al., 2007). It might be possible that unfavorable/gender-inequitable environment of low developed countries increases effortful deliberation and working memory in females, whereas stress impairs working memory in males, thereby bridging the gender-gap in working memory in low industrialized and developed countries. By contrast, in countries that have gender equity and are highly industrialized/developed, the gender-gap in working memory remains relatively unchallenged or unchanged.

These results need to be interpreted considering several limitations of this approach, specifically, that the data pooled from three countries did not include explicit measures of cultural or national identity of the participants. Further, we use the term sex and gender interchangeably because we did not account for sexual identity; instead, we relied on binary categories of self-reported sex/gender to reflect female/woman and male/man. The absence of other measures such as mood, personality, and intelligence, and working memory in particular, that can influence task decision making pose a limitation. Similar to other multi-laboratory collaborations that have pooled the IGT data (e.g., Steingroever et al., 2015), the present study lacks information on socioeconomic level, ethnicity/race for the data sets. One redeeming factor might be that the three institutions are public/national institutions and admit students on the basis of performance in a centralized/national-level entrance exam, and drawing students who represent diversity of the national population. All participants from the three countries had completed post-secondary education; however, we did not analyze the effect of years of formal education on the task performance, it is possible that effect of education are sex-specific. For example, a study conducted in Canada found formal education improved decision making in the IGT independent of sex, specifically in the risk trials (blocks 3 and 4 in **Figure 1**; Davis et al., 2008), however, another study conducted in the United Kingdom observed that formal education had a detrimental effect on IGT performance in an all-female sample, particularly females with less formal education performed well in the last trials assessing risk-taking (Evans et al., 2004). Future efforts should be directed toward building a multi-laboratory data repository of the IGT and similar decision-making tasks, demographic and education-level information, assessment of mood, intelligence, working memory, executive function, and disposition measures of personality, risk taking, and reward sensitivity across diverse population.

Sex differences in reference to cognitive tasks are changing. Our findings (a) confirm the male-advantage in the IGT across three countries; (b) demonstrate the male-advantage in the shift from the uncertainty to the risk phase is common across the three countries, and (c) present insight that the highest male-advantage in uncertainty-risk shift occurred in a sample from the most gender-equitable country. Because cognitive sex differences are gaining importance in neuroscience (Cahill, 2006), future studies should include measures of brain asymmetry and sex-related neurobiological measures such as cortisol and testosterone and test the interaction of structural and neurobiological factors with country/culture-specific factors to determine their contribution to sex-differences in decision making in uncertainty and risk.

So far, the extant literature has explored age, sex, country, and IGT phase-specific differences in isolation, therefore the present results offer insight into the link between sex, age, and country and phase-specific decision-making. Advantageous decision making differed under uncertainty and risk such that advantageous decision making was lowest under uncertainty and highest under risk. In addition, the difference in advantageous decision making based on IGT phase across age, sex, and country. Even though sex and country influenced advantageous decision making, the results suggest that national/environmental factors in the form of country-level variation might additionally influence advantageous decision making, but in ways that counter-intuitively accentuate, rather than abate sex differences.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by an Institute Ethics Committee (India: IIT Delhi; Germany: University of Duisburg-Essen; United States: The Ohio State University, Newark). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

VS, MTB, SM, and ML: equal contribution to the analysis and writing of the manuscript. JS and MB: initializing/facilitating collaboration. All authors made equal contribution.

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Goal-Conflict EEG Theta and Biased Economic Decisions: A Role for a Second Negative Motivation System

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Economic decision biases can reflect emotion and emotion dysfunction. Economic paradigms thus provide a solid framework for analysis of brain processes related to emotion and its disorders. Importantly for economic decisions, goal-conflict activates different negative motivational processes than pure loss; generating negative decision biases linked to anxiety and fear, respectively. Previously, right frontal goal-conflict specific EEG rhythmicity (GCSR) was shown to reflect anxiety processing. Here, we assessed GCSR in a forced-choice, economic decision-making task. Ninety participants were tested in three key conditions where gain:loss ratios of left mouse clicks were set to 75:25 (GAIN), 50:50 (CONFLICT) and 25:75 (LOSS). Right clicks produced no monetary consequences and skipped the current trial. The participants were not told the different conditions but could learn about them by associating the background stimulus color with the specific payoff. Goal-conflict was defined as the mathematical contrast of activity in CONFLICT minus the average of that in GAIN and LOSS. Replicating previous findings with somewhat different conditions, right frontal GCSR was detected. Importantly, greater right frontal GCSR significantly predicted a preference for economic safety in CONFLICT but not in GAIN or LOSS; but did not predict trait anxiety or neuroticism. We conclude that goal-conflict has unique neuroeconomics effects on choice biases; and that these reflect anxiety processing that is not effectively captured by trait anxiety or neuroticism.

Keywords: theta, uncertainty, decision bias, conflict, anxiety, emotion, approach-avoidance, RST

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INTRODUCTION

The study of human decision-making in economics provides clear examples of decision biases. Classic examples include over-representing sure and rare events (Kahneman and Tversky, 2013), ambiguity aversion in the Ellsberg paradox (Ellsberg, 1961), loss aversion in Prospect theory (Kahneman, 1979), and "framing effects" (Tversky and Kahneman, 1981). The field has also developed tight definitions of the factors (Glimcher and Fehr, 2013) that affect economic decisions, such as the assessments of context (history of consequences in reinforcement learning), unknowns (availability of information), chance occurrences (probability), and valuation (sensitivities to gains and losses).

Importantly, emotion affects economic choices. Hence, using economic paradigms to study the neural processes in emotional dysfunction and the development of *psychiatric* disorders, provides

instant access to existing detailed neuroeconomics analysis (Kishida et al., 2010; Hasler, 2012; Sharp et al., 2012). Particularly, the economic paradigms allow us to test for extreme sensitivities, not only to gain and loss but, also goal conflict (when the possibility of both gain and loss generates approach-avoidance conflict). This links back to existing neuropsychological analysis, which suggests links between: (a) low punishment sensitivity and psychopathy (Corr and McNaughton, 2014); (b) high punishment sensitivity to fear and phobic disorders (McNaughton, 2011, 2019); low conflict sensitivity to ADHD-inattentive (Sadeghi et al., 2019); and of specific relevance here, high conflict sensitivity to anxiety (Gray and McNaughton, 2000).

Current neurally detailed theories of anxiety are based on the study of threat in rodents and generalization to humans. A hierarchy of defensive behaviors in rodents (Blanchard and Blanchard, 1990) and humans (Blanchard, 2017) matches a hierarchical neural organization based on rodent work (Gray and McNaughton, 2000; McNaughton and Corr, 2004) that also appears to apply to humans (McNaughton, 2019). This map distinguishes a Fight-Flight-Freeze System (FFFS) from a Behavioral Inhibition System (BIS). The FFFS mediates processes relating to fear of danger/unmixed threat (loss); and the BIS mediates processes relating to anxiety/goal conflict/mixed threat (loss + gain) – when appetitive and aversive goals are balanced (Gray and McNaughton, 2000). Separating the FFFS from the BIS behaviorally in human decision-making is challenging, since the BIS amplifies already existing negative behavioral tendencies *concurrently* mediated by the FFFS.

Human brain activity has been linked to the processing of anxiety in a Stop-Signal Task (SST) (Verbruggen and Logan, 2009), which does not have any explicit payoffs. Specifically, electroencephalographic (EEG) rhythmicity (4–12 Hz, i.e., spanning the conventional theta and alpha bands) was detected in the right frontal scalp area F8 (Neo et al., 2011; McNaughton et al., 2013; Shadli et al., 2016) in an analog of approach-avoidance (goal) conflict. In the SST, participants make a mouse click as fast as they can in response to a go-cue. On some trials, a stop-signal occurs unpredictably at variable delays after the go-cue (producing easy, intermediate, and difficult stopping), and participants have to withhold clicking the mouse. Goal-conflict was presumed to occur more in intermediate stop-signal delays (generating 50% successful inhibition of the mouse click with stopping and going tendencies roughly equal) and so could be extracted by contrasting intermediate against short and long delays.

Importantly, this right frontal goal-conflict-specific rhythmicity (GCSR) in the SST is sensitive to all classes of anxiolytic drug, and can be considered a biomarker of a process specific to anxiety (McNaughton et al., 2013; Shadli et al., 2015b; McNaughton, 2018). These studies also showed modest correlations of GCSR with trait anxiety (Spielberger et al., 1983), or neuroticism (Eysenck and Eysenck, 1994) – personality traits associated with anxiety (Bishop and Forster, 2013). Consistent with other studies on the SST, the conflict response appears to be localized to the right inferior frontal gyrus (Shadli et al., 2015a). However, across the SST studies, GCSR consistently did not predict stop inhibition reaction times, a standard measure of overt behavior in the SST.

Neo and McNaughton (2011) tested for the effects of goal-conflict in an economic context using a forced choice decision-making task. In their key condition (CONFLICT), potential gains and losses had values that were *known* (+10/−10 cents) but were equivocal (50:50 probability). Specificity to goal-conflict was achieved by a mathematical contrast of CONFLICT with net gain (GAIN) and net loss (LOSS), with a fourth background pure gain condition excluded from analysis. In theory, CONFLICT would concurrently activate roughly equal but incompatible goals/behavioral tendencies (McNaughton, 2011; McNaughton et al., 2016) and induce specific behaviors (e.g., risk assessment, inhibition of ongoing pre-potent responses, passive avoidance) to resolve the goal-conflict. In GAIN and LOSS, approach and avoidance tendencies would dominate, respectively. Critically, for many processes such as net payoff value, the average of GAIN and LOSS should be equivalent to CONFLICT. However, the process of goal conflict should be maximal in CONFLICT and so directly estimated by the subtraction of the GAIN + LOSS average from CONFLICT. As with the SST, the Neo and McNaughton (2011) economic task generated GCSR.

However, unlike the SST, the GCSR generated by this economic conflict did not correlate with trait anxiety or neuroticism. More importantly, like the SST, a link with overt behavior, i.e., economic decisions, was not observed.

Anxiety is hyper-sensitive to uncertainty (Grupe and Nitschke, 2013; Carleton, 2016; Tanovic et al., 2018). But, when we consider its effects on economic choice, we must note that neuroeconomics distinguishes two forms of uncertainty: risk and ambiguity. These are defined as contexts in which probabilities about economic outcomes are known and unknown, respectively (Bach and Dolan, 2012). Consistent with this, previous studies (Zhang et al., 2015; Smith et al., 2016) showed that trait anxiety and decision-making were related only under ambiguity and not under risk. Hence, the lack of correlations in the Neo and McNaughton (2011) study could be due to the fact that decision-making was made under risk not ambiguity.

So, in the current study, we set up decision-making under ambiguity by removing the information about outcome values from the Neo and McNaughton (2011) task. Not only did net value in a condition have to be learned but net value was controlled via probability with fixed payoffs rather than varying payoffs at fixed probability (50:50). We predicted that under these conditions, goal-conflict rhythmicity in the right frontal scalp site F8 would be correlated with decision-making, and with trait anxiety and neuroticism.

MATERIALS AND METHODS

Participants

Ninety participants were recruited from the University of Otago Student Job Search. They took part in variants of the economic decision-making paradigm in Neo and McNaughton (2011), referred to here as "LEARN" (15 females and 14 males) and "TRIM" (29 females and 27 males), respectively. Ages ranged

from 19–25 years. Participants were compensated with cash at hourly rates slightly above the minimum wage rate at the time of testing. All participants identified themselves as right-handers and did not report any psychological treatment in the past year. Ethical approval was provided by the Lower South Regional Committee and the University of Otago Human Ethics Committee (OTA/04/03/019).

Data Acquisition

Electro-caps (Electro Cap International, United States) mounted with pure tin electrodes were used for recordings. Three caps, large (580–620 mm), medium (540–580 mm) and small (500–540 mm) were used to accommodate different head circumferences. EEG data were recorded from F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6. EEG was also recorded from Fp1, to detect the occurrence of eye blinks. The electrodes were referenced to activity averaged across the two earlobes, recorded with clip-on pure tin ear electrodes. Electrodes on the caps were filled with Electro Cap International Electro-Gel. Impedances were checked with a General Devices impedance meter (EIM 107-37A, United States). Mindset Model MS-1000 hardware (Nolan Computer Systems, United States) was used to capture, amplify and digitize the EEG signals at a 128 Hz sample rate with 1.8–36 Hz bandpass filters. EEG recording software controlling the MindSet was written in Visual Basic and formed part of the same program that controlled the experiments.

Questionnaires

Questionnaires included measures of neuroticism and extraversion in the Eysenck Personality Questionnaire-Revised (EPQ-R) (Hodder and Stoughton, United Kingdom), and the Spielberger State-Trait Anxiety Inventory (STAI) (Mind Garden Inc., Menlo Park, CA, United States).

Task Stimuli

Here, we describe the methods for LEARN. TRIM was set up as a shorter task to address experimental fatigue in LEARN (see exclusion of participants due to artifacts in EEG processing). The changes in TRIM are indicated in brackets below. The computer stimuli in each part of the sequence of events in an experimental trial are shown in **Figure 1**. A trial starts with the presentation of a colored rectangular box with a frame on the outside and a smaller white box on the inside. The frame shrunk every 1,000 ms until it disappeared after 3,000 ms (TRIM: 1,000 ms). A choice of a left or right mouse click was required to call up the next stimuli. A left click produced a gain or loss with a fixed absolute value of +10/−10 cents. Gain:loss ratios of left clicks varied with experimental conditions and were set to 75:25 (GAIN), 50:50 (CONFLICT) and 25:75 (LOSS). A right click displayed a blank screen with no monetary consequences. The feedback for both left and right clicks lasted for 2 s (TRIM: 1,000 ms). The inter-trial interval consisted of a blank screen presented for 2 s.

The larger rectangular box and its outer frame (gray areas in **Figure 1**) displayed different colors depending on the experimental conditions. GAIN was in aquamarine [RGB (0, 255, 255)], CONFLICT in brown [RGB (139, 69, 19)], and LOSS in purple [RGB (72, 61, 139)]. LEARN included a fourth Continuous Gain condition in green [RGB (0, 100, 0)]. Practice trials were in gray [RGB (169, 169, 169)]. The stimuli were presented against a blue background (RGB [0, 0, 255], black areas in **Figure 1**). 10 practice trials and eight, 10-trial, blocks from each payoff condition with optional rest breaks between trial-blocks were presented. The order of the payoff conditions across and within trial-blocks was counter-balanced. The sequences of the payoffs were fixed across participants so that right clicks did not alter the pre-determined consequences of the next left click, i.e., the

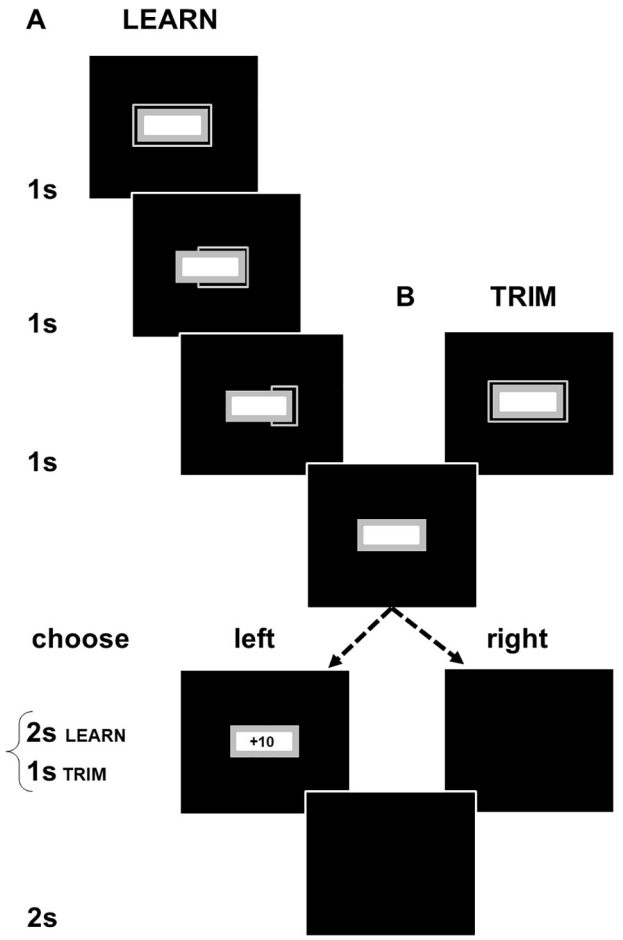

FIGURE 1 | Schematic illustrations of **(A)** LEARN and **(B)** TRIM. Participants had to choose to left or right click at the end of a 3000 ms countdown period (in TRIM, the countdown and feedback periods were shortened to 1 s). Left clicks produced either a gain or loss of 10 cents. Right clicks produced no monetary consequences and allowed the participant to proceed to the next trial. Gain:loss ratios were adjusted across three color-cued experimental conditions. Participants were not informed of this but, over successive trials, could learn the association of the color cues with the probabilistic payoffs in each condition (gray box in **Figure 1** showed a different color in each condition). The interval between a click and the start of the next trial was the same with both left and right clicks even though a left click produced feedback and a right click did not. There was, thus, no time incentive for participants to make either a left or right click. Participants were not given details of the timing of the task components and were only informed that the computer task would take about 45 min (TRIM: 20 min).

sequence of payoffs experienced by a participant in each of the payoff conditions was the same for all participants, regardless of when right clicks were made.

Procedures

Participants filled out consent forms and the questionnaires upon arrival, followed by EEG preparation and the experimental task. They were instructed to make as much money as possible. On top of the compensation they received for participating in the experiment, participants had a chance to earn a bonus. In LEARN, they received a bonus amount made above $9.50. In TRIM, they were given the actual amount made during the task. There was no penalty if earnings were in deficit by the end of the experiment. The experimenter used the practice trials to demonstrate the general consequences of a left and right click, but did not inform the participants that there were different payoff conditions that were color coded. Hence, participants had to learn the payoff condition via the consistent relation of each stimulus color to a particular payoff. Participants were informed of the amount of their earnings after they completed the task. After clean up, they received payment for their participation, together with bonus earnings from the task, if any.

EEG Processing

Ocular artifacts in the EEG were removed automatically by fitting a template to the ballistic components of eye blinks recorded on Fp1 (Zhang et al., 2017) and then removal of the fitted components from each channel scaled via linear regression (Gratton, 1998). Remaining artifacts were removed manually by deletion and were replaced with missing data markers. Deletions were always made across all channels for the relevant time period.

After artifact removal, we extracted Fast Fourier Transforms (FFT) for nominal 0.5 s epochs. A 1 s overlapping Hanning window was centered on the midpoint of the 0.5 s period of interest with 0.25 s leading and trailing overlaps. If any datum in an epoch was a missing value, the entire FFT was set to missing values. The data were then log transformed to normalize error variance, and then averaged across trials for the same payoff condition. If more than 30% of the trials contributing to the averaged power spectrum for a participant contained missing data for the same time period, the averaged spectrum for that period was replaced with missing data markers. Participants were excluded if missing values for the segments to be analyzed exceeded 10%. 11 participants showed a large number of movement EEG artifacts toward the end of LEARN, probably due to fatigue. We therefore tested more participants with a shortened version of the task, TRIM. No participants had to be excluded in TRIM due to artifacts.

Statistical Analyses

All statistical analyses were conducted with Analysis of Variance (ANOVA) and linear regression in SPSS. Where appropriate, we extracted linear (lin) and quadratic (quad) trends using orthogonal polynomial contrasts.

Behavioral Analyses

We examined the effects of payoff conditions (**P**), gender (**G**), trial-blocks (**B**) and Choice task (**C**) on the number of left clicks made in each 10-trials block.

EEG Analyses

Consistent with Neo and McNaughton (2011), conflict and loss-gain activity were separately analyzed in the theta and alpha bands; and in the early and late phases of the tasks, respectively. Power spectra in the theta and alpha bands were averaged across 4–7 Hz and 9–12 Hz; and trials in the early and late phases were averaged across the first and last 30 trials. Conflict activity was examined with quadratic contrasts of payoff conditions (**P**). Mathematically, this is equivalent to subtracting power averaged across GAIN and LOSS from CONFLICT. Loss-gain activity was analyzed with the linear contrasts. Mathematically, this is the equivalent of subtracting power in GAIN from LOSS, while ignoring CONFLICT. Linear and quadratic contrasts were extracted for "Site" (**S**) with F7, F3, Fz, F4, and F8 as the respective levels (i.e., the quadratic term assesses midline power relative to the average of left and right; while the linear term assesses left-right differences).

In previous work (Neo and McNaughton, 2011), right frontal theta activity was detected in the 0.5 s period immediately after the onset of the stimuli that cued the start of a 3-s countdown before the forced choice. Since changes across time were not examined, it was unclear if the observed theta was related to the previous trial or the upcoming choice. We therefore analyzed a factor, "Time" (**T**), which compared activity in the period of interest (0.5 s from the onset of the start cue) with the periods before and after. This comparison was reduced to a single df term using a quadratic contrast.

Stepwise Regressions

We extracted Cook's distance and leverage values to determine potential outliers. Seven participants with leverage value three times over k + 1/n and Cook's distance over 4/n were identified (k is the number of predictor variables and n is the number of observations). We used their behavioral responding as a basis for exclusion as it showed a significant relationship (see results). Six of the participants showed adaptive behavioral responding, adopting strategies normally seen in the tasks. A female participant was excluded as she showed an unusually low number of left-clicks across all the payoff conditions (average of 5 clicks in each condition).

RESULTS

Behavioral Responses to the Payoff Conditions GAIN, CONFLICT, and LOSS

As can be seen in **Figure 2**, males and females responded differently to payoff conditions over the trial-blocks, averaged across the Choice tasks [**P**(lin) × **B**(lin) × **G**, $F(1,86) = 4.80$, $p < 0.05$]. *Post hoc* tests show that males, compared to females, showed a steeper decrease in left clicking over trial-blocks in

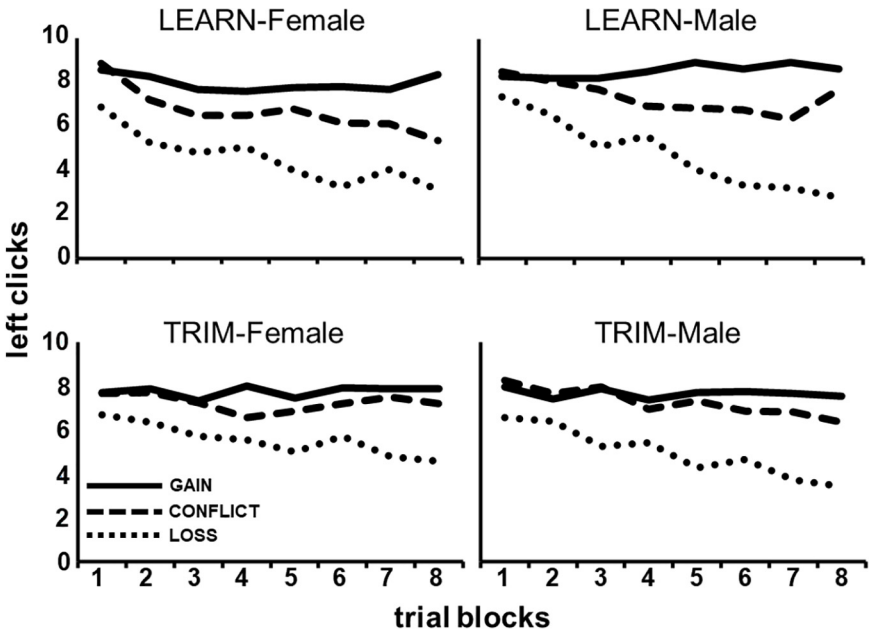

FIGURE 2 | The average number of left clicks across eight, 10-trial, blocks for each of the three payoff conditions (GAIN, CONFLICT, and LOSS) for each gender and task (LEARN, TRIM).

LOSS [**B**(lin) × **G:** GAIN, $F(1,88) = 0.06$, $p = 0.80$; CONFLICT, $F(1,88) = 0.56$, $p = 0.46$; LOSS, $F(1,88) = 4.49$, $p < 0.05$].

Figure 2 also shows that LEARN, compared to TRIM, showed a larger increasing separation between payoff conditions over trial-blocks, averaged across gender [**P**(lin) × **B**(lin) × **C**, $F(1,86) = 3.80$, $p < 0.05$]. *Post hoc* tests show that this was a result of a steeper decline in LOSS left clicking over trial-blocks in LEARN [**B**(lin) × **C:** GAIN, $F(1,88) = 0.03$, $p = 0.86$; CONFLICT, $F(1,88) = 2.92$, $p = 0.09$; LOSS, $F(1,88) = 4.07$, $p < 0.05$].

EEG Effects Common Across Tasks and Gender

As mentioned before, we tested more participants with TRIM to address the unexpected large number of data lost due to EEG artifacts in the late task phase of LEARN. Task differences were therefore not a key focus of our study. Hence, we focus our report here only on effects that were common across tasks and gender that did not show higher order task-related interactions. Note also that the period of interest under study here was chosen for fair comparison across the tasks. For readers interested in interactions between gender and task, a summary of the full ANOVA statistics and supporting figures can be found in **Supplementary Material**.

Early task phase conflict activity and late task phase loss-gain activity were the only two activities that did not differ across tasks and gender, and both were in the theta band. As shown by the solid line in **Figure 3A**, the effect of time period on early phase conflict activity increased steadily across the recording sites from F7 to F8 [**T**(quad) × **P** × **S**(lin), $F(1,86) = 6.73$, $p < 0.05$]. The same trend (dotted line) was not observed in the late task phase. Details of the summarized effects in **Figure 3A** are shown in **Figures 3B,C**, which show the change in activity over the recording sites for each time period and task phase, respectively. The effect of time period on late phase loss-gain activity is indicated by the dotted line in **Figure 3D**. The increase of activity from F7 to F8 was reliable [**T**(quad) × **P** × **S**(lin), $F(1,72) = 5.08$, $p < 0.05$] and a similar trend was not detected in the early phase. As per above, the details of the summarized effects in **Figure 3D** are shown in **Figures 3E,F**.

We conducted *post hoc* tests to assess if conflict and loss-gain theta significantly change over the time periods, separately, for each individual recording site in the early and late task phases. The F-ratios are summarized in **Table 1** below. Notably, only F8 early phase conflict theta showed a reliable time difference (see highlight in **Table 1**).

F8 Early Conflict Theta: Correlations With Behaviors and Personality Traits

Early phase F8 conflict theta power, which showed a reliable peak in the period where the trial-start stimulus was presented, was submitted to a stepwise regression. Trait anxiety, neuroticism, early and late phase GAIN, CONFLICT, and LOSS left clicks were entered as predictor variables. F8 conflict power was negatively related to late phase left clicks in CONFLICT [$r^2 = 0.59$, $F(1,89) = 5.50$, $p < 0.05$; see **Figure 4A**]. The stepwise regressions were repeated for females and males separately for LEARN and TRIM to determine if the relationship was driven by sub-groups [LEARN females: $r^2 = 0.02$, $F(1,16) = 0.34$, $p = 0.57$; LEARN males: $r^2 = 0.12$, $F(1,11) = 1.44$, $p = 0.25$; TRIM females: $r^2 = 0.10$, $F(1,28) = 3.19$, $p = 0.09$; TRIM males: $r^2 = 0.22$, $F(1,26) = 7.51$, $p = 0.01$]. As shown in **Figure 4B**, only females in LEARN showed opposite trends.

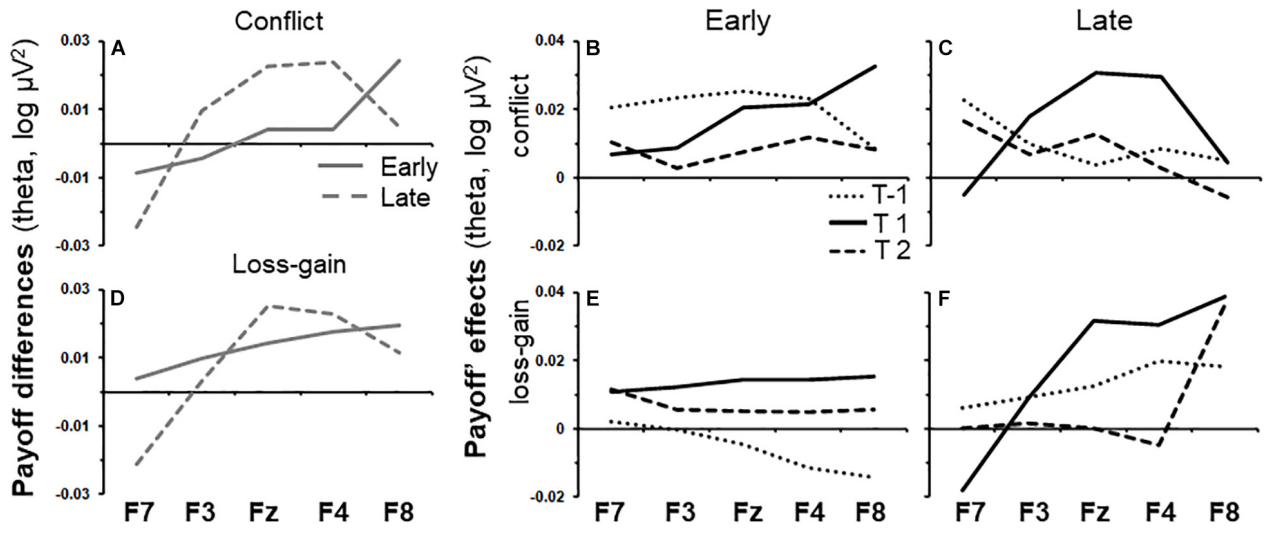

FIGURE 3 | Variations of payoff effects across recording sites (F7, F3, Fz, F4, and F8) and time periods for early and late task phases. **(A)** Conflict theta activity specific to the mid time point, calculated as the average of T-1 and T2 subtracted from T1. **(B,C)** show variations of conflict theta activity for each time period of interest, for the early and late task phases, respectively. T1 is the 0.5 s period from the onset of the trial-start stimulus. T-1 and T2 indicate the 0.5 s periods before and after T1, respectively. **(D–F)** as **(A–C)** but for the loss-gain activity difference rather than for conflict activity.

TABLE 1 | Summary of *post hoc* tests. The values shown are F-ratios for the interaction between the quadratic contrast of time period ("Time") and the respective payoff conditions ("Payoff").

	Conflict		Loss-gain	
	Early	Late	Early	Late
F7	0.54	2.96	0.18	1.5
F3	0.03	0.02	0.31	0.2
Fz	0.72	0.36	0.03	0.68
F4	0.4	0.41	0.1	1.1
F8	6.8*	0.02	0.03	0.05

*The degrees of freedom for analyses of early and late phase activity are early phase: 1, 89; and late phase: 1, 75. *p < 0.01.*

People in the remaining groups all showed trends consistent with the main effect.

DISCUSSION

Here, despite the change from risk to ambiguity and the variation of probability rather than size of payoff, we replicated the general findings from the economic choice task of Neo and McNaughton (2011) and our unrewarded SST studies (Neo and McNaughton, 2011; Neo et al., 2011; McNaughton et al., 2013; Shadli et al., 2015b, 2016). That is, we observed GCSR in the right frontal region. Notably, the results were obtained in a large sample size, and did not differ across two *new* variants of the task used in Neo and McNaughton (2011), showing good generalization. The findings suggest that the right frontal region is involved in goal-conflict processing across domains. We also replicated specific findings from Neo and McNaughton (2011), detecting GCSR only in the early phase of training and in the theta band. GCSR observed in the early phase likely reflects active goal-conflict assessment or adaptation, which should be less dominant in the late phase once response strategy starts to stabilize (McNaughton, 1985).

More importantly, for the first time, right frontal GCSR showed a link with a neuroeconomic choice/decision bias. We think that the relationship observed here (and not in Neo and McNaughton, 2011), was a result of the increase in demand to search for information when decision-making has to be made under ambiguity (Huettel et al., 2006; Bach et al., 2009, 2011; Horga et al., 2011). Consistent with our theory of anxiety (Gray and McNaughton, 2000), people who showed more GCSR showed a preference for economic safety specific to the economic context of CONFLICT. This provides replicable, empirical evidence that a motivational system (BIS) other than pure loss (FFFS), can lead to negative, overt decision biases.

Contrary to our expectations, decision-making under ambiguity did not result in a relation of GCSR with either trait anxiety or neuroticism, casting doubt on whether the bias is anxiety-related. Anxiety can be measured in various ways (Polak et al., 2015; Heeren et al., 2018). If the right frontal GCSR observed here reflects processing specific to anxiety, our findings suggest it reflects an aspect of anxiety that is not effectively captured by the trait anxiety and neuroticism questionnaires. While we cannot rule out that the bias reflects other forms of emotional processing, this is unlikely since all the current forms of conflict processing being studied, such as goal-, response- and outcome- conflict processing (Gray and McNaughton, 2000; Cavanagh and Shackman, 2015), have been implicated in anxiety processes. These are not just different forms of conflict by definition, but also differ in terms of the regions that they have been commonly associated with (right frontal versus frontal midline). Consistent with a previous review of human frontal

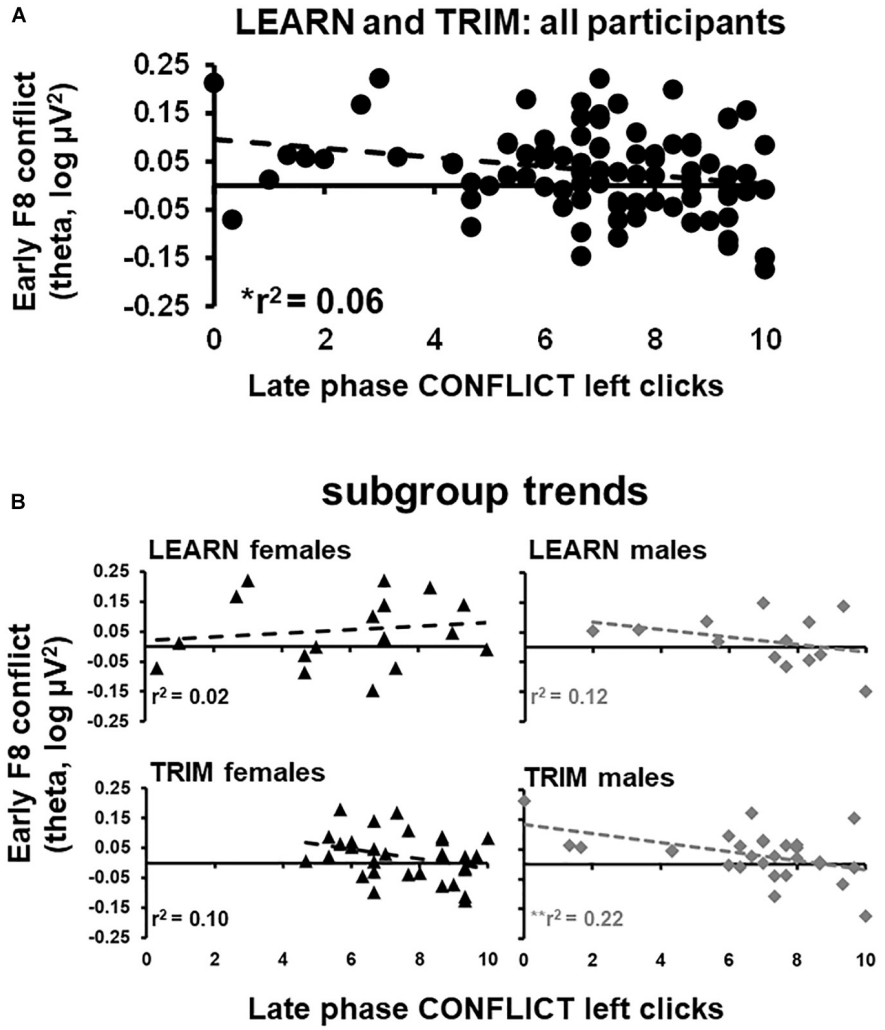

FIGURE 4 | Scatterplots of early phase conflict theta activity and late phase left clicks in CONFLICT. **(A)** scatterplot for all participants in both LEARN and TRIM. **(B)** Scatterplots for each subgroup: LEARN females, LEARN males, TRIM females and TRIM males. Trend lines are indicated by dotted lines. *$p < 0.05$; **$p < 0.01$.

midline theta from the perspective of rat hippocampal theta (Mitchell et al., 2008), Beaton et al. (2018) found that in the flanker task, ventrolateral prefrontal but not frontal midline conflict theta activity, was sensitive to an anxiolytic, alcohol. It therefore appears that there are at least two and possibly more independent conflict mechanisms, and each of these could influence different aspects of anxiety processing.

Finally, our findings support the existing view of EEG theta as an electrophysiological mechanism for adaptive, cognitive control of flexible behavior, involved in conflict resolution. For example, in addition to right frontal GCSR, theta band activity, albeit from the frontal midline region, has been consistently observed during response- (Cohen, 2014), and outcome-conflict monitoring (Cavanagh and Frank, 2014). Theta band activity has also been observed in the lateral prefrontal regions in the same response- and outcome-conflict monitoring tasks (Nigbur et al., 2012; Tang et al., 2013; Beaton et al., 2018). However, conflict processing is not limited to theta processes. GCSR spanned into the alpha range during action inhibition in the SST. Conflict adaptation in the classical Stroop task also recruits higher frequencies (Tang et al., 2013) with right frontal theta activity in the "look" condition (no response required) and, additionally, right frontal alpha in the "do" condition (response required). Taken together with the observation of only theta band activity here, where goal-conflict was generated by slower decision-making processes, it appears that alpha frequencies are also recruited when the conflict is generated by faster motor processes (the SST involves speeded responses). However, it is unclear if the shift in frequencies is a result of the motor processes *per se* or a result of physiological arousal generated by time-pressured actions.

To conclude, the BIS is neurally detailed. However, how it impacts economic decisions is not well understood; and remains unexplored within decision neuroscience. Here, we provide the first demonstration that goal-conflict theta activity is linked to a decision bias. Both the brain and behavioral

measures used were distinct from gain and loss, *per se*. The findings here are a crucial demonstration of BIS applicability and integration with neuroeconomics. They provide a new lens through which to view decision biases, and should help us to dissect choice processes, and the associated emotional processing more precisely. Conversely, we did not find direct evidence that the conflict-decision bias link here is an anxiety process. However, taken together with previous studies, goal-conflict appears to be one of multiple independent conflict mechanisms, which share common electrophysiological features, such as the recruitment of EEG theta activity for adaptive cognitive control. Notably, all of the conflict mechanisms have previously been linked to anxiety processing. It is likely that the bias observed here is linked to anxiety, albeit, one that is not effectively captured by the self-report measures of trait anxiety and neuroticism used here.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

These studies were reviewed and approved by the Lower South Regional Committee (LRS/09/05/017) and the University of Otago Human Ethics Committee (OTA/04/03/019). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PN collected, processed, and analyzed the data and prepared the manuscript. JT collected and processed the data. NM provided academic supervision and guidance for the experimental design, data collection, analyses and preparation of the manuscript, and edited the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnins.2020.00342/full#supplementary-material

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CASE REPORT
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Functional Cerebral Specialization and Decision Making in the Iowa Gambling Task: A Single-Case Study of Left-Hemispheric Atrophy and Hemispherotomy

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The Iowa Gambling Task (IGT) is a decision-making task that preferentially involves the right prefrontal cortex (PFC). However, the performance of the task is driven by two attributes: intertemporal (long vs. short-term) and frequency-based processing of rewards-punishments, and differs over the two phases of uncertainty (early trials) and risk (later trials). Although intertemporal decision making involves the right PFC, the extent of hemispheric specialization in attribute and phase-specific decision making is unknown. Therefore, the current study assessed decision making in a patient with a uni-hemispheric disease, who underwent hemispherotomy surgery, comparing pre-surgical IGT performance (3 days prior to surgery) with post-surgical performance (1 month, and 12 months post-surgery). The patient's pre- and post-surgical IGT performances were analyzed to examine changes in attribute and phase-specific decision making, including the widely reported deck B phenomenon. The results for the two attributes of deck selection at the pre- and post-surgical assessments suggested marked changes in the two IGT phases of risk and uncertainty. Pre-surgery, the patient made more intertemporally disadvantageous choices, and task-progression contributed to it; within 1 month of surgery, intertemporal disadvantageous deck choices were contingent on task progression, after 1 year, disadvantageous choices were independent of task progression. Intertemporal attribute alteration was unresponsive to uncertainty and risk phase. The effect of task progression on frequency attribute remained unchanged before and immediately after the surgery, and preference for infrequent decks was observed only after 1 year. Further, pre and post surgery alteration in frequency attribute was phase-specific: within 1 month of surgery, infrequent deck choices decreased in uncertainty and increased in risk, whereas the reverse was observed after 12 months. Deck B choice increase was in the uncertainty phase. Results are discussed in reference to valence-linked hemispheric specialization and its potential role in attribute and phase-specific IGT decision making.

Keywords: decision making, hemispheric specialization, Iowa Gambling Task, lateralized function, valence

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BACKGROUND

The Iowa Gambling Task (IGT) was devised to account for decision making deficits in patients with focal damage in the ventromedial prefrontal cortex (PFC; Damasio, 1996). The PFC enables somatic markers to guide long-term decision making in the IGT (see for task description; Bechara et al., 2005). Over a period of time, the IGT has been considered as complex task such that usage of two types of decision making strategies have been observed: cognition-intensive processing of long term payoffs (over a period of trials), intertemporal and emotion-based, and automatic, frequency-based decision making (choices made based on the frequency of rewards and punishments) (Stocco et al., 2009). These two attributes contribute to the heterogeneity observed in the IGT (Singh and Khan, 2009). Further, there are different phases in the 100 trials of the task that assess different constructs; the initial 50 trials, where punishments get introduced, assess decision making under uncertainty (unknown payoffs/outcomes), whereas the subsequent trials (after 50) evaluate decision making under risk (known payoffs/outcomes) (Brand et al., 2007; Bagneux et al., 2013; Singh et al., 2020). Some researchers have observed the intertemporal attribute decision making to differ between the first half trials and the last half trials (e.g., Rocha et al., 2011; Steingroever et al., 2013). Further, the first and the last phase vary in cognitive demands, the earlier uncertainty phase has the lesser demands (Bagneux et al., 2013), whereas the last risk phase is more demanding of cognitive resources (Brand et al., 2007). Therefore, there is a possibility of attribute, and phase-specificity in the IGT decision making; however, most of the IGT studies focus solely on the intertemporal attribute, and consider all trials of the IGT to be homogenous in terms of the cognitive demands.

This far, studies of laterality in the IGT have offered insight in intertemporal decision making and how it progresses across the 100 task trials (Bolla et al., 2003; Clark et al., 2003; Fukui et al., 2005; Li et al., 2010). For instance, studies have suggested that right PFC injury results in poor intertemporal decision making in the IGT (Clark et al., 2003), whereas lesions in the left hemisphere do not impair intertemporal task performance (Tranel et al., 2002), the extent of hemispheric laterality involved in attribute and phase-specificity in IGT decision making remains unclear. Further, the right-PFC link to the IGT intertemporal decision making shows sex-specificity: male decision making is impaired by the right ventromedial PFC damage, while left-hemispheric damage impairs female intertemporal decision making in the IGT (Tranel et al., 2005). Aligned with the contention of lesion laterality, male advantage in the task's intertemporal decision making is attributed to greater right-hemispheric specialization in men (van den Bos et al., 2013). Frequency-based choice of infrequent punishment deck B is intertemporally disadvantageous (Lin et al., 2007), but this preference for infrequent punishment/losses is prominent in females (Overman and Pierce, 2013). Sex-differences are not limited to attribute-specificity but also show phase-specificity. For instance, the deck B choice among females was observed in the uncertainty phase (Okdie et al., 2016). One potential reason for the speculation of hemispheric role in attribute and phase-specificity in the IGT decision making might be that the processing of uncertainty shows lateralization (Goel et al., 2007; Marinsek et al., 2014). Additionally, uncertainty is linked with anticipatory anxiety or negative valence about the future emotion states (Grupe and Nitschke, 2013). Hemispheric lateralization linked to valence processing might contribute to sex differences in intertemporal attribute (Bolla et al., 2004; Singh, 2016), however, hemispheric role in attribute and phase-specificity in IGT decision-making remains poorly understood.

Functional cerebral specialization may influence IGT decision making in attribute, and phase-specific manner (i.e., uncertainty and risk), and this presents a need for understanding of hemispheric specialization in the IGT. However, examining hemispheric specialization while accounting for interhemispheric connectivity and exchange is a challenge that can be addressed by examining the effects of uni-hemispheric damage on the task across the disconnection of the two hemispheres (Gazzaniga, 2000). We herein present the case of a woman with Rasmussen encephalitis, a condition characterized by uni-hemispheric damage and the occurrence of epileptic seizures; in the present case, the patient exhibited left-hemispheric atrophy. Due to drug resistance, seizure-alleviation was attained with hemispherotomy (Chandra and Tripathi, 2015): a procedure that functionally dissociated the epileptogenic left hemisphere from the non-epileptogenic hemisphere.

Rare neurological drug-resistant epilepsy such as the Rasmussen Encephalitis entails uni-hemispheric atrophy, further; the treatment is dissociation of the epileptogenic hemisphere. Even though the deficit in the IGT cannot be attributed to solely to epilepsy-linked structural or functional atrophy (Delazer et al., 2010), uni-hemispheric atrophy and post-surgery changes offer insights about the hemispheric contribution to cognitive functions, for instance, uni-hemispheric epilepsy localized either to the right or to the left hemisphere did not differ in terms of the deficit observed in the intertemporal IGT decision making (Bonatti et al., 2009; Labudda et al., 2009; Delazer et al., 2010, 2011). This observation is reported in a recent meta analysis of the IGT epilepsy studies (Zhang et al., 2018), however, so far the studies have either analyzed intertemporal IGT decision making prior to the hemispheric dissociation (e.g., Labudda et al., 2009; Delazer et al., 2010) or after the surgery (e.g., Butman et al., 2007; Bonatti et al., 2009). To our knowledge, this is the first case study of a female patient with left hemispheric atrophy, whose IGT performance is analyzed for pre and post surgery changes within a short (1 month) and a long duration (12 months) of hemispheric dissociation. Others have used single case study of epilepsy for understanding emotion processing (e.g., Tamune et al., 2018). Therefore, a rare case of female patient of Rasmussen Encephalitis epilepsy with left hemispheric atrophy is used herewith for understanding how the two attributes (i.e., cognition-intensive and emotion-based attributes) in two phases differing in cognitive demands (i.e., uncertainty and risk) influence performance in a task that shows right-laterality-linked male advantage. It was expected that uni-hemispheric damage and a comparison of the patient's performance after hemispherotomy enabled examination of the attribute and

phase-specific IGT decision-making changes occurring within 1 month and 12 months of post-hemispheric disconnection. Further, we explored pre and post-surgery changes in valence processing (pictures and words of positive, negative and neutral valence) as a possible contributor to attribute and phase-specificity in the IGT.

CASE REPORT

A 26-year-old woman with late-onset, drug-resistant left-hemispheric Rasmussen encephalitis (onset age: 15 years; seizure duration: 12 years) presented with aphasia and progressive right hemiparesis. She was admitted with a 6-year history of progressive right hemiparesis, a 4-year history of intact comprehension with impaired speech production, and attendant progressive cognitive impairment. In preparation for the surgery, neuropsychological evaluation, brain imaging [magnetic resonance imaging (MRI), three-dimensional fluid-attenuated inversion recovery (3D FLAIR) imaging, functional MRI (fMRI)], and semiology tests were performed. We used pre-surgical evaluations to ascertain the following abnormalities: left-hemispheric atrophy, left-lateralized atrophy in areas commonly implicated in the IGT, and functional left-lateralization of language (motor speech production and word comprehension). The Ethics Committee at the medical institute approved the study protocol. Written informed consent for study-participation, and publication of this report was obtained from the participant and her caregiver.

The patient could not complete the routine pre-surgical neuropsychological evaluations (Mental State Exam: MSE). The auditory verbal functioning and visuospatial functioning tests were attempted but could not be completed on account of the patient's seizures and speech difficulties. The summary of the neuropsychological evaluation suggested that the patient had impaired intellectual functioning and an absence of anxiety or depressive symptoms.

Left-Hemisphere Atrophy and Left-Lateralized Atrophy in IGT Circuitry

Assessing the state of the left hemisphere, the pre-surgical seizure semiology test findings were used to verify focal onset of seizures in the left hemisphere with clonic movements of the right limbs (upper and lower) and right facial twitching (video-EEG). Subsequent visual inspection of 3D FLAIR images (**Figure 1**) verified left-hemispheric atrophy in the frontal regions (co-authors: MT, SC, and SK). Further, in agreement with the observation that stage 4 encephalitis occurs approximately 8 years after seizure onset and leads to hemispheric atrophy (Varghese et al., 2014), the brain regional volume in our patient, who had experienced seizures for 15 years, showed that the left anterior frontotemporal region was the most affected area (volume of atrophy/damage: 15.13 cm^3, mean $\pm$ standard deviation: 248.05 $\pm$ 126.34). The volume of atrophy was estimated using OsiriX Lite (v.10.0.3, Switzerland) 3D medical image processing software.

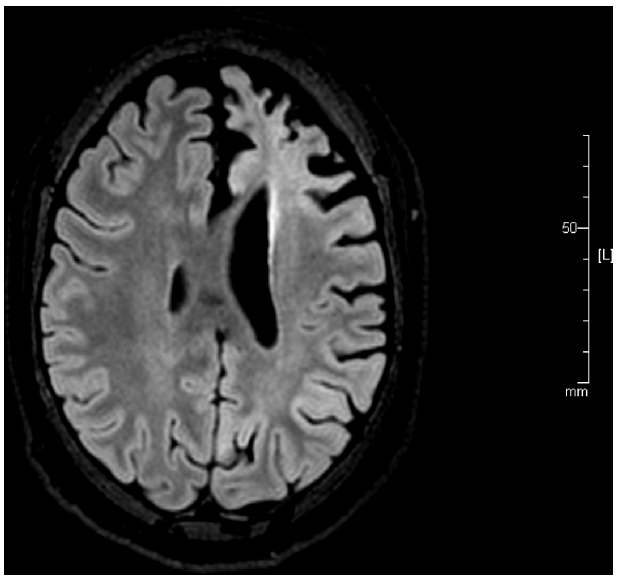

FIGURE 1 | A reconstructed axial three-dimensional fluid-attenuated inversion recovery image obtained from the patient with left-hemispheric Rasmussen encephalitis before surgery shows atrophy in the left hemisphere indicated by 'L' (repetition time: 4800 ms, echo time: 270.9 ms, slice thickness: 1.0 mm, matrix size 512 $\times$ 512).

Along with verifying of lateralized atrophy and functional lateralization (language and motor), details of laterality in the IGT-related neural circuitry in the patient were added as supplementary to the left-lateralized atrophy. Pre-surgical fMRI evaluations helped add further clarification in terms of the extent of lateralized atrophy in key brain areas identified to be critical to intertemporal IGT (Lin et al., 2008). Regional gray matter volume estimation of the ventrolateral PFC, dorsolateral PFC, orbitofrontal PFC, hippocampus, amygdala, thalamus, and anterior cingulate cortex was undertaken to add details related to lateral atrophy in the IGT circuitry. Gray matter analysis was performed by the second author (KC), using 3T MRI following the realignment, segmentation, and co-registration steps of SPM12 (Friston et al., 1995). Due to atrophy, the percentage of gray matter volume showed reduction in the left hemisphere. The regions in the left hemisphere with the most atrophy were the ventrolateral PFC (30%), dorsolateral PFC (10%), orbitofrontal PFC (10%), thalamus (23%) anterior cingulate cortex (21%), amygdala (14%), and the hippocampus (5%). Therefore, pre-surgery evaluation was to verify left-lateralized foci, and left-hemispheric atrophy in the patient and add information about the extent of laterality observed in the IGT-linked neural circuitry.

Recently, PFC lesion laterality study using a predominantly male-sample suggested that left hemisphere is critical for frequency-based attribute, specifically for infrequent punishment deck choices of deck D in the IGT decision making (Besnard et al., 2015). It was expected that the present case will enable us to explore the extent to which left-hemispheric atrophy and

left-hemispheric dissociation will influence, attribute and phase-specific IGT decision making immediately (within 1 month) and after 1 year of hemispheric dissociation. Pre and post-surgery changes in the IGT decision were expected to be: (a) attribute specific, that is, differ for the cognition-intensive intertemporal decision making and for the emotion-focused, frequency-based decision-making, specifically for infrequent punishment deck B, and (b) phase-specific, that is, linked with uncertainty phase, due to its valence-directed anticipatory nature, and (c) linked with changes in valence-specific affect processing.

Functional Specialization for Language

The presurgical fMRI evaluation was examined to ascertain the functional cerebral specialization for language for two reasons: (a) motor-related lateralization (right-handedness) affects decision making in the IGT in women (Singh, 2016), and seizure onset and right-side hemiparesis led to a shift from the patient's original right-handedness to left-handedness. Since the conventional measure of motor specialization was inconsistent/ambiguous, functional specialization for language performed at the pre-surgical evaluation was examined. (b) Patients with epilepsy show atypical, i.e., right- rather than left-hemispheric, language specialization (Rausch and Walsh, 1984), and language-related variations affect post-surgical outcomes (Chaudhary et al., 2017). The fMRI language tasks consisted of word generation, which involved reading simple Hindi words (production), and comprehension, which involved correcting simple jumbled sentences (see Chaudhary et al., 2017 for task description and protocol for presurgical fMRI). Greater blood oxygen level-dependent activations were observed in posterior frontal and temporal regions, and the weighted-mean laterality index values for the frontal and temporal regions (0.56 and 0.6, respectively) suggested left-hemispheric lateralization of language (speech production and comprehension).

Single-Case Design and the IGT

A pre-test–post-test design was used to assess preoperative and postoperative IGT decision making with a 3-day interval between the baseline test and surgery and a 30-day interval between surgery and the first retest, and the second retest after a 12 months gap from the surgery.

A day after the routine presurgical neuropsychological evaluation, the patient and her caretaker (mother) were presented an information sheet describing the study and procedures. Informed consent, which included information about preoperative evaluations (imaging, seismological, and neuropsychological evaluations) and presurgical and postsurgical assessments of the three tasks, was obtained from both the patient and the caretaker. The three tasks included were the International Affective Picture System (30 stimuli), Affect Norms for English Words (Hindi translated; 30 stimuli), and the IGT [100 trials of progressive reward versions (A′B′C′D′)]. With the aid of a research assistant, one experimenter (VS) administered the task to the patient in an outpatient department (OPD) room in the presence of the caretaker. The patient was comfortably seated on a bed with a backrest and a Hewett-Packard laptop (HP: ProBook) that was situated on a table in front of the patient to present the tasks. The first two tasks were <20 min each, and the patient was able to take a 5–7 min break between the first two tasks. Following the second task, the patient was given a 30 min break before starting the IGT (computerized IGT, PAR, FL, United States), which was administered using standardized bilingual (English and mother tongue) task instructions. A research assistant served as a proxy to mark the patient's selections on the computer because the patient demonstrated weakness in the right hand/limb, unfamiliarity with operating a computer, and brief seizures during the tasks. Importantly, after the completion of each seizure, the patient was enabled to continue or discontinue the tasks. The total duration of the experimental session was 2 h; the IGT lasted for 24.09 min. Five seizures that each lasted <2 min occurred during the IGT (trials 11–12, 24–25, 34–35, 66–67, and 87–88). When asked if she wanted to continue/discontinue, the patient always preferred to continue and appeared to immediately resume interest in the tasks. The patient may have been more motivated to complete tasks than the preoperative neuropsychological evaluation because they latter were presented on a computer: the three digital tasks involved a livelier response format that was more entertaining for the patient (all three tasks involved "smileys" as the response format; smileys indicated positive valence in the picture and word tasks and the amount won in the IGT), while the neuropsychological assessment was paper-and-pencil based and non-interactive.

The two postoperative reassessments investigated the effects of disconnecting the epileptogenic left hemisphere. At 1 month's post-surgery assessment (follow up 1), the patient was seizure free, exhibited slight swelling in the right foot, and could move her right hand with greater facility, at the 1-year post surgery assessment (follow up 2), the patient was seizure free, and there was no leg swelling. The same protocols that were used at baseline testing were repeated during the two follow up reassessments, emotion pictures were followed by words, followed by the IGT. The patient's speech did not evince any noticeable changes after surgery. At the first follow-up, patient had no recollection of the IGT task, but we observed moments of insight as the task progressed – e.g., exclamations of "ah-ha" in between trials – however, these moments were transitory. Her interest in the task appeared to be the same as that demonstrated when she performed it the first time. At the second follow-up, the patient had recollection of performing the IGT, but continued to explore the task showing no visible/explicit effects of being familiar with the task.

The IGT Attributes (Intertemporal and Frequency)

The IGT task features four decks labeled A′, B′, C′, and D′, and this progressive reward version was purchased from the Psychological Assessment Resources (PAR, FL, United States). It uses the same reward–punishment structure as used in the original task, except that the difference between the intertemporally advantageous and disadvantageous decks is more prominent/evident (Bechara et al., 2000). As per the intertemporal attribute, decks A′ and B′ are risky because they

are poor long-term choices that yield high magnitude long term punishment, whereas decks C′ and D′ are safely profitable in the long term because of low magnitude and few long term punishment. Frequency-based attribute suggests that decks A′ and C′ are risky because of frequent punishment, and decks B′ and D′ are preferred due to infrequent punishment, lowest frequency of punishment being in the deck B′. Deck choices at baseline and retests were calculated based on two attributes: (1) intertemporal (decks A′ and B′ vs. decks C′ and D′) and (2) frequency-based choices (decks B′ and D′ vs. decks A′ and C′). The deck analysis of the patient's preoperative and postoperative choices was performed for the first and last halves of the task trials to assess decision making under uncertainty and risk, respectively (Steingroever et al., 2013).

Mixed analyses of variance (ANOVAs) were conducted using SPSS version 21 to analyze the presurgical and postsurgical deck choices at follow-up 1 and 2 (intertemporal: decks A′ and B′ and decks C′ and D′; frequency: decks B′ and D′ and decks A′ and C′) for 100 trials (1 block = 20 trials, 5 blocks, as per Bechara et al., 2005) and for the 100 trials that were divided into two trial phases (trials 1–50 = uncertainty block and trials 51–100 = risk block, as per Steingroever et al., 2013). The deck choice was the within-subject variable and block was the between-subject variable [5 blocks in case of 100 trials task progression and 2 blocks in case uncertainty (trials 1–50) and risk phase (trials 51–100)]. The level of statistical significance was set at $p < 0.05$.

Affect and Valence Processing

International Affective Picture System [two sets of 30 stimuli (set 1 and set 2), 10 stimuli for each of the three valence: positive, negative, neutral] (Lang et al., 1999), set 1 was used at presurgery, and set 2 at follow-up 1, both sets were used at follow up 2 (set 2 followed by set 1). Affect Norms for English Words (Hindi translated; 30 stimuli, 10 stimuli for each of the three valence: positive, negative, neutral) (Bradley and Lang, 1999) were used to assess valence processing at three assessments. Picture stimuli were presented on computer screen one by one in the order of 10 positive, 10 negative, and 10 neutral pictures, whereas the words were read out (by the first author, VS) one by one in two blocks each block of 15 words (positive words followed by neutral words, and negative words). Valence ratings from the database of the stimuli were as follows (negative stimuli mean valence rating = 1–3, neutral stimuli mean valence rating = 4–6, and positive stimuli mean valence rating = 7–9); all arousal ratings were above 2. Patient was asked to respond to the picture in term of how it made her feel by pointing to one of the three smiley faces each depicting a valence of negative/frown, and neutral/normal face, and positive/smile (0 = negative, 1 = neutral, 2 = positive), with the spontaneity with which the patient responded being assessed on a 3-point scale (1 = very hesitant and unclear while responding, 2 = somewhat hesitant and unsure while responding, 3 = immediate and confident while responding). Ratings were calculated by considering two attributes, the valence reported and the spontaneity of valence response (1 = low, 2 = medium, and 3 = high) to produce ratings, for instance a picture rated as '0' or negative, and with immediate and confident responding '3' will produce a rating of '0 + 3 = 3.' This procedure enabled simplification of valence processing assessment (unlike the elicitation of affect response on a 9-point rating scale) as well as enabling a comparison of the obtained response with the 9-point response scale that is used in affect database to assess valence (i.e., low ratings indicate negative valence, mid-scale ratings indicate neutral valence, and high ratings indicate positive valence). Aligned with the valence-specific hemispheric lateralization (Davidson, 1992), it was expected that post-surgery affect response/ratings (pictures and words) will show valence-specific alteration. Mixed analyses of variance (ANOVAs) were conducted using patient's stimuli ratings as within-subject variable (pre-surgery vs. post-surgery at follow up assessment 1 vs. follow up assessment 2) and valence (negative vs. neutral vs. positive) as between-subject variable. Analysis addressed pictures and words separately; and pictures at follow-up 2 used the ratings of set 1 (pictures shown prior to surgery) and of set 2 (pictures shown at post surgery follow up 1), in other words presurgery ratings (set 1), post surgery follow up 1 ratings (set 2), and post surgery follow up 2 ratings of set 1, and post surgery follow up 2 ratings of set 2 served as four levels of within-subject variable for analysis of valence processing.

RESULTS

We first examined IGT deck choices across the 100 trials of the task to determine whether choice of decks alters with task progression, separately for the two attributes (intertemporal: decks A′ and B′ vs. decks C′ and D′; frequency-based: decks B′ and D′ vs. decks A′ and C′) assessed at three points (pre- and post-surgery assessments).

Specifically, in terms of attribute and task progression across the five blocks of trials, our analysis revealed a main effect of intertemporal deck choice (decks A′ and B′ vs. decks C′ and D′) [$F(1,95) = 4.38$, $p = 0.04$] and of deck × block interaction [$F(4,95) = 2.52$, $p = 0.05$] on presurgical performance, disadvantageous deck choices were prominent, and they altered as the trials progressed. There was no main effect of decks, but a significant deck × block interaction was observed on the first post-surgical performance within 30 days of surgery [$F(4,95) = 2.79$, $p = 0.03$], whereby disadvantageous deck choices altered only as the task progressed. After 1 year at the second postsurgical follow up, there was a main effect of intertemporal deck choice [$F(1,95) = 23.70$, $p < 0.001$] but the deck × block interaction was non-significant suggesting choices from the disadvantageous decks increased, independent of the task progression. Unlike presurgical behavior, differentiation of long-term advantageous decks vs. short-term disadvantageous decks seemed contingent on task trials at the first postsurgical follow up within 30 days of the surgery, but reverted to the presurgery trend, that is, prominent preference for disadvantageous decks, independent of task progression.

There was no main effect of frequency-based deck choice (decks B′ and D′ vs. decks A′ and C′) [$F(1,95) = 0.00$, $p = 1.00$] or of a deck × block interaction [$F(1,95) = 0.09$, $p = 0.98$] on pre- and post-surgical follow up performance within 1 month. One year of post-surgery follow up suggested

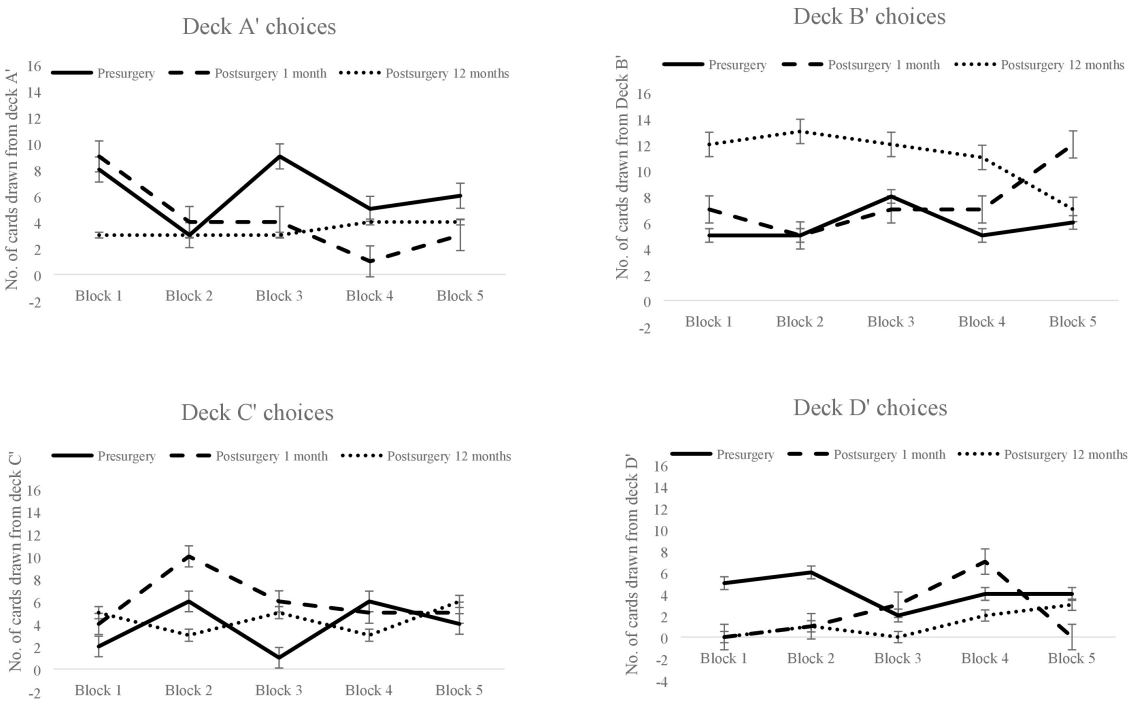

FIGURE 2 | The patient's pre- and post-surgical block-wise choices for each of the four decks in the Iowa Gambling Task. Block-wise deck A′ choices made pre-surgery, post-surgery within 1 month, and post-surgery after 12 months (top left-hand corner), similarly deck B′ choices (top right-hand corner), deck C′ choices (bottom left-hand corner) and deck D′ choices (bottom right-hand corner). Error bars show the standard error.

main effect of deck choices, there was a prominent preference for infrequent punishment decks B′ and D′ [$F(1,95) = 6.24$, $p = 0.01$]. Frequency-based preference was undifferentiated and unaffected by task trials at presurgery, and remained undifferentiated within a month of surgery but showed alteration after 1 year (see **Figure 2**).

Next, we examined if deck choices in uncertainty and risk trials vary pre and post-surgery follow-ups. To test if the two attributes were differentially sensitive to the uncertainty- and risk-related trials/phases of IGT decision making, changes in intertemporal deck choices at three assessments (pre-surgery vs. post-surgery follow up 1 vs. follow up 2) (e.g., decks A′ and B′ at pre- and post-surgery follow up at 1 month and at 12 months) were analyzed as within-subject variable and the task phase (uncertainty and risk) as the between-subject variable. Four separate analyses were performed, two for the two intertemporal deck choices (decks A′ and B′, and decks C′ and D′) and two for the two frequency-based choices (decks B′ and D′, and decks A′ and C′). There was no main effect of deck [$F(2,196) = 2.36$, $p = 0.10$] or a block × deck interaction for decks A′ and B′ [$F(2,196) = 0.41$, $p = 0.68$]. Similarly, neither a main effect of deck nor a deck × block interaction was identified for decks C′ and D′ suggesting that intertemporal choice decks of decks A′ and B′ and C′ and D′ under uncertainty and risk across surgery and the two follow up assessments remained constant. There was no main effect of frequent punishment decks, but a significant deck × block interaction for decks A′ and C′ was observed at 1 month follow up which demonstrated a postsurgical increase in the selection of frequent punishment decks (decks A′ and C′) under uncertainty but a decrease under risk [$F(1,98) = 14.33$, $p < 0.001$], which reversed after 1 year, that is, choices from frequent punishment decks decreased under uncertainty but increased under risk. For decks B′ and D′, there was a main effect of deck [$F(2,196) = 3.03$, $p = 0.05$] suggesting that compared to pre-surgery, fewer cards were drawn from these decks at the 1 month follow up, but infrequent punishment deck choices increased after 1 year of surgery. The deck × block interaction [$F(2,196) = 8.33$, $p < 0.001$] was significant, indicating a postsurgical reduction in the choice of infrequent punishment decks (decks B′ and D′) under uncertainty but an increased selection of the infrequent punishment decks under risk phase at 1-month follow up. After a year, the reverse was observed, that is, choices from infrequent punishment decks increased under uncertainty and decreased under risk (see **Figure 3**).

Next, we examined whether choice of deck B varies with task progression, and varies across the uncertainty-risk phase. To investigate frequency-based attribute, specifically the 'Deck B' preference that is observed widely in female participants (Overman and Pierce, 2013), we analyzed deck B choices (before surgery, immediately after 1 month, and after 12 months) using two separate analysis, one addressing deck B choice and the task progression (five blocks), and second addressing selection of deck B choices across two phases (uncertainty and risk). Results for task progression showed main effect of deck B [$F(2,190) = 7.66$, $p = 0.001$] suggesting that number of cards drawn from deck B increased across the three assessments;

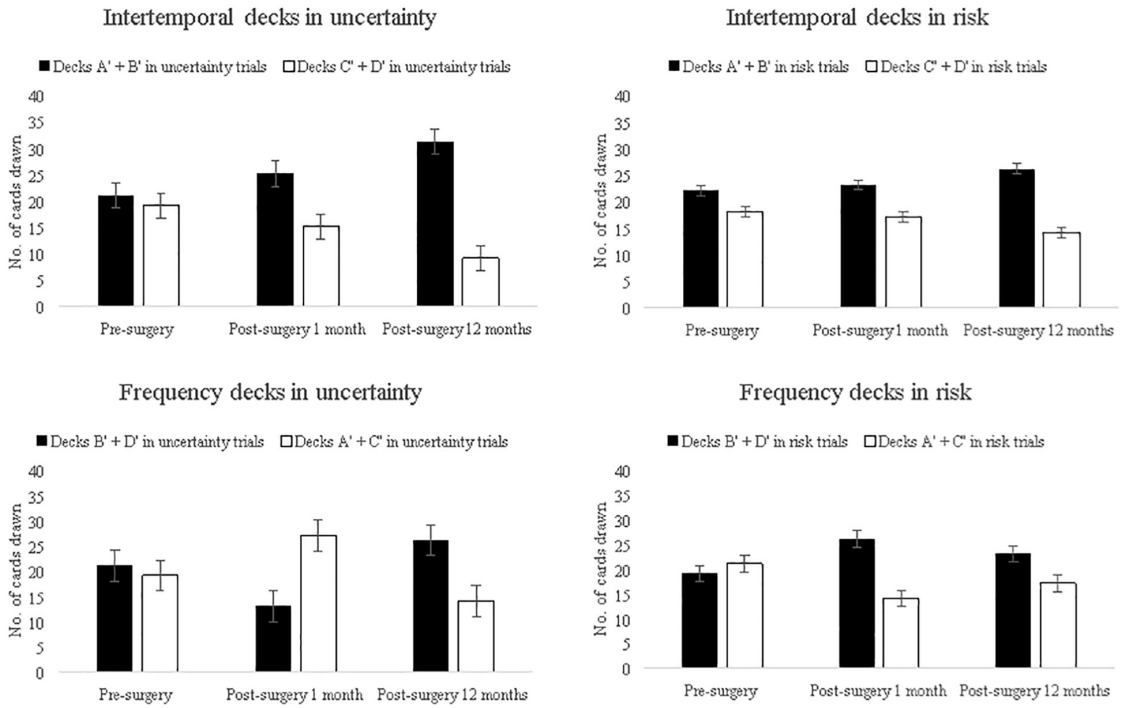

FIGURE 3 | Number of cards drawn from long-term risky decks (A′ + B′) and safe decks (C′ + D′) during uncertainty (top left-hand corner) and risk trials (top right-hand corner) before and after surgery, and number of cards drawn from infrequent punishment decks (B′ + D′) and frequent punishment decks (A′ + C′) during uncertainty (bottom left-hand corner) and risk trials (bottom right-hand corner) before and after surgery. Error bars show the standard error.

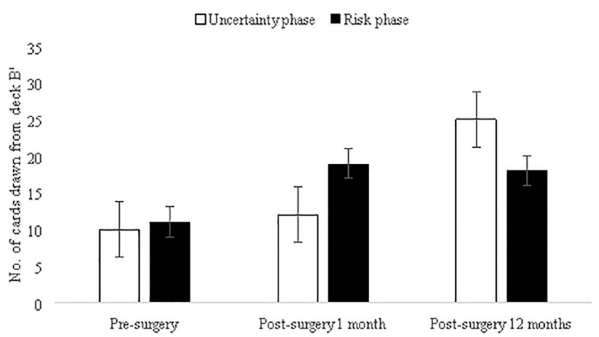

FIGURE 4 | Number of cards drawn from infrequent punishment deck B′ during uncertainty and risk trials before and after surgery. Error bars show the standard error.

non-significant interaction of deck × blocks suggests that task progression did not contribute to this increase. Results for uncertainty and risk phase showed main effect of deck B [$F(2,196) = 7.72$, $p = 0.001$], and deck × blocks interaction was significant [$F(2,196) = 3.50$, $p = 0.03$] suggested that the deck B choices varied across the three assessments in the uncertainty phase (see **Figure 4**).

Lastly, valence processing was examined using affect pictures and results showed main effect for affect ratings [$F(2,54) = 4.57$, $p = 0.02$] suggesting that affect processing altered from pre- to post-surgery follow ups, and the interaction of affect ratings and valence was significant [$F(4,54) = 3.80$, $p = 0.01$] suggesting that the affect alteration was valence-specific. Valence processing was examined using affect words and the results showed main effect of affect ratings [$F(2,54) = 24.09$, $p < 0.001$] suggesting alteration of affect processing of words across pre- and post-surgery follow ups as well as the interaction of affect ratings and valence was found to be significant [$F(4,54) = 10.35$, $p < 0.001$] suggesting valence-specific alteration in word affect processing (see **Figure 5**). Using two types of affect eliciting stimuli (pictures and words), the results suggests that affect processing altered across pre- to post-surgery assessments, and that valence contributed to this alteration in affect processing.

DISCUSSION

We first used pre-surgical neuroimaging evaluations of a patient with unilateral brain damage (left-hemispheric Rasmussen encephalitis) to ascertain (a) uni-hemispheric atrophy, (b) functional lateralization of language functions, and (c) lateralized atrophy in neural circuitry crucial to the performance of the IGT. Next, we examined cognition-intensive intertemporal and emotion-based frequency-based processing of deck choices by comparing the patient's preoperative and postoperative performances on the IGT at three assessment points: pre-surgery and post-surgery (after 30 days and after 12 months from the

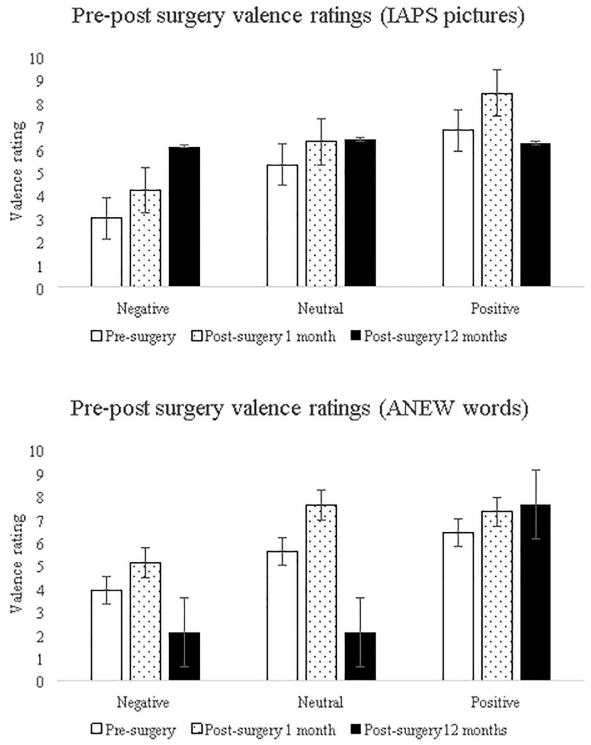

FIGURE 5 | The patient's valence-specific pre- and post-surgical affect ratings using affect-eliciting pictures (IAPS: top) and words (ANEW: bottom). Error bars show the standard error.

surgery). Additionally, we examined valence-specificity in pre- and post-surgery alteration of affect processing.

Our results showed that prior to hemispheric dissociation surgery, the patient made more disadvantageous choices, and this preference changed as the trials progressed. Within 30 days of the surgical dissociation at follow-up 1, drawing of risky decks progressed only as the task progressed, but after 1 year, more disadvantageous deck choices were observed and this preference for disadvantageous decks remained unaffected by task progression. The patient showed indifference to frequency-based deck choices prior to the surgery, and this indifference continued after 30 days of the surgery, however, frequency-based deck choice, specifically preference for infrequent punishment decks was observed after 1 year of surgery, and this preference was independent of task progression. Thus, results of the two attributes in a case of uni-hemispheric left atrophy, and pre and post-hemispheric dissociation offered an opportunity to examine the two attributes: cognition-intensive intertemporal-based decisions showed alteration in terms of its dependency on task progression at the three assessment points, whereas task-progression did not contribute to frequency-based decision making either pre- or at post-surgery.

On comparing the extent to which the two attributes respond to uncertainty and the risk phase of the IGT task, results suggests that the intertemporal choice decks (long term advantageous decks C and D, as well as disadvantageous decks A and B) in uncertainty and risk phase of the task remained un-altered after surgery, whereas the frequency-based choice decks (infrequent punishment decks B and D as well as frequent punishment decks A and C) in uncertainty and risk phase showed pre- and post-surgery alteration. As expected, phase-specificity of frequency-based choices altered pre- and post-surgery, most notably, the choice of infrequent punishment deck B in the uncertainty phase varied from pre- to post-surgery assessment. Thus, after the hemispheric-dissociation surgery, frequency-based preferences reversed in uncertainty and risk trials, and as expected, were phase-specific. These findings align with those of Besnard et al. (2015), who observed that the frequency-based choices of patients with frontal lobe damage and healthy participants differed in uncertainty trials but not in risk trials. Compared to intertemporality-based selection, frequency-based decision making may be differentially sensitive to uncertainty and risk in the IGT, and hemispheric specialization might be a potential contributor to this phase-sensitivity. Studies documenting effects of laterality of atrophy should consider both the attributes of decision making, as well as include phase-specificity into consideration because it is possible that frequency-based decision making alteration may be specific to the uncertainty vs. risk phase of the IGT, leaving intertemporal decision making unaltered across the two phases.

Together with existing data, the present findings add support to the hemispheric involvement in the IGT decision making (Clark et al., 2003; Tranel et al., 2005). For instance, lateralized sex-differences, that is male-advantage in intertemporal choices is attributed to right hemisphere (van den Bos et al., 2013) whereas the female disadvantage is attributed to usage of frequency-based processing and is linked with left-laterality (Lin et al., 2007; Overman and Pierce, 2013), the present result expand this sex-specific hemispheric role and are suggestive of further attribute, and phase-specificity in the IGT. According to the hierarchical information processing theory, the right hemisphere specializes in the processing of global features, whereas the left hemisphere specializes in local processing (Fink et al., 1996). Studies have reported that frequency-based IGT choices reflect automatic processing (Wilder et al., 1998; Stocco et al., 2009); specifically the selection of the infrequent punishment deck B recruits the left hemisphere (Lin et al., 2008). Additionally, the right hemisphere specializes in cognitive control in uncertainty (Garavan et al., 1999; Goel et al., 2007); therefore, it is possible that the intertemporal decision making in the IGT reflects right-lateralized, global processing, whereas the emotion-based automatic and local processing of frequency is left-lateralized, and probably it is the latter that is differentially sensitive to uncertainty and risk in the IGT. Therefore, the present results lend support to hemispheric specialization in the IGT intertemporal decision making (Clark et al., 2003; Tranel et al., 2005), and further draw attention to attribute, and phase-specificity potentially impacting decision making in the IGT decision making.

It was further speculated that attribute, and phase-specific alteration observed post-hemispherotomy might be linked to valence processing. As expected, affect processing (pictures and words) showed valence-specific alteration suggesting that

processing of valence (negative, neutral, and positive) was altered from pre-surgery to the two assessments carried out within 1-month and 12-month post-surgery. In line with the valence hypothesis, that is, left-lateralized positive valence processing and right-hemispheric specialization for negative valence (Davidson, 1992), post-hemispheric dissociation showed valence-specific alteration in affect processing. A recent study found that in comparison to controls, epilepsy patients showed increased affect ratings to affect pictures (IAPS), and ratings were independent of valence, however, the study recruited mixed-gender epilepsy patients (males > females) with mixed laterality (right-side patients > left) (Ciuffini et al., 2018). It is possible that altered valence-processing contributes to disadvantageous decision making in uni-lateral epilepsy patients, however, the effect of laterality in affect processing itself remains poorly understood (Hixson and Kirsch, 2009). Recently, processing of affect words (ANEW) showed valence-specific laterality in normal healthy participants (Martin and Altarriba, 2017). The implication of altered valence-processing linked with IGT decision making implies that the preference for the infrequent punishment deck B that is widely observed in females might be linked to valence-related lateralization, and potentially contributing to sex differences in attribute and phase-specificity in the IGT (i.e., emotion-based frequency attribute sensitive to uncertainty phase in females). Within the context of epilepsy, localization of language observed prior to seizure onset, during seizure, and post-seizure (i.e., pre, ictal, post-ictal) has been used for predicting epilepsy surgery outcomes. It is possible that affect-linked valence-processing and affect-guided decision making such as that observed in the IGT, could potentially serve as a lateralized constructs that can be useful in predicting the extent of decision-making deficits and quality of life outcomes in the epilepsy patients.

There were several limitations of the current study. As recommended (Fisch, 2001), single-case designs utilized visual inspections of data in combination with pre- and post-test comparisons, a larger gender-balanced sample of patients with uni-hemispheric atrophy are needed to fully examine hemispheric specialization in attribute (intertemporal vs. frequency-based) and phase-specific (uncertainty vs. risk) IGT decision making. Neuropsychological evaluations of frontal lobe-based functions (i.e., executive functions, esp. working memory) may have facilitated the interpretation of our results; however (a) the patient's incomplete neuropsychological evaluations indicate the presence of cognitive impairment, which is a hallmark of drug-refractory Rasmussen encephalitic epilepsy (b) the patient's emotion/affect processing, and affect-aided decision making that is independent of cognitive resources (i.e., independent of cognitive impairment), is the focus of this investigation. Similarly, the current study did not evaluate mood, which could have impacted performance. Future studies should employ neuroimaging during the IGT to identify the neural circuitry recruited by patients with lateralized hemispheric damage both before and after surgery. We expect that this first IGT study of pre and post-hemispheric dissociation will give way to future studies that will identify potential cerebral specialization in the IGT decision making, after accounting for executive functions such as working memory resources.

CONCLUSION

Evaluating decision making in a female patient with uni-hemispheric atrophy in the language-specialized left-hemisphere across hemispheric disconnection, this single-case study improves our understanding of the potential hemispheric specialization for intertemporal- and frequency-based decision making during two phases of the IGT (uncertainty and risk). Sex differences in the IGT have been attributed to greater right lateralization of intertemporal decision making in men, and left lateralization and preference for infrequent punishment decks in females (Tranel et al., 2005; van den Bos et al., 2013). Preoperative preference for infrequent punishment decks was absent in this female patient with left hemispheric atrophy, but we observed this preference to increase post-surgery, and we further observed that this preference is prominent in the uncertainty phase of the IGT, possibly due to uncertainty phase characterized by valence. Even though our results contribute to the understanding of right-lateralization and sex differences in the IGT, male–female comparisons between the IGT performance done before and after hemispheric dissociation are needed to test this assumption.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Written informed consent was obtained from the individual for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

VS conceived and carried out the study. KC and SK carried out the brain imaging and analysis. MT and SC performed the diagnosis, surgery/treatment and planned the follow ups. All authors had equal contribution.

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MINI REVIEW
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Electrophysiological Measurement of Emotion and Somatic State Affecting Ambiguity Decision: Evidences From SCRs, ERPs, and HR

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Twenty-three years ago, the Somatic Marker Hypothesis (SMH) proposed by Damasio was introduced to explain the role of emotion in decision-making, and provided a unique neuroanatomical framework for decision-making and its influence by emotion. The core idea of the SMH is that decision-making is a process that is affected by somatic state signals, including those that express themselves in emotion and feeling. In order to verify the SMH, the Iowa Gambling Task (IGT) was originally designed by Bechara et al. and the skin conductance responses (SCRs) was recorded during the IGT. The initial confirmatory results showed that normal subjects would generate anticipatory SCRs when they received reward or punishment, but patients of the VMPFC lesion entirely failed to generate anticipatory SCRs prior to their selection of a card. With the further development of the SMH–related researches, other electrophysiological methods of measuring somatic state was gradually used to test the SMH, including event-related potentials (ERPs), and heart rate (HR). In this mini review article, we summarize the extant electrophysiological research on the SMH and decision-making under ambiguity, propose an integrative perspective for employing different electrophysiological measurement methods, and indicate the application of electrophysiological measurement based on the SMH in daily social decision-making.

Keywords: somatic marker hypothesis, Iowa gambling task, skin conductance responses, event-related potentials, heart rate

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INTRODUCTION

Emotion is considered a destructive factor in the cognitive process for a long time (Reimann and Bechara, 2010). However, twenty-three years ago, neuroscientist Antonio Damasio proposed the Somatic Marker Hypothesis (SMH) and introduced it to explore decision-making under ambiguity (Bechara et al., 1994; Damasio, 1994). The positive role of emotions in the decision-making process is gradually being valued by researchers. The consensus reached in previous studies is that emotions unrelated to current decision-making tasks can interfere with the decision-making process. But emotions related to current tasks, especially in complex decision-making under ambiguity, can guide decision makers avoid disadvantageous choices or situations and instead consider advantageous choices or situations (Bechara and Damasio, 2005). The SMH suggested

that positive or negative emotional responses from external or internal stimuli can activate changes in the peripheral and central nervous systems of somatic, producing positive or negative somatic markers (e.g., heart rate, blood pressure, heart rate) that characterize emotional and emotional responses, and then guiding decision making. Whether you realize it or not, the somatic markers will always affect the decision-making at the unconscious level (Reimann and Bechara, 2010).

In order to simulate ambiguity decision scenarios in real life and further validate SMH through empirical research, Bechara et al. (1994) developed the Iowa gaming task (IGT). In this task, the size and probability of win and loss are systematically manipulated (Bechara et al., 1994, Bechara et al., 2000). Participants were asked to repeatedly pick up a card from the four decks representing different amounts for 100 trials, and then feed back the results of the selection (gain or loss). The ultimate goal was to obtain most gain or least loss. The two disadvantageous decks have a high immediate reward and also give higher levels of punishment (so leading to a net loss every 10 trials), whereas other two advantageous decks have low immediate reward and also give lower levels of punishment (so leading to a net gain every 10 trials). Participants only know that there are two advantageous decks and two disadvantageous decks, but they do not know which decks are advantageous or disadvantageous and the probability of loss or gain in these decks. Healthy participants must undergo a long process of exploration and step-by-step learning during the IGT (Bechara et al., 1996; Chiu et al., 2008). In this process, somatic markers generated by emotional components help to predict long-term positive or negative outcomes, especially before conceptualized explicit knowledge has been developed. Eventually, decision makers are shown a preference for advantageous decks than disadvantageous decks. However, some participants(e.g., patients with ventrolateral medial prefrontal cortex damage) always have difficulty making the right decisions, Even though they obtained conceptualized explicit knowledge in the later blocks of the IGT. Due to the lack of emotional-related somatic signals caused by damage to the medial prefrontal cortex, they were affected by short-term interests and still showed stubborn preference for advantageous cards, which ultimately led to poor performance in the IGT (Giustiniani et al., 2015).

Damasio first used the multichannel physiological recorder to measure the skin conductance response (SCRs) of participants in the IGT as a index of somatic markers, and thus explored and verified the physiological basis of the SMH. With the development of cognitive neuroscience technology, researchers began to explore the neural basis of the SMH with brain imaging techniques such as Functional Magnetic Resonance Imaging (fMRI) (Ernst et al., 2002). Neuroimaging studies of the SMH confirmed two key structures that triggers somatic markers. The first category is called the primary inducers, which is the somatic markers that triggers the amygdala produced by emotional events in the external environment; The second category is secondary inducers, which is the somatic markers that triggers the orbital frontal cortex (OFC) and the ventromedial prefrontal cortex (VMPFC) produced by information in memory, knowledge, and cognition (Bechara and Damasio, 2005). VMPFC and OFC are believed to be the core brain regions of the SMH, which can integrate emotional-related somatic signals from the periphery to the central nervous system to regulate and monitor cognitive processes of decision-making (Damasio, 1994, 1996). In addition, the neural structures of the SMH also include somato sensory and Island cortex, as well as the peripheral nervous system. The results of brain imaging studies provide support for further exploration of the physiological basis of the SMH. Subsequent researchers began using EEG and ECG as a complement to brain imaging and SCRs research. From the existing research, SCRs, EEG and ECG can quantify the emotional and feeling responses related to decision-making, which help to reveal the relationship between emotion-related somatic signals and decision-making, and is the most extensive physiological indicator for studying on SMH and ambiguity decision. However, there are still many controversies in the existing research results (see **Table 1** and Wong et al., 2011; Chiu et al., 2018), and SMH has been questioned by many researchers. Therefore, the current study intends to review the existing research on the influence of the SMH on the IGT performance from three aspects of SCRs, EEG and HR, try to reveal the causes of inconsistent results, and explore propose possible future research directions. We hope to provide a basis for more accurately and completely revealing the neurophysiological mechanism of SMH.

ELECTROPHYSIOLOGICAL INDICATORS OF SMH

Skin Conductance Responses

Skin Conductance Responses (SCRs) are the most commonly used indicators for measuring emotion-related somatic markers in ambiguity decisions, which is to measure the electrical conductivity of the skin by applying a small constant voltage between the two points of the skin (Park, 2009). When the participants are stimulated to cause an emotional response, the electrical conductivity will change significantly (Boucsein, 2012). The higher the level of emotional initiation, the stronger the SCRs. In the IGT, researchers often focus on SCRs in two time periods: (1) The anticipatory SCRs before selection reflect the expected assessment of the outcome in subsequent decision. (2) The reactive SCRs in the feedback phase reflect the evaluation of the feedback outcome. Because SCRs have an latency period of 2–3 s. Therefore, the time window for reactive SCRs is generally set to 5 s after feedback, the time window of anticipatory SCRs is set to 5 s before selection, and the interval between two trials is set to 6 s (Bechara et al., 2000). Healthy participants showed higher sympathetic excitation and SCRs prior to select disadvantageous decks rather than advantageous decks (Bechara and Damasio, 2002; Bechara et al., 2002). This increase in anticipatory SCRs will unconsciously guide participants to avoid disadvantageous decks and select advantageous decks in subsequent decisions before forming conceptualized conscious knowledge (Bechara et al., 1996, 1997).

The early evidence for the SMH is mainly from clinical studies of the patients with VMPFC or amygdala damage but maintaining a normal intellect. These clinical studies have shown

TABLE 1 | Main electrophysiological studies on decision-making under ambiguity in our review.

Authors	N	Participants	Task	Index	Electrophysiology Results
Bechara et al., 1996	19	12 healthy participants;	IGT	SCRs	•Healthy subjects generated an anticipatory SCRs prior to their selection of a deck. •Patient did not produce a similar anticipatory SCRs.
		7 patients with prefrontal damage	100		
Carter and Pasqualini, 2004	30	Healthy women	IGT	SCRs	•The amount of money gained and mean anticipatory SCRs were positively correlated. •No relationship was found between reactive SCRs and either reward or punishment.
			100		
Ottaviani and Vandone, 2015	445	Experts in economics and finance	IGT	SCRs	•The anticipatory SCRs during the first 40 trials were negative significant predictors of insurance purchase.
			100		
Mardaga and Hansenne, 2012	32	Healthy participants	IGT	SCRs	•More anticipative responses are recorded before disadvantageous than advantageous deck picking.
			100		
Fernie and Tunney, 2013	32	Post-graduate students	IGT	SCRs	•Most participants had knowledge sufficient to guide behavior after approximately 40 trials. •Their not find anticipatory physiological activity sufficient to differentiate between deck types in the period prior to acquiring this knowledge.
			100		
Gutbrod et al., 2006	19	8 healthy participants	IGT	SCRs	•Healthy participants acquired a preference for advantageous choices and generated large SCRs to high levels of punishment.
		11 patients with memory impairment	100		•The anticipatory SCRs to disadvantageous choices were larger than to advantageous choices. •This dissociation occurred much later than the behavioral preference for advantageous alternatives
Bianchin and Angrilli, 2011	16	Healthy men	IGT	ERP	•A greater negativity activated before picking from disadvantageous decks than advantageous desks in the right frontal sites. •N260 showed a significant Feedback effect, in which participants showed greater positivity for gains than for losses.
			150		
Giustiniani et al., 2015	20	Healthy subjects	IGT	ERP	•P200 was more positive for the favorable group than for the undecided group regarding the frontal electrodes, and P300 was more positive after a loss only in the favorable group. •Before choosing a disadvantageous deck, a more negative potential was present in the emotion-related right frontal sites.
			200		
Tamburin et al., 2014	48	24 normal subjects; 24 patients with cLBP	IGT	ERP	•The FRN amplitude in the Fz channel was higher to wins than losses in controls, while the opposite happened in patients.

(Continued)

TABLE 1 | Continued

Authors	N	Participants	Task	Index	Electrophysiology Results
			100		
Jang et al., 2012	13	Healthy students	IGT	ERP	•Greater FRN amplitudes were elicited in "loss" than "win" conditions. •Significant negative correlation between FRN amplitude and total number of selected advantageous deck was observed.
			300		
Di Rosa et al., 2017	36	21 were assigned to the younger group, 15 participants formed the older group	IGT	ERP	•The P300 amplitude was significantly reduced after negative feedback in older adults, compared with the younger ones. •The difference between the P300 amplitude elicited after positive and negative feedback was significantly larger in older than in younger adults, and this same difference is positively correlated with age.
			100		
Dong et al., 2016	34	17 high group participants (7 males, 10 females) and 17 low group participants WCST	IGT	ERP	•The P300 recorded from central and parietal regions when a bad deck appeared was larger in the high group participants than in the low group participants.
			600		•Losses evoked a larger FRN than wins in the high group, but the opposite result was found in the low group.
Schutter et al., 2004	18	Healthy participants	IGT	EEG	•Relative enhancement of resting alpha levels in the left prefrontal cortex (PFC) compared to the right hemisphere is associated with poor performance in IGT.
			100		
Giustiniani et al., 2019	20	Healthy participants	IGT	EEG	•The unilateralization of the resting alpha level of PFC is only related to risky behavior and has no direct relationship with performance in IGT.
			200		
Balconi et al., 2014	31	17 high reward sensitivity participants	IGT	EEG	•Compared with low reward sensitivity group, high reward sensitivity group have a less-sided alpha power, that is more left activity when selecting unfavorable cards.
		14 low reward sensitivity subjects	100		
Crone et al., 2004	96	Healthy students	IGT	SCRs	•Only performance group produced a larger SCRs before disadvantageous choices compared with advantageous choices. •SCRs rose following punishment in all samples.
			100	HR	•Only performance group produced a slower HR before disadvantageous choices compared with advantageous choices. •The main effect of feedback is significant which indicated that HR slowed down following punishment in all samples.
Lee et al., 2010	28	Healthy students	IGT	HR	•Subjects tended to make bad decisions rather than good decisions when the anticipatory HR slowed down.
			100		

Each line refers to authors, index, the number of participants and major findings of the study.

that the anticipatory SCRs will affect the patient's performance in the IGT (Bechara et al., 1994, Bechara et al., 1996, 1999, 2000). Subsequent researchers have further expanded their research areas, mainly involving material addict, non-material addict, neurological and psychiatric patients, patients with hippocampus damage, and parkinson's patients (Manes et al., 2002; Mapelli et al., 2014). The results of those studies are basically consistent with the conclusions of brain imaging studies. Individuals whose emotion-related brain regions are damaged are unable to produce anticiptory SCRs that characterize long-term negative outcomes in decision-making, which leads to impaired decision-making ability. Even if they gain conceptualized explicit knowledge, they are still stubborn in their preference for disadvantageous options (Giustiniani et al., 2015).

Simonovic et al. (2019) conducted a comprehensive mate analysis of the relationship between IGT performance and aSCR of healthy participants in existing studies, which provides an important basis and direction for future research on SMH and SCRs. Based on the effect sizes, author found that 11 studies reported overall aSCR correlates with successful performance on the IGT was small, significant differences, and 4 studies found medium and large effect sizes. The results show that the performance of healthy participants in IGT is closely related to aSCR. However, research on the relationship between aSCR and IGT success remains inconsistent over the past two decades. Mardaga and Hansenne (2012) found that the level of aSCRs of healthy participants positively predicted IGT performance. Similar research also found a significant positive correlation between IGT performance and overall aSCRs of healthy participants (Carter and Pasqualini, 2004; Wagar and Dixon, 2006; Guillaume et al., 2009; Werner et al., 2009; Miu et al., 2012), which indicates that overall aSCRs represent a good somatic signal. Larger good somatic signals will guide participants in subsequent decisions and lead to IGT success. However, the research by Ottaviani and Vandone (2015) gave the opposite result, they found that aSCRs reversely predicted IGT performance of healthy participants. That is to said, overall aSCRs represent a bad signal. Participants producing larger aSCRs will lead to worse IGT performance. This may be because two-thirds of the participants in this study were experts in economics and finance. Experts in economics and finance may perform differently than others in economic decision-making. In other studies, participants were generally not allowed to be professionals in economics and psychology.

In addition, whether there is a causal relationship between the success of IGT and aSCRs is also questioned. Some studies suggest that aSCRs represent a better IGT performance, but the success of IGT and aSCRs is caused by conscious knowledge (Maia and McClelland, 2004; Wagar and Dixon, 2006; Guillaume et al., 2009). For example, Fernie and Tunney (2013) found that participants had sufficient knowledge of task accidents to guide behavior after about 40 trials. Although the enhancement of aSCRs signal represents a better IGT performance, the relationship between aSCRs and IGT performance was not found until sufficient conscious knowledge was generated. Gutbrod et al. (2006) also found that preference for favorable cards appeared before the differences in aSCR occurred. These studies show that aSCR and IGT success are related, but may not be causal, and the enhancement of aSCRs signal may not be a necessary condition for IGT success. Conversely, some studies have found that healthy participants generate larger SCRs in the face of negative feedback during the feedback phase, which may guide the participants' decisions in IGT. And when participants learn of such unexpected events, feedback on SCRs becomes less important (Suzuki et al., 2003; Wright et al., 2017). This indicates that healthy participants may have learned about IGT based on card feedback. Once conceptualized knowledge is formed, they can ignore somatic signals and directly guide subsequent decisions. These inconsistent findings may be due to their differences in IGT design. For example, compared to Fernie and Tunney (2013) and others' studies, Bechara's series of studies are more obscure in measuring conceptual knowledge. In addition, most of the samples in the existing studies are relatively small, which may lead to interference factors such as gender, age, personality, and cognitive abilities. Based on the existing research, we can speculate that there may be an interaction on the time axis between SCR, conscious knowledge about IGT, and IGT success. In the early days of IGT, feedback SCR was the main somatic signal that guided healthy participants to develop unconscious knowledge of each card (within 30 trials). Subsequently, the unconscious knowledge of the card will cause the expected somatic signal (aSCR) before the card selection, forming a "hunch" that guides decision-making at the unconscious level, and will also gradually form the conceptualization of IGT (10 to 80 trials). At this time, aSCR and conceptualized conscious knowledge may be a mutually reinforcing relationship. When conceptualized knowledge is formed (60 to 100 trials), healthy participants can use conceptualized knowledge to guide decision-making. At this time, aSCR signals and feedback SCR signals are no longer important, but may still exist. Future research should increase the number of subjects, control the individual differences of the subjects, optimize the experimental design as much as possible (e.g., increase the sensitivity of IGT knowledge measurement), and conduct a more detailed analysis of each block to validate the timeline relationship between SCR, conceptual knowledge, and IGT success.

It is doubtful whether the enlargement of an absolute somatic marker can guide decision-making. It is important to select whether there is a difference between aSCRs before favorable cards and unfavorable cards. Previous studies have found that as IGT trials progress, healthy participants gradually gain a preference for favorable choices, and their aSCR for unfavorable cards is significantly greater than that for favorable cards (Bechara et al., 1996, 1999; Bechara and Damasio, 2002; Crone et al., 2004; Gutbrod et al., 2006; Wagar and Dixon, 2006; Guillaume et al., 2009). This is consistent with the original hypothesis of SMH (Damasio, 1994). However, a review by Simonovic et al. (2019) found that the difference in aSCR between favorable and unfavorable cards was less significant. Furthermore, in many existing studies on SCR and SMH, researchers have reported overall aSCRs, but have not reported detailed differences in aSCRs between favorable and unfavorable cards (Simonovic et al., 2019). This suggests that some authors may have problems with publication bias. In addition, SCR is affected by the activation

of neuropsychological, behavioral, and inhibitory systems that involve responses to punishment and frustration (Fowles, 1988). SCR is also related to the advantages of card selection and the successful execution of tasks (Denburg et al., 2006; Hinson et al., 2006). Therefore, future research requires more repetitive research on the difference between aSCRs for favorable and unfavorable cards.

Furthermore, disputes about SMH and SCRs have always existed (Chiu et al., 2018). include: (i) The reason for the increase in SCRs is not clear, it may be due to loss (Bechara and Damasio, 2002) or win (Tomb et al., 2002), or caused by the probability or magnitude of win or loss (Wilder et al., 1998; Shurman et al., 2005). For example, Chiu et al. in their series of studies found that healthy participants' decisions in IGT are related to the profit and loss probability of cards, and healthy participants show a persistent preference for unfavorable cards B with low loss frequency. However, the series studies did not record details of aSCRs. (ii) There may be multiple mechanisms that regulate both IGT performance and anticipatory SCRs production. Anticipatory SCRs may only be a part of the decision outcome, not the cause. Existing studies cannot confirm the causal relationship between anticipatory SCRs and task performance. (iii) Due to the relatively slow time course of SCRs signals, it is difficult to separate reactive SCRs and anticipatory SCRs in the next trial, which leads to a drop in the accuracy of the results (Amiez et al., 2003). In sum, IGT performance is significantly correlated with expected SCRs, but future research still requires more ingenious experimental design and careful analysis to support the SMH, and electrophysiological measures with high temporal resolution (e.g., EEG, HR) will be complementary to SCRs.

Event-Related Potential

Electroencephalography (EEG) has higher temporal resolution, which provides direct access to neuronal signals compared with SCRs, and measured by Event-related Potential (ERP) (Michel and Murray, 2012). Therefore, researchers have shifted their focus to using EEG to record somatic signals in ambiguity decision making in recent years. Similar to SCRs, EEG research also focuses on the physical responses in the two stages of before selection and after feedback. Common ERP indicators include Decision Preceding Negativity (DPN), P300, and P200, P300, and feedback-related negativity (FRN) after result feedback. DPN generally selects the negative wave in the 0-500ms time window before the decision (Bianchin and Angrilli, 2011), which reflects expectations of card outcomes (Bianchin and Angrilli, 2011; Cui et al., 2013; Giustiniani et al., 2015). P300 before decision-making is a forward wave that peaks at a time window of 350-500ms after the stimulus appears (Maurage et al., 2007; Kraus and Horowitz-Kraus, 2014), and is a sign of attention and working memory. P200 and P300 in the feedback phase are late positive waves appearing in the time window of 150∼250 ms and 250∼600 ms after the feedback result, whose average latency is about 200 ms and 300 ms, respectively. P200 is generally considered to be an early evaluation of the results, using a binary classification method with good or bad results (Gehring and Willoughby, 2002; Hajcak et al., 2006; Schuermann et al., 2012). P300 reflects performance monitoring and behavioral adaptation (Schuermann et al., 2011; Cui et al., 2013; Ferdinand and Kray, 2013). This process is related to both the potency and size of the feedback (Ferdinand and Kray, 2013). FRN is a negative wave that appears during 200 ∼ 350 ms after the feedback result is presented (Wang et al., 2016), which reflects the early feedback evaluation of a binary good and bad classification, the degree of violation of the subject's expectations (Alexander and Brown, 2011; Schuermann et al., 2011), and the process of implicit learning through feedback (Cui et al., 2013; Balconi et al., 2015).

Electroencephalography study using ERP technology to explore SMH found that, compared to favorable cards, unfavorable cards would induce greater pre-decision P300 and DPN. Cui et al. (2013) found that healthy participants induced greater DPN amplitude before choosing unfavorable cards (compared to choosing favorable cards). Furthermore, healthy participants with a higher average amplitude of overall DPN performed better in IGT. In addition, Bianchin and Angrilli (2011) found that the DPN difference between unfavorable and favorable cards was unilateralized in the brain area, and only appeared in the right prefrontal cortex. This is consistent with the results of previous brain imaging studies. Activation of the right prefrontal cortex has important roles in emotional expression (especially negative emotions) and control (Coan and Allen, 2003; Wager et al., 2008). These studies show that the somatic signals generated by the activation of the right prefrontal cortex can help participants' learning process and guide participants to avoid adverse cards in subsequent decisions. However, Giustiniani et al. (2015) suggested that DPN may not be a key factor influencing whether healthy participants can perform well in IGT, and DPN amplitude cannot predict participants' performance in IGT in their study. The reason why the two come to different conclusions may be due to different experimental paradigms. The participants need to make a play / pass decision on one of the four decks preselected by the computer on each trial in the study by Cui et al. (2013), where participants' DNP reflects the EEG response caused by a particular card. The study by Giustiniani et al. (2015) is a standard IGT computer version, which participants are free to choose cards among four non-different cards. Four simultaneous non-different cards will attract participants' attention, which may lead the DPN amplitude change caused by the final selected card is covered up. ERP research in the feedback stage found that participants produced ERP components (FRN, P200 and P300) with different amplitudes when facing positive and negative feedback. The difference in the amplitude of these ERP components in the two feedback situations can guide participants to correctly distinguish favorable and unfavorable cards in subsequent trials, so as to have better performance in IGT. However, previous studies have failed to reach a consistent conclusion. Jang et al. (2012) found that compared to positive feedback, negative feedback produces a larger amplitude FRN, which showed that FRN reflects ACC activities

related to the evaluation of positive and negative feedback results. Moreover, there is a significant correlation between FRN amplitude and IGT performance, which indicates that the evaluation process reflected by FRN can be used to adjust subsequent decision-making behaviors. Subsequent research also found that the FRN amplitude difference during positive and negative feedback remained stable over age (Di Rosa et al., 2017). However, Tamburin et al. (2014) found that positive feedback produced a slightly larger FRN amplitude of the healthy control group than negative feedback, but the difference was not significant. The opposite happened in chronic low back pain (cLBP) patients, and the FRN amplitude in negative feedback was significantly higher than that in positive feedback. The authors believe that clbp patients seem to invert the correct placement of feedback according to the good vs. bad outcome basic classification. The absence of FRN effect in the healthy control group may be due to the inclusion of some relatively older participants in the control group (West et al., 2014), or the personality profiles and / or genetic variables (Mueller et al., 2014), and may be affected by unmeasured reward sensitivity (Balconi et al., 2015). It may also be because there is a slight difference in the IGT of the two studies. In the Tamburin et al. (2014) task, participants were told that there were two good cards and two bad card, which lead healthy participants gaining a part of the knowledge about IGT cards in advance, and there was some psychological preparation in evaluating the results of positive and negative feedback, so there was no significant difference in EEG activity. But Jang et al. (2012)'s study did not report whether participants were informed of this information.

Tamburin et al. (2014) found that the P300 amplitude of healthy participants during positive feedback was significantly greater than the P300 amplitude of negative feedback. This indicates that P300 is a kind of positive feedback (that is, the amplitude of the positive feedback is greater than the negative feedback), which reflects the realization of the expected goal (Ferdinand and Kray, 2013). Therefore, the study showed that at an advanced stage of outcome processing, healthy participants were able to distinguish between positive and negative outcomes, using the experience of previous trials to guide subsequent decisions. However, Giustiniani et al. (2015) found that, compared to positive feedback, healthy participants who formed a successful strategy in IGT had stronger activation of the frontal medial gyrus when processing negative feedback, and produced a larger P300 amplitude. The discrepancy between the results of the two studies may be due to the difference in the research paradigms adopted by the two studies. In the study of Tamburin et al. (2014), the number and potency of the feedback results were presented simultaneously, while in Giustiniani et al. (2015)'s study, the card amount was presented before feedback on the potency. The P300 in the feedback may not only reflect the card's potency, but may also be motivated by the card amount presented in advance. Moreover, healthy participants were further subdivided into forming a successful strategy group, an unsuccessful strategy group and an undecided group in the study by Giustiniani et al. (2015). Differences within the healthy participant group are frequent, and studies have reported a failure rate of 55% of IGT in healthy people (Mapelli et al., 2014). Therefore, future research should be further subdivided into groups based on the performance of healthy participants to conduct more detailed analysis.

In addition, existing studies have also found that somatic signals are also reflected on the EEG spectrum. For example, alpha activity is considered to be a measure of the inactivity of the cerebral cortex and can provide information about the state of brain activation in the opposite way (Harmon-Jones and Allen, 1997; Cooper et al., 2003), and IGT is sensitive to tonic / stable physiological and psychological correlates of personality. Therefore, alpha activity has also become a potential indicator for measuring SMH. Schutter et al. (2004) found that the relative enhancement of the resting alpha level of the prefrontal cortex (PFC) in the left hemisphere was associated with poor performance in IGT compared to the right hemisphere. Because alpha is a counter-indicator, the study suggests that the unilateral advantage of right hemisphere activation can lead to the failure of IGT. This is in contradiction with the traditional emotional electrophysiology model, that is to said, the processing of punishment and reward is considered to be right-side and left-side of PFC, respectively. This may be because the explanation of PFC unilateralization did not take into account the psychological activities involved, nor did it take into account the differences between actions in preparation and execution. Moreover, Giustiniani et al. (2019) research found that the unilateralization of the resting alpha level of PFC was only related to risky behavior, and not directly related to IGT performance. Therefore, whether the resting alpha level can be used as an indicator of somatic signals still needs further investigation. However, the discussion of the relationship between resting alpha level and IGT can reveal individual differences in the IGT, which helps explain some inconsistent conclusions in existing studies.

Previous studies have found that ERP components in the IGT are affected by many factors, such as cognitive ability, working memory, cognitive load, and reward sensitivity. Dong et al. (2016) found that, compared with the low cognitive ability group, the high cognitive ability group showed a larger amplitude of P300 within the time window of stimulus lock time, which may be caused by the low cognitive and abstract generalization ability and working memory ability of the low cognitive ability group, which can not form a physical signal to guide decision-making. In addition, the high cognitive ability group had a more negative DPN when selecting pass than play, while the low group showed stronger DPN amplitude for play, which indicates that the high cognitive group is more inclined to explore the rules of the card, so they tend to "play" to identify the rules as quickly as possible. In the feedback evaluation phase, compared with positive feedback, the high cognitive ability group caused a larger FRN during positive feedback, while the low cognitive ability group had the opposite result. This is because FRN is more sensitive to loss. The high cognitive ability group can conduct implicit learning

through feedback results, while the low cognitive flexibility group has defects in feedback learning and concept formation, which leads to the lack of FRN effect. In addition, Balconi et al. (2014) used alpha band modulation to measure the IGT performance of individuals with different reward sensitivities. They found that compared with individuals with low reward sensitivity, individuals with high reward sensitivity produced a less-sided alpha power, that is more left activity when choosing a disadvantaged card.

Age also affects participants' IGT performance and their brain activity. Di Rosa et al. (2017) found that compared with positive feedback, young people had greater P300 amplitudes when negative feedback, while older people had the opposite result. Older people seem less willing to shift their attention from positive to negative feedback during the feedback phase, which may be the reason for their poor performance on the IGT. As Frank and Kong (2008) argues that performance at probabilistic selection tasks like IGT reflects individual set-shifting ability, i.e., the capacity to shift the focus of attention among stimulus dimensions, while relying on reinforcement to guide decisions. However, the study did not find that age has an effect on the early components of feedback processing (FRN), which suggests that aging may affect only the later stages of feedback processing (P300), but has no effect on the early stages (FRN).

Heart Rate

Heart rate (HR) is another important indicator for measuring SMH. The main advantage of HR is that HR is jointly regulated by the sympathetic nervous system and the parasympathetic nervous system compared to SCRs. Conversely, due to the sweat glands do not have parasympathetic involvement, SCRs only reflects the sympathetic nervous system response. Therefore, the measurement of HR can reflect a situation when parasympathetic nerve activity changes while sympathetic nerve activity remains unchanged (Mark et al., 1985; Hampton et al., 2007). The main measurement methods of HR are electrocardiogram (ECG) and pulse oximetry. The results measured by these two methods are highly correlated (Giardino et al., 2002; Selvaraj et al., 2008). Due to the high temporal resolution of the ECG, it can provide very accurate continuous HR information. Therefore, ECG is widely used in clinical practice and scientific research, especially in the analysis of heart rate variability (HRV). The pulse oximetry measures the pulsation waveform of the internal finger artery by calculating the penetration of red light and infrared light in the finger, thereby measuring the continuous HR. The pulse oximetry has the advantage of being safe and simple. However, the accuracy of pulse oximetry for measuring HR is relatively low compared to ECG (Wong et al., 2011).

Anticipatory HR slows down when individuals are prepared to deal with offensive or threatened events (Somsen et al., 1983). Similar conclusions have been found in research on the IGT. Crone et al. (2004) found that participants who performed better had a slower anticipatory HR before choosing a disadvantageous decks than choosing an advantageous decks in the IGT. Participants whose anticipatory HR has no significant difference between choosing a disadvantageous decks and advantageous decks performed poorly in the IGT. Lee et al. (2010) also found that participants' anticipatory HR changes are related to subsequent different types of decisions. When anticipatory HR is slower, participants are more inclined to make disadvantageous decisions than to make advantageous decisions. It can be seen that anticipatory HR is a relatively stable somatic signal, which can predict and explain the performance in the IGT. When a disadvantageous choice causes a slower anticipatory HR, then an evasive signal is formed that directs the participant to avoid disadvantageous choices in subsequent decisions. In addition, Miu et al. (2008) have explored the effects of anticipatory HR on the IGT performance in individuals with different trait anxiety. They found that compared with low trait anxiety individuals, anticipatory HR of high trait anxiety individuals before choosing disadvantageous decks would decrease significantly in the IGT, which makes it difficult for high trait anxiety individuals to distinguish between disadvantageous and advantageous decks. This result is consistent with the poor performance of high trait anxiety individuals in the IGT. The study of the feedback results found that HR of outcome feedback was significant, whether performing well, medium or poor in the IGT. This indicates that the change in HR caused by the feedback result may only be an autonomous reaction to the different valence of the results, which cannot provide favorable guidance for subsequent decisions (Crone et al., 2004).

However, although the main measurement method of HR, ECG, has higher temporal resolution and sensitivity than SCRs. However, the usage rate of HR is still relatively low in the study of emotional influence decision-making. This may be due to the limitations of HR measurements. For instance, ECG is similar to SCRs measurement, requiring electrodes to be placed on the participant's arm, which results in HR accuracy being affected by arm activity (Park, 2009). The pulse oximetry measures HR through pulsating waveforms, and there are more possible influencing factors (e.g., heat loss and vasoconstriction), so the accuracy is relatively poor. Future research should be combined with other electrophysiological techniques to compensate for the inadequacies of HR measurements to better reveal and explain the impact of emotions on decision making.

In addition to the three main somatic signals of SCRs, ERP and HR, which can explain the impact of emotions on ambiguity decisions. Other biological states (e.g., endocrine and immune responses) can also have an impact on decision making. Therefore, electrophysiological measurements of emotion and body state also include pupils, blood pressure, and neurotransmitters such as DA, 5-HT, NA, and Ach, which also have a large potential for application. Researchers have begun to do some exploratory research. For example, Bierman et al. (2004) use eye tracking to explain the process associated with the generation of somatic marker signals. The pupil dilation was found to be a physical signal that predicts IGT performance. When the participant looked at the last card on the unfavorable card, the pupil dilation predicted a poor overall IGT performance, while pupil dilation on gaze at the last favorable card predicts better overall IGT performance (Simonovic et al., 2017). Byrne et al. (2015) found that blink

rate promoted the success of depression in patients with IGT. In addition, neurobiochemical studies have found that the activity of its neurotransmitter noradrenaline is also related to ambiguity signaling (Lavin et al., 2014), and high baseline levels of cortisol (a steroid hormone related to fear and behavioral inhibition) predict participants' success on the IGT (Van Honk et al., 2003).

CONCLUSION

A Combination of Multiple Electrophysiological Measurement Techniques

After more than two decades of development, the use of electrophysiological techniques to measure emotion-related somatic signals has become an important method for exploring the neurophysiological mechanisms of ambiguity decision making. However, as mentioned above, many existing studies based on an electrophysiological technology have found some inconsistent conclusions due to their limitations. To date, few integrated studies have used multiple measurement techniques. In fact, the several main electrophysiological techniques have their own advantages and complementarity. If two or more of these measurement techniques are combined, it will help to complement and compare the indicators. For example, SCR is a long time course index in seconds, while ERP is generally a high time sensitivity index within 1 s. At the same time, measurement of SCR and ERP can obtain a complete somatic signals on the time course. as mentioned earlier, HR is regulated by the sympathetic nervous system and the parasympathetic nervous system, while SCRs reflect the response of the sympathetic nervous system (Mark et al., 1985; Hampton et al., 2007). Therefore, if SCRs and HR are measured at the same time, it will provide empirical support for the differential response and interaction of the sympathetic and parasympathetic nervous systems in the decision-making process, and also help to explain the impact of emotions on ambiguity decisions more comprehensively. Moreover, SMH is a neural framework that contains many different neural processes involved in the decision making process. Different types of electrophysiological indicators such as ERPs and SCRs are only one part of them, and the relationship between these indicators is not clear. For example, SCRs are controlled by the peripheral nervous system. ERPs mainly measure EEG activation in the cerebral cortex such as VMPFC, while VMPFC is thought to integrate the somatic signals of the peripheral and central nervous systems (Damasio, 1994, 1996). Should there be some connection between ERPs and SCRs? Previous studies have found that the level of autonomic excitation reflected by SCRs and HR is relevant in decision-making (Batson et al., 1999; Tomb et al., 2002; Campbell et al., 2004; Crone et al., 2004). However, few studies have clarified the specific relationship between these indicators. In future research, a variety of electrophysiological measurement techniques should be further integrated to explore the intrinsic relationship of various electrophysiological indicators, so as to comprehensively reveal the physiological mechanism of the SMH.

Moreover, combining electrophysiological techniques with brain imaging techniques would be a potential way to validate SMH. Electrophysiological indicators such as SCR and ERPs reflect the temporal progression of peripheral and central nervous system activation, while brain imaging techniques can provide more accurate spatial localization. Therefore, the integration of electrophysiological techniques and brain imaging techniques will help to explore the physiological basis and neural basis of the SMH at the same time, and understand the psychological significance of various indicators as a whole. The lack of evaluation of electrophysiological indicators in previous fMRI studies limits the interpretation of the data. For example, it is difficult to determine whether VMPFC activation reflects emotionally related autonomic responses or other cognitive processes. Therefore, integrating fMRI with electrophysiological measurements will help to gain a more comprehensive understanding of the neurophysiological mechanisms of the decision-making process. How to solve the compatibility problem between fMRI equipment and electrophysiological equipment is the core to carry out this integrated research. For example, electrophysiological signals (e.g., SCRs) are often affected by magnetic induction and radio frequency (RF) pulses in an fMRI environment (Abacherli et al., 2005), resulting in the appearance of artifacts, which is more frequently present in ECG measurements. Fortunately, researchers and equipment vendors have begun to use a built-in real-time filter, a low-pass filter and a linear convolution model to separate clean SCRs signals and achieved good results in recent years (Wong et al., 2011). Future researchers can use these techniques to conduct more integrated research on electrophysiological techniques combined with brain imaging techniques. It is worth noting that artifacts from the data obtained from these systems are common, so it is necessary to perform the corresponding pre-processing before performing statistical analysis.

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FX conceived and designed the review. LH and FX wrote the manuscript. LH revised the manuscript.

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Narcissism, the Experience of Pain, and Risky Decision Making

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Personality characteristics and situational factors are known to influence performance on behavioral decision making tasks; however, variability exists in the relationship between narcissism and decision making. In addition, recent research suggests that the presence of acute pain can negatively affect decisions, and even the threat of pain can also cause changes in decision making. Narcissists are known to experience social pain differently than non-narcissists, but relatively little is known about how physical pain is experienced. The present study examined the influence of both pain and narcissism on risky decision making task performance. Participants (n = 248) completed assessments of the narcissistic admiration and rivalry concept as well as vulnerable narcissism. They were asked to complete a pain recall task before administration of the Balloon Analog Risk Task (BART), Columbia Card Task (CCT), Game of Dice Task (GDT), and Iowa Gambling Task (IGT). Although individuals who recalled a socially painful experience took less risks on the IGT across trials, no effect of narcissism was seen on any of the tasks. Recalling a physically or socially painful situation did not negatively affect decision making on the BART, CCT, or GDT. Results are discussed in the context of previous research on narcissism, pain, and cognitive task performance.

Keywords: risky decision making, Iowa Gambling Task, pain, grandiose narcissism, vulnerable narcissism

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INTRODUCTION

Individuals engage in risk-taking behaviors with potential negative consequences for health and well-being. Researchers often use behavioral tasks, such as the Iowa Gambling Task (IGT; Bechara et al., 1994) and Balloon Analog Risk Task (BART; Lejuez et al., 2002), to assess risk-taking behavior and risky decision making in lab-based settings. Recently, significant interest has grown in determining the predictors of risky decision making, including in the domains of cognitive function, personality, and situational factors. Two topics that are of particular recent interest as potential predictors of risky decision making are narcissism and pain.

Narcissism

Narcissism is described here as a personality trait found in the overall population. It is a complex construct, entailing a collection of traits that seemingly contradict one another. Grandiose narcissism (GN) is characterized by high self-esteem and extraversion, whereas vulnerable narcissism (VN) is characterized by low self-esteem and negative emotionality (e.g., Miller and Campbell, 2008), including greater anxiety and depression (Brunell and Buelow, 2019). Although distinguishing between GN and VN is important, GN is not conceptualized as a homogenous

variable. One model of narcissism, the Narcissistic Admiration and Rivalry Concept (Back et al., 2013), distinguishes between an agentic dimension, termed *narcissistic admiration*, and an antagonistic dimension, termed *narcissistic rivalry*. Narcissistic admiration includes striving for uniqueness and realizing grandiose fantasies, as well as charming behavior (Back, 2018). Thus, narcissistic admiration reflects a self-promotion strategy. However, when the desired outcomes of status, praise, and admiration are thwarted, the strategy of narcissistic self-defense in the form of narcissistic rivalry may be used instead. Thus, narcissistic rivalry encompasses behavior dynamics including striving for supremacy, devaluation of others, as well as hostile and insensitive behavior, especially following conflict such as rejection and criticism. It is possible these two components may lead to differing responses following a painful experience, with narcissistic admiration's effects thwarted and narcissistic rivalry's effects more prominent on subsequent behaviors. One such behavior that could occur after a painful experience is decision making.

Research into the effects of narcissism on decision making are quite varied and can depend on how narcissism is assessed. Despite evidence that narcissists take greater risks in leadership positions (Chatterjee and Hambrick, 2007), in finance (Foster et al., 2009a,b), and across risk-taking behaviors (Buelow and Brunell, 2018), data is mixed when behavioral tasks are examined. Grandiose narcissists take greater risks on a monetary gambling task (Yang et al., 2018b) but not on tasks such as the BART or IGT (Crysel et al., 2013; Brunell and Buelow, 2017). Specific narcissistic traits such as entitlement, rather than GN, do relate to performance on behavioral tasks (Brunell and Buelow, 2017), indicating the need for a more detailed examination of the elements of narcissism that affect risk-taking behavior. Finally, situational factors, such as social support, can also affect a narcissist's performance on behavioral tasks (e.g., Carre and Jones, 2016; Yang et al., 2018a). Thus, the current literature is mixed with regard to narcissism's effects on behavioral tasks. In addition, to the best of our knowledge, no research to date examined this topic from the lens of the Narcissistic Admiration and Rivalry Concept (Back et al., 2013), a conceptualization that appears well-designed to assess narcissism's effects on decision making following a painful experience.

Pain

Pain can be acute or chronic and both types of pain can negatively affect attention, in turn distracting valuable resources from the task at hand (Van Damme et al., 2002). Pain can negatively affect attention and working memory (e.g., Crombez et al., 1996, 1998; Dick and Rashiq, 2007; Dohrenbusch et al., 2008; Moore et al., 2012), both of which are necessary to complete many behavioral risky decision making tasks. Acute (Porcelli and Delgado, 2009; Koppel et al., 2017; Barnhart et al., 2019) and chronic (Apkarian et al., 2004; Tamburin et al., 2014; Muñoz Ladrón de Guevara et al., 2018) pain impair performance on the IGT and other tasks, in that participants are riskier in their decisions when in pain versus no pain. One theory behind riskier decision making during a painful experience is that participants are using the positive "win" element of making a riskier decision to offset the negative experience of pain (Koppel et al., 2017). Even the threat of additional pain in the future can negatively affect performance on tasks such as the IGT and BART (e.g., Barnhart et al., 2019).

The negative effects of pain on decision making and other cognitive processes are not limited to just physical pain. Social pain activates similar brain structures as physical pain (e.g., anterior cingulate cortex; Eisenberger et al., 2003), meaning that experiencing social pain can be just as painful as experiencing physical pain. Social pain most often occurs when an individual is ostracized – is excluded and ignored. Previous research suggests that experiencing social pain can increase risky decision making (Duclos et al., 2013; Buelow et al., 2015; Buelow and Wirth, 2017). In addition, participants asked to recall a burdensome friend reported greater levels of physical pain and negative affect (Okdie and Wirth, 2018), indicating that even recalling a previous experience of social pain can negatively affect the individual in the present moment.

The Present Study

The present study sought to examine the influence of narcissism and pain on risky decision making. GN is associated with a hypersensitivity to social exclusion and threatening situations (e.g., Kelsey et al., 2001; Sommer et al., 2009), and shows increased activation in neural pain areas during such experiences (Cascio et al., 2015). In addition, narcissists do experience physical pain, reporting worse mood following a cold pressor task (Brunell et al., 2020). In the present study, we had participants self-report a time in which they experienced social or physical pain, then completed risky decision making tasks. Several hypotheses were examined. Experiencing social or physical pain can lead to impaired performance on cognitive tasks, including on those that assess decision making. To our knowledge, no research has specifically examined how recalling a previously painful experience might in turn affect cognitive abilities in the present moment. We hypothesized recalling a painful experience would result in riskier decisions than in the control condition, consistent with previous research indicating experiencing an acute pain affects decisions. It is also possible that following a painful experience, or in this case recalling a painful experience, an individual with high levels of narcissistic admiration and rivalry may be inclined to take risks in order to regain their grandiose sense of self. Thus, we predicted higher levels of narcissistic admiration and rivalry would predict greater risky decision making following a pain recall task (no specific hypothesis was made about VN).

MATERIALS AND METHODS

Participants

Participants were 248 undergraduate students at a regional campus of a large University (79 males, M_{age} = 18.62, SD_{age} = 2.03). Most self-identified as Caucasian or African-American (see **Table 1**). All were enrolled in psychology courses in which course credit was provided for participation in research studies. Participants were not paid for their participation, nor were real incentives tied to task performance.

TABLE 1 | Demographic information and study variable means and standard deviations.

	Recall condition			
Variable	**Control**	**Anger**	**Social pain**	**Physical pain**
n	114	45	44	45
Gender	36 Males	15 Males	12 Males	16 Males
Age	18.38 (0.74)	19.07 (4.05)	18.49 (1.08)	18.89 (1.91)
Ethnicity	62.5% Caucasian	73.3% Caucasian	58.1% Caucasian	59.1% Caucasian
NARQ-A	2.91 (0.83)	3.14 (1.08)	3.03 (1.06)	3.24 (1.14)
NARQ-R	1.93 (0.73)	1.90 (0.75)	2.12 (1.00)	1.89 (0.97)
HSNS	2.70 (0.71)	2.65 (0.77)	2.70 (0.65)	2.53 (0.70)
PANAS-P	2.70 (0.91)	2.50 (0.83)	2.59 (0.88)	2.58 (0.97)
PANAS-N	1.43 (0.50)	1.74 (0.75)	1.54 (0.48)	1.47 (0.44)
BART	23.49 (13.17)	25.01 (14.39)	20.77 (14.13)	25.72 (11.98)
CCT	13.07 (4.71)	12.62 (5.27)	14.47 (4.80)	13.80 (5.35)
GDT	4.74 (9.29)	0.59 (10.14)	4.43 (11.43)	0.85 (12.09)
IGT 1-40	−2.97 (9.21)	−1.45 (12.13)	−2.60 (9.97)	−2.55 (12.14)
IGT 41-100	−6.29 (18.45)	1.59 (23.29)	1.72 (24.37)	−3.98 (17.27)

NARQ, Narcissistic Admiration and Rivalry Questionnaire; HSNS, Hypersensitive Narcissism Scale; PANAS, Positive and Negative Affect Schedule; BART, Balloon Analog Risk Task, average adjusted pumps per balloon; GDT, Game of Dice Task, net score; CCT, Columbia Card Task, average selections; IGT, Iowa Gambling Task, advantageous minus disadvantageous selections during early (1–40) and later (41–100) trials.

Narcissism Measures

The Narcissistic Admiration and Rivalry Questionnaire (NARQ; Back et al., 2013) assesses these characteristics of GN by having participants respond to a series of 18 items using a 1 (*not agree at all*) to 6 (*agree completely*) scale. Admiration items focus on self-enhancement (e.g., being famous, special, and great) whereas rivalry items focus on self-defense (e.g., enjoying failure of rivals, annoyance at criticism). Higher average scores indicate greater narcissistic admiration ($M = 3.04$, $SD = 0.99$, $\alpha = 0.86$) and rivalry ($M = 1.96$, $SD = 0.84$, $\alpha = 0.86$).

The Hypersensitive Narcissism Scale (HSNS; Hendin and Cheek, 1997) assesses VN. Participants respond to a series of 10 items using a 1 (*very uncharacteristic*) to 5 (*very characteristic*) scale (e.g., dislike sharing credit with others and interpreting remarks in a personal way). Higher average scores indicate greater VN ($M = 2.66$, $SD = 0.70$, $\alpha = 0.75$).

Risky Decision Making Measures

On the BART (Lejuez et al., 2002), participants pump up a series of 30 balloons, earning five cents per pump. Participants can pump up the balloon as much as they want, clicking "collect $$$" to bank that money. If the balloon pops, however, the money earned on that balloon is lost. Unknown to participants, each balloon has a breaking point between 1 and 128 pumps. To earn money, participants must stop pumping the balloon before it pops and bank the earned money. Average adjusted number of pumps per balloon was calculated, with higher scores indicating greater risky decision making.

The Columbia Card Task (CCT; Figner et al., 2009) assesses risky decision making by having participants turn over a set of 32 cards. Some are "win" cards, earning 10 or 30 points, and some are "loss" cards (1 or 3), subtracting 250 or 750 points. At the start of each trial, participants are told the win points, loss points, and number of loss cards. The "cold" version was administered, which had participants indicate the total number of cards to turn over. No feedback about their selection is provided before the next trial begins. The average number of cards per trial was calculated, with higher scores indicative of riskier decision making.

The Game of Dice Task (GDT; Brand et al., 2007) assesses risky decision making by having participants guess the roll of a die. Participants place a bet on a series of 1, 2, 3, or 4 digits that matching their prediction. If the prediction is correct, they win money and if it is wrong they lose money. Participants are told the relative risk associated with each decision. A total score was calculated by subtracting the number of disadvantageous bets (1, 2) from the number of advantageous bets (3, 4), with lower scores indicative of riskier decision making.

The IGT (Bechara et al., 1994; Bechara, 2007) was created to assess real-world decision making impairments among individuals with frontal lobe injuries. Participants are given $2,000 and told to maximize profit over a series of 100 selections from one of four decks (A, B, C, and D). On each trial, participants win some money but might also lose some money. Selecting Deck A or B results in larger immediate rewards, but the losses outweigh the gains (long-term negative consequences). Selecting Deck C or D results in smaller immediate rewards, but the gains outweigh the losses (long-term positive consequences). Performance is divided into decisions made under ambiguity, when not much is known about the decks (Trials 1–40), and decisions made under risk, when participants are at least somewhat aware of the relative risks and benefits of each deck (Trials 41–100; Brand et al., 2007). For the present study, performance was examined by subtracting the disadvantageous selections (A + B) from the advantageous selections (C + D) during the early (1–40) and later (41–100) trials.

Although these four tasks all assess risky decision making, each differs from the others in some way. The IGT assesses elements of both decision making under ambiguity and decision making under risk, given that participants do not know much about the pros and cons of each deck during early decisions compared to later decisions. Decision making under ambiguity turns into decision making under risk as participants utilize the feedback from each decision to change their perception of each deck and thus their decision making strategy. On the CCT, participants do not receive feedback on the outcomes of their decisions, but start the task with a wealth of information to determine how risky a decision actually is. Participants can balance the knowledge about the number of loss cards and their value with the value of the gain cards to arrive at an optimal decision. On the GDT, participants are also given explicit information about the wins/losses associated with each decision, but it is up to the participants to determine the probability associated with winning/losing on a particular trial. The BART introduces an element of randomness, as the explosion point varies across trials and can lead to a different decision making strategy.

Procedure

The University's Institutional Review Board approved the study and all participants provided informed consent. Participants were told that they were part of a study examining predictors of cognitive task performance. They then completed the NARQ, HSNS, and demographic questionnaire in a random order. Next, participants were assigned to one of four recall conditions: (1) previous social pain (n = 44; recall a time they felt socially ostracized); (2) previous physical pain (n = 45; recall a time they felt a high level of physical pain); (3) previous anger [n = 45; recall a time they experienced a high level of anger (emotional control condition)]; or (4) control (n = 114; write about activities completed earlier in the day). Participants were not given further direction as to what the recalled situation should entail, thus they might have written about ostracism by a familiar person or ostracism by an unknown or casual acquaintance. They then completed the Positive and Negative Affect Schedule (Watson et al., 1988) to assess their post-manipulation level of positive and negative affect before completing the BART, CCT, GDT, and IGT in a counterbalanced order. Participants were then debriefed and course credit assigned. Of note, the control condition was oversampled to allow for analyses that collapsed across the recall conditions (n = 134 across the three recall conditions).

Data Analysis and Results

Due to computer malfunction, data was missing for the BART (n = 9), CCT (n = 11), GDT (n = 16), and IGT (n = 10) (3.6–6.5% of data by task). Demographic information and variable means and standard deviations are presented in **Table 1**. Gender was correlated with performance on the IGT, so gender was included as a covariate in the remaining analyses.

First, hypotheses regarding the influence of recalled pain on decision making were examined. To assess whether the pain recall tasks elicited an emotional response, a series of ANOVAs were conducted on the PANAS positive and negative subscales, with gender as a covariate. There was not a significant difference in positive affect across pain recall conditions, $F(3, 240) = 0.74$, $p = 0.529$, $\eta^2 = 0.01$; however, there was a significant between-groups difference in negative affect, $F(3, 240) = 3.93$, $p = 0.009$, $\eta^2 = 0.05$. The anger recall condition reported greater negative affect than the control ($p = 0.001$), physical pain ($p = 0.018$), and social pain ($p = 0.030$) conditions. No differences emerged between the remaining groups (ps > 0.477).

A series of ANOVAs were conducted on the BART, CCT, and GDT, including gender as a covariate. Because the IGT is separated into two blocks of trials, a mixed ANOVA was also conducted with trial block (1–40 and 41–100) as the repeated-measures factor and pain recall condition (social, physical, anger/emotional control, and control) as the between-subjects factor. Gender was again entered as a covariate. No significant pain-recall group effects were seen on the BART, $F(3, 235) = 0.79$, $p = 0.502$, $\eta^2 = 0.010$; CCT, $F(3, 233) = 1.62$, $p = 0.185$, $\eta^2 = 0.021$; or GDT, $F(3, 228) = 2.62$, $p = 0.052$, $\eta^2 = 0.034$. In addition, gender was not associated with performance on any of these tasks (ps > 0.128). For the IGT, the main effects of Block, $F(1, 229) = 2.00$, $p = 0.158$, $\eta^2 = 0.009$, and Group, $F(3, 229) = 2.12$, $p = 0.098$, $\eta^2 = 0.027$, were not significant. Men showed more advantageous decisions than women, $F(1, 229) = 5.85$, $p = 0.016$, $\eta^2 = 0.025$, but there was not an interaction with Block, $F(1, 229) = 1.54$, $p = 0.215$, $\eta^2 = 0.007$. There was a significant Block × Group interaction, $F(3, 229) = 3.55$, $p = 0.015$, $\eta^2 = 0.044$. Among participants in the control group, less risky decisions were seen in the earlier than in the later trials, $p = 0.034$, whereas those in the social pain recall group made less risky decisions in the later than in the earlier trials, $p = 0.036$ (see **Figure 1**).

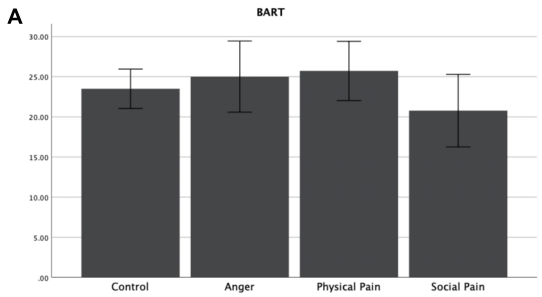
Next, hypotheses regarding narcissism's effects on decision making were examined via a series of linear regressions. The pain recall conditions and centered narcissism variables were entered in Step 1. The interaction between the narcissism variables and pain recall conditions were entered in Step 2. As recall condition was a categorical variable, the conditions were first dummy-coded as follows: Social pain (1 = Social pain and 0 = all other conditions), Physical pain (1 = Physical pain and 0 = all other conditions), and Anger (1 = Anger and 0 = all other conditions) (see **Figure 2**).

Results of the regression analyses are presented in **Table 2**. To account for multiple comparisons, the Bonferroni correction was applied. Results are considered significant at the $p < 0.007$ level (0.05/7 Step 2 predictors per regression). No significant associations emerged for performance on the BART, CCT, or IGT-1-40. No significant associations emerged at the $p < 0.007$ level for the GDT (NARQ-A was significant at $p = 0.02$ level) or the IGT-41-100 (conditions were significant at the $p = 0.03$ level).

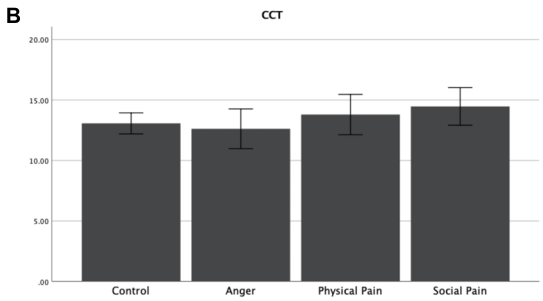
DISCUSSION

The present study examined the effects of both a pain-recall manipulation and the personality characteristic of narcissism on decision making. We hypothesized that recalling a painful experience would result in riskier decisions, as acute pain (Porcelli and Delgado, 2009; Koppel et al., 2017; Barnhart et al., 2019) and recalling a previously painful experience (Okdie and Wirth, 2018) can negatively affect individuals. Contrary to prediction, minimal recall manipulation effects were seen across the decision making tasks. The only significant findings were on the IGT, as participants who recalled a socially painful experience were less risky as the task progressed whereas the control participants instead became riskier as the task progressed. Although unexpected, poor performance among healthy controls (and those in control conditions) is commonly found on the IGT (e.g., Steingroever et al., 2013). It is possible, however, that the unusually low performance of the control group – and the increased preference for disadvantageous decks as the task progressed – affected our ability to detect group differences in the physical pain recall condition and on other tasks.

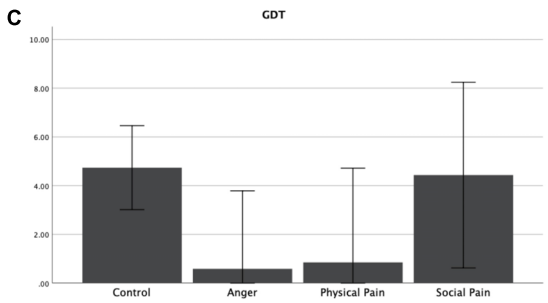
Our finding of improved performance on the IGT as a function of social pain recall condition generally runs counter to prediction and previous research suggesting pain impairs decision making. It is possible that our pain recall manipulations tapped into individuals' current mood states, as previous research found both state positive and negative mood can affect decision



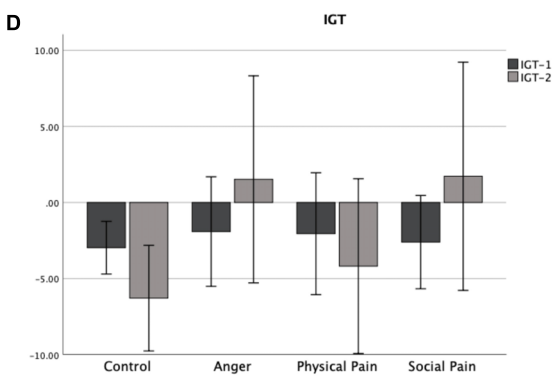
Y-axis indicates number of adjusted pumps per balloon.



Y-axis indicates average number of cards selected per trial.



Y-axis indicates number of advantageous minus disadvantageous selections.



Y-axis indicates number of advantageous minus disadvantageous selections in the early (IGT-1) and later (IGT-2) trials.

FIGURE 1 | Performance on the BART **(A)**, CCT **(B)**, GDT **(C)**, and IGT **(D)** as a function of pain recall condition.

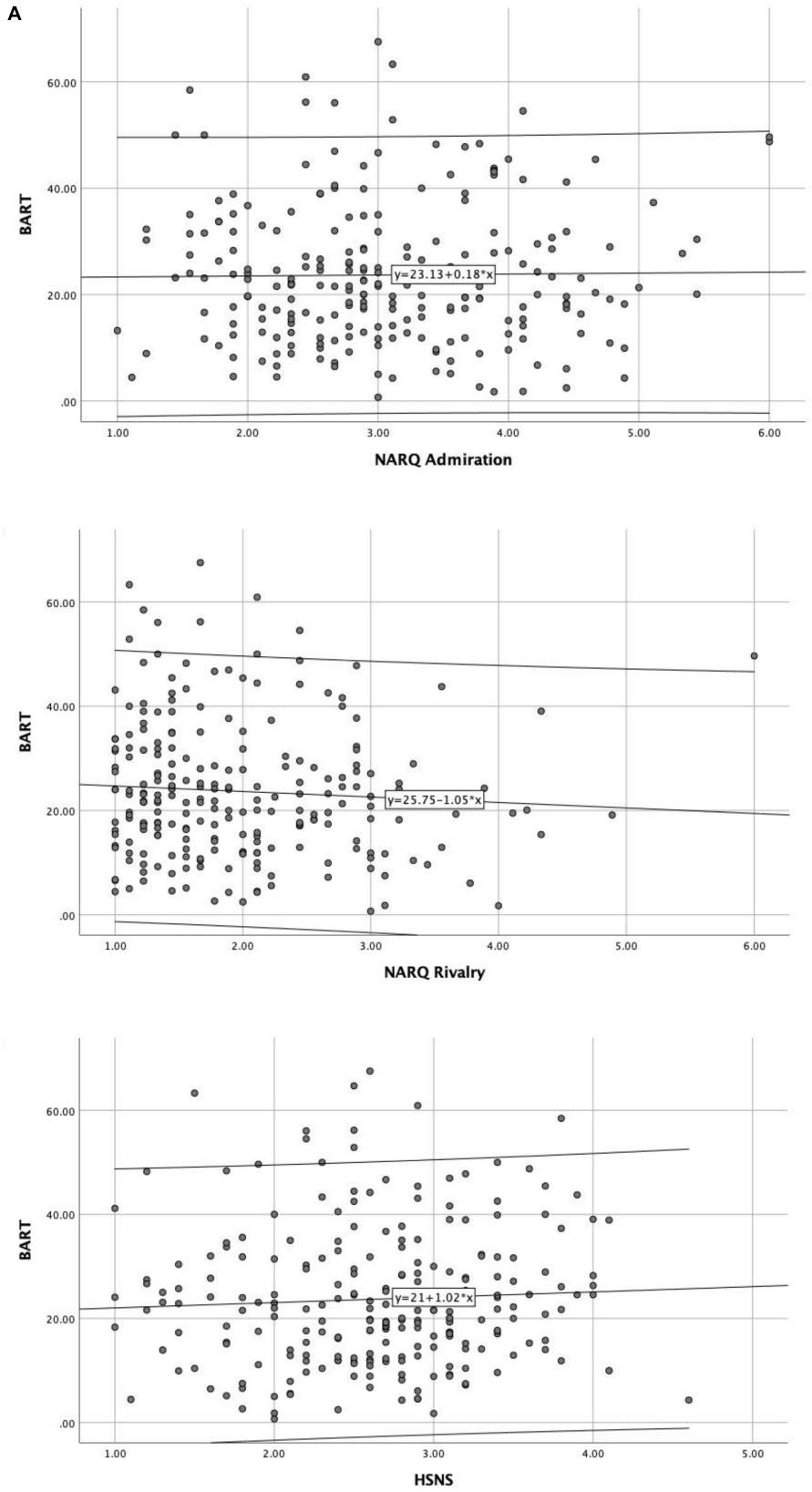


FIGURE 2 | Continued

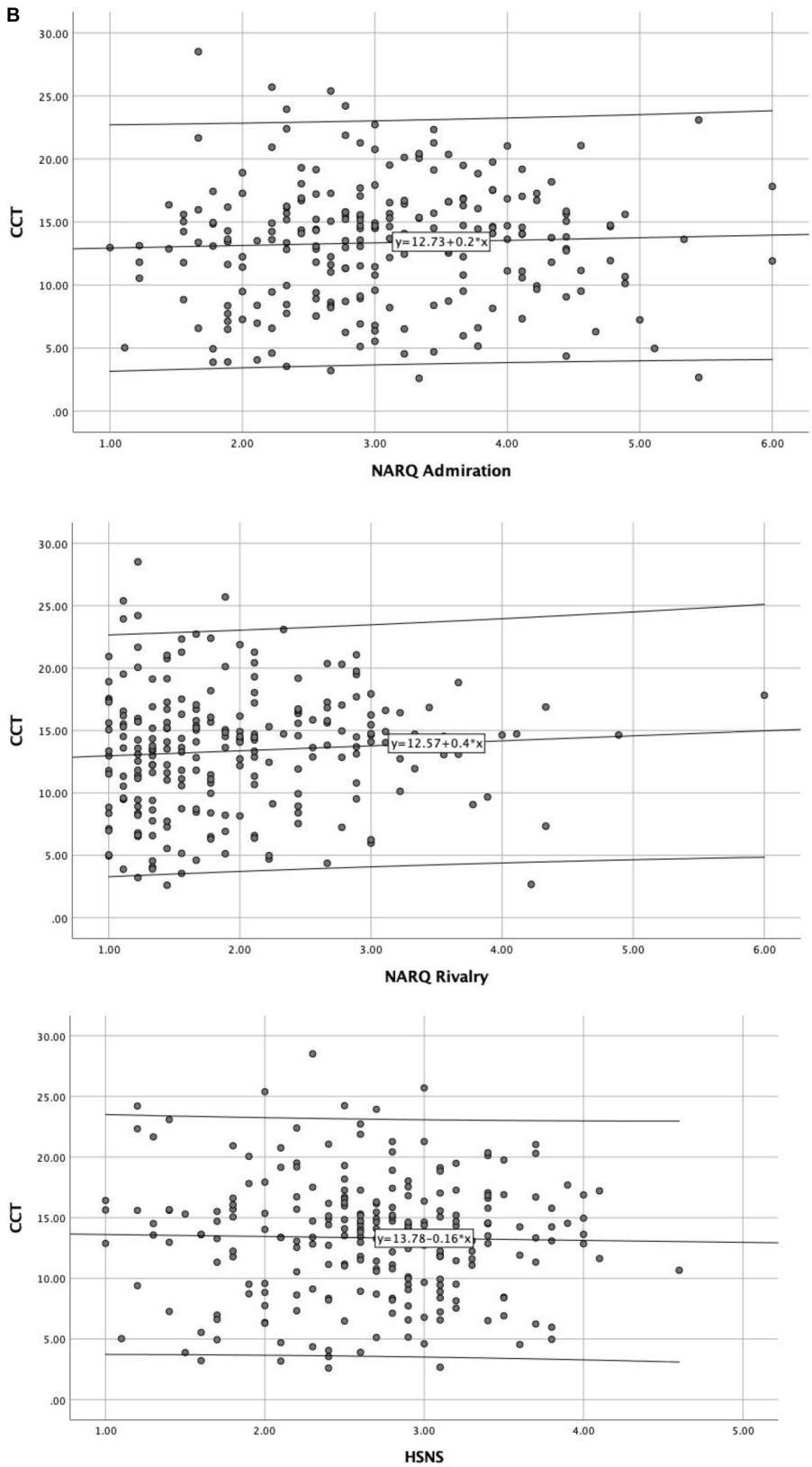


FIGURE 2 | Continued

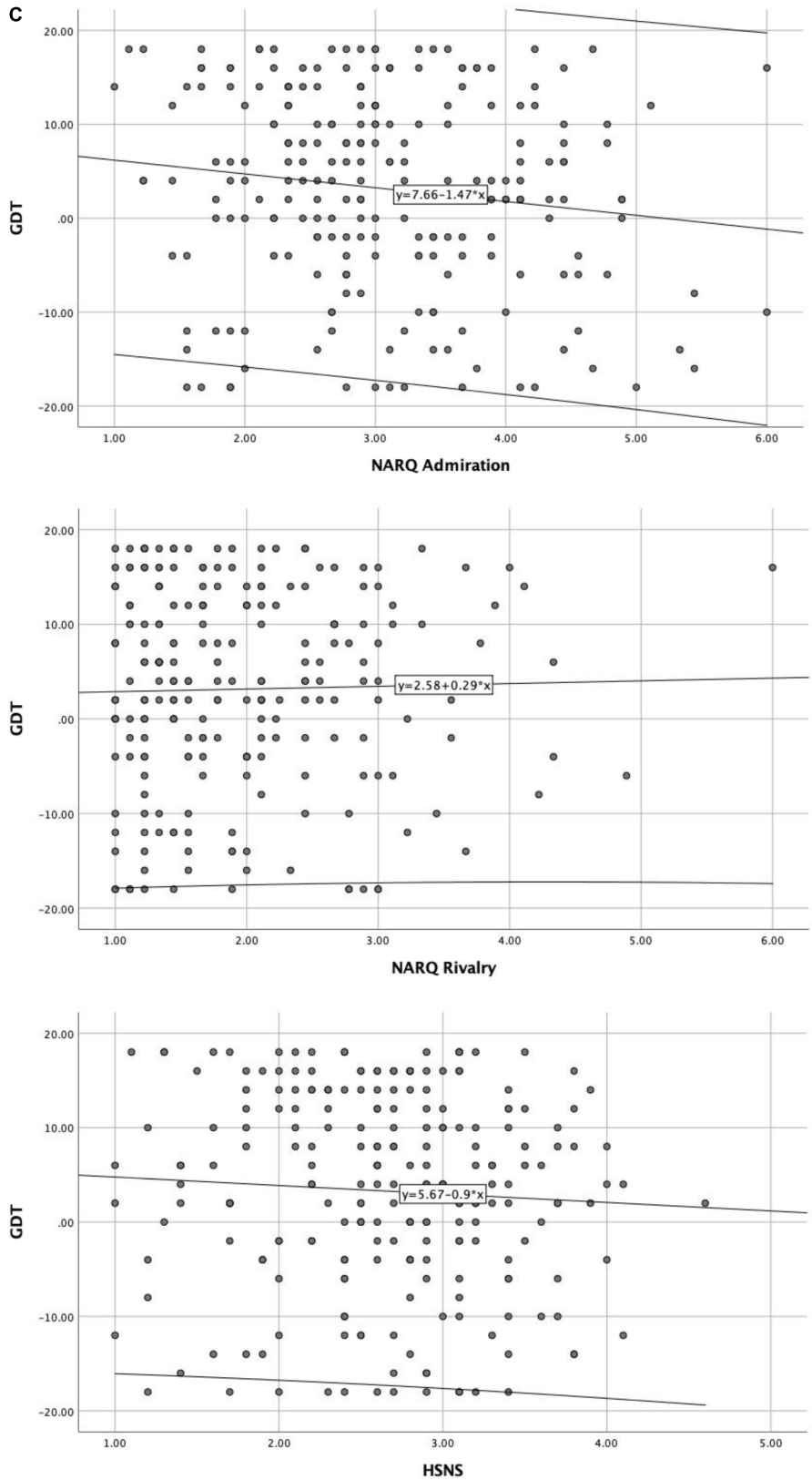


FIGURE 2 | Continued

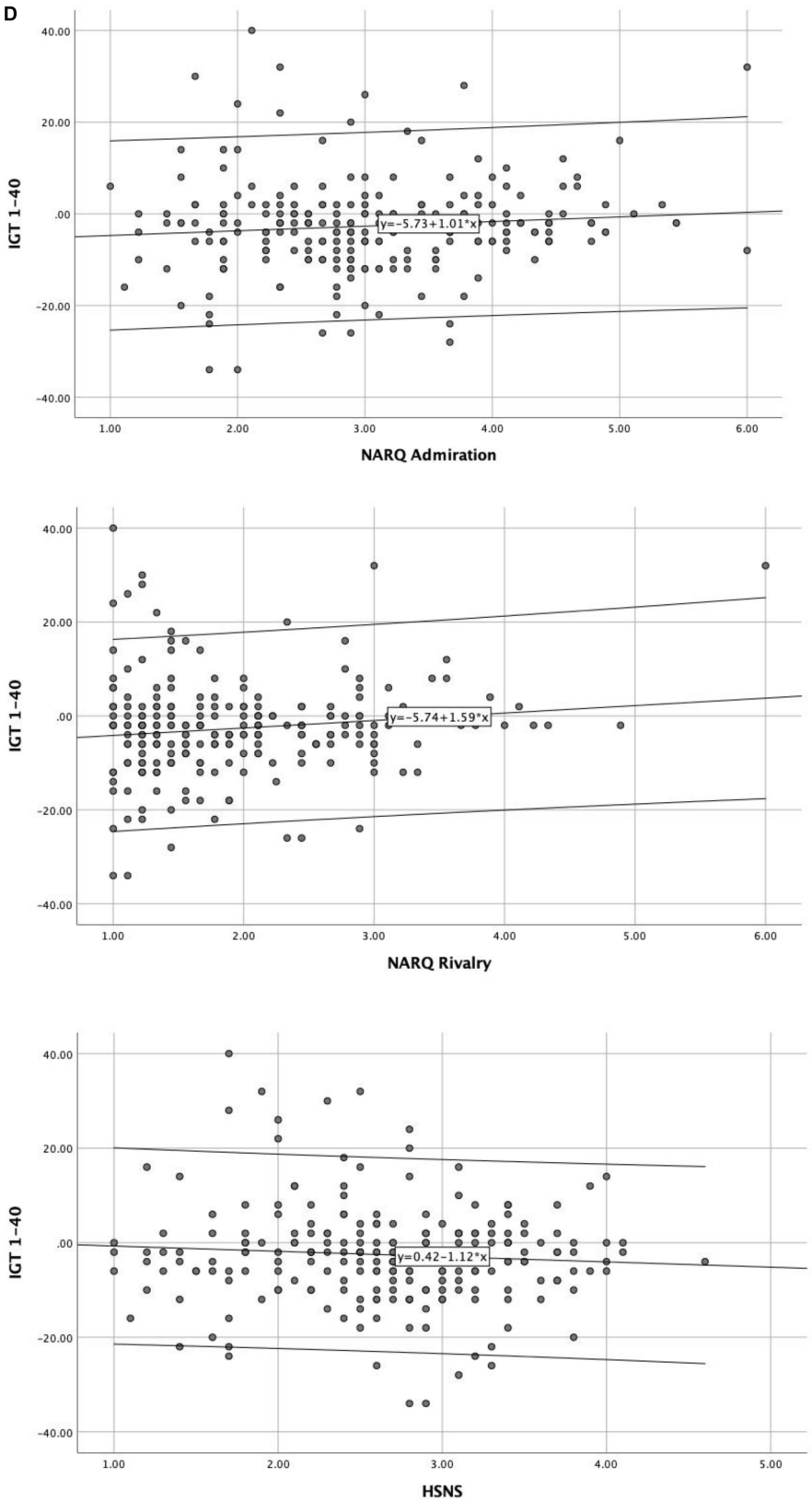


FIGURE 2 | Continued

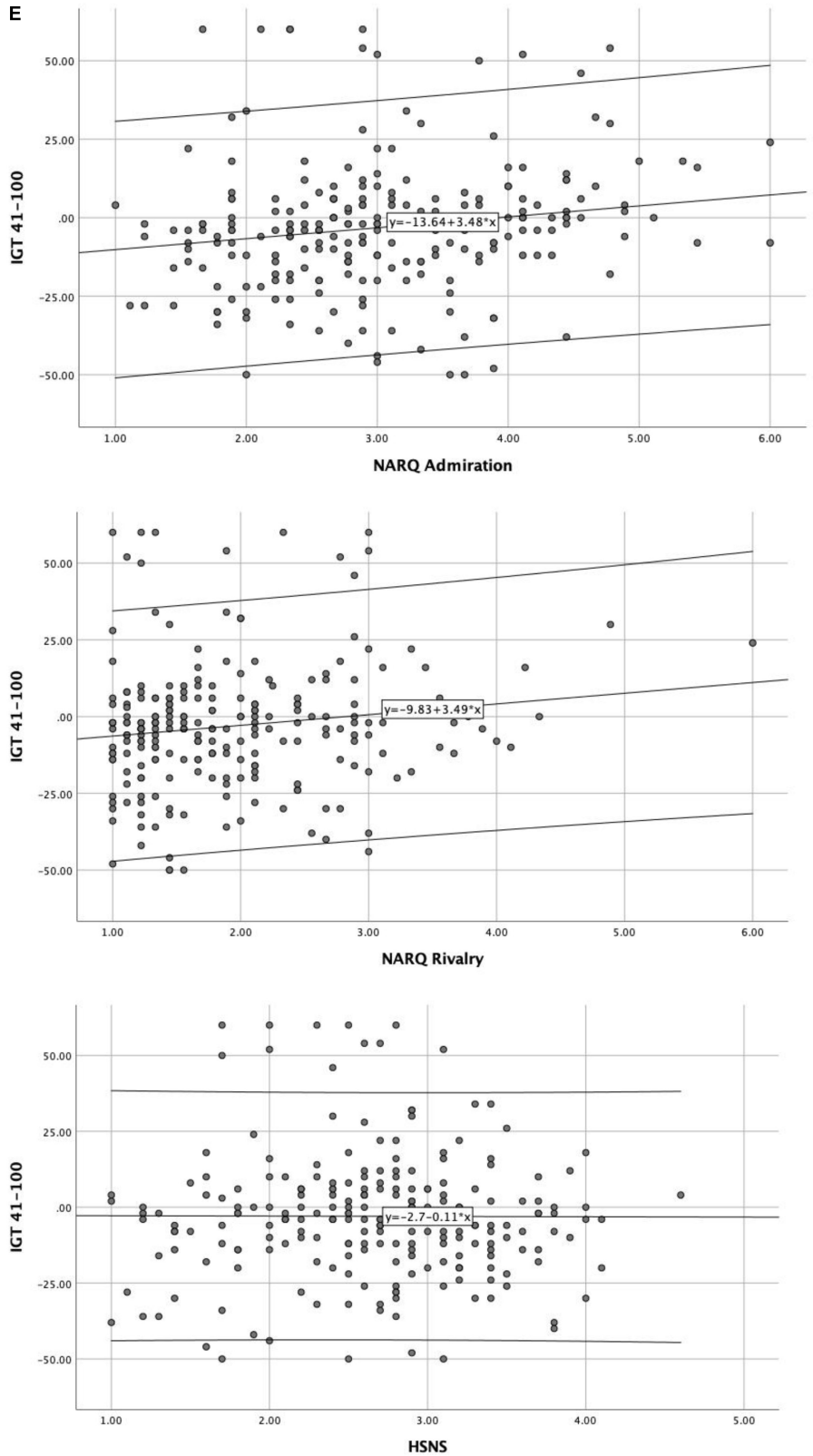


FIGURE 2 | Relationship between performance on the BART **(A)**, CCT **(B)**, GDT **(C)**, IGT-1 **(D)**, and IGT-2 **(E)**, and the narcissism measures [admiration (1), rivalry (2), and vulnerable (3)].

TABLE 2 | Results of regression analyses on decision making and narcissism.

Variable	*F*	*p*	R^2	β	*t*	*p*	VIF
BART							
Step 1: Narcissism, condition	0.97	0.446	0.03				
Social pain				−0.08	−1.13	0.259	1.15
Physical pain				0.06	0.78	0.435	1.17
Anger				0.01	0.08	0.938	1.15
NARQ-A				0.06	0.79	0.432	1.34
NARQ-R				−0.11	−1.38	0.170	1.45
HSNS				0.09	1.31	0.192	1.12
Step 2: Narcissism × Condition	0.67	0.811	0.04				
Social pain				−0.07	−0.98	0.326	1.19
Physical pain				0.05	0.71	0.479	1.22
Anger				0.01	0.18	0.856	1.18
NARQ-A				−0.08	−0.59	0.558	3.99
NARQ-R				−0.15	−1.15	0.251	3.94
HSNS				0.09	0.91	0.366	2.31
NARQ-A × Social pain				0.07	0.67	0.507	2.38
NARQ-A × Physical pain				0.15	1.46	0.145	2.39
NARQ-A × Anger				0.06	0.61	0.541	2.07
NARQ-R × Social pain				0.02	0.15	0.879	1.94
NARQ-R × Physical pain				0.05	0.49	0.622	2.44
NARQ-R × Anger				0.03	0.37	0.715	2.84
HSNS × Social pain				−0.02	−0.26	0.795	1.62
HSNS × Physical pain				−0.00	−0.03	0.979	1.57
HSNS × Anger				0.00	0.05	0.964	1.76
CCT							
Step 1: Narcissism, condition	0.82	0.555	0.02				
Social pain				0.10	1.43	0.155	1.14
Physical pain				0.06	0.78	0.438	1.17
Anger				−0.03	−0.48	0.634	1.15
NARQ-A				0.00	0.01	0.990	1.35
NARQ-R				0.07	0.92	0.357	1.46
HSNS				−0.05	−0.70	0.487	1.12
Step 2: Narcissism × Condition	0.76	0.722	0.05				
Social pain				0.12	1.61	0.110	1.18
Physical pain				0.05	0.68	0.500	1.24
Anger				−0.03	−0.45	0.653	1.16
NARQ-A				−0.05	−0.39	0.697	3.92
NARQ-R				0.11	0.87	0.386	3.93
HSNS				−0.11	−1.06	0.290	2.30
NARQ-A × Social pain				−0.06	−0.62	0.537	2.36
NARQ-A × Physical pain				0.12	1.17	0.244	2.40
NARQ-A × Anger				0.02	0.25	0.800	2.02
NARQ-R × Social pain				−0.06	−0.53	0.597	1.95
NARQ-R × Physical pain				−0.04	−0.35	0.726	2.45
NARQ-R × Anger				0.05	0.49	0.627	2.81
HSNS × Social pain				−0.01	−0.09	0.931	1.62
HSNS × Physical pain				0.08	0.97	0.336	1.56
HSNS × Anger				0.02	0.24	0.811	1.76

(Continued)

TABLE 2 | Continued

Variable	*F*	*p*	R^2	β	*t*	*p*	VIF
GDT							
Step 1: Narcissism, condition	2.31	0.035	0.06				
Social pain				0.00	0.00	1.000	1.14
Physical pain				−0.11	−1.59	0.113	1.17
Anger				−0.13	−1.84	0.068	1.14
NARQ-A				−0.18	−2.35	0.020	1.37
NARQ-R				0.13	1.63	0.104	1.46
HSNS				−0.10	−1.47	0.144	1.11
Step 2: Narcissism × Condition	1.27	0.226	0.08				
Social pain				−0.01	−0.09	0.926	1.17
Physical pain				−0.10	−1.41	0.159	1.24
Anger				−0.13	−1.89	0.061	1.16
NARQ-A				−0.06	−0.48	0.635	3.89
NARQ-R				−0.04	−0.34	0.734	3.88
HSNS				−0.03	−0.26	0.794	2.21
NARQ-A × Social pain				−0.11	−1.13	0.258	2.33
NARQ-A × Physical pain				−0.11	−1.12	0.265	2.36
NARQ-A × Anger				−0.04	−0.42	0.677	2.08
NARQ-R × Social pain				0.16	1.41	0.161	1.96
NARQ-R × Physical pain				0.20	1.99	0.048	2.38
NARQ-R × Anger				0.03	0.29	0.772	2.82
HSNS × Social pain				−0.08	−0.96	0.340	1.46
HSNS × Physical pain				−0.07	−0.87	0.384	1.52
HSNS × Anger				−0.03	−0.40	0.691	1.72
IGT 1-40							
Step 1: Narcissism, condition	1.30	0.256	0.03				
Social pain				0.01	0.18	0.856	1.15
Physical pain				0.02	0.30	0.767	1.18
Anger				0.08	1.14	0.256	1.15
NARQ-A				0.02	0.28	0.783	1.37
NARQ-R				0.15	1.85	0.066	1.46
HSNS				−0.11	−1.53	0.128	1.10
Step 2: Narcissism × Condition	1.63	0.067	0.10				
Social pain				0.01	0.14	0.886	1.19
Physical pain				0.01	0.11	0.914	1.27
Anger				0.08	1.09	0.276	1.17
NARQ-A				−0.08	−0.60	0.548	4.26
NARQ-R				0.19	1.44	0.150	3.95
HSNS				−0.05	−0.47	0.636	2.32
NARQ-A × Social pain				−0.09	−0.89	0.374	2.53
NARQ-A × Physical pain				0.21	2.04	−0.043	2.47
NARQ-A × Anger				0.05	0.49	0.625	2.17
NARQ-R × Social pain				0.06	0.51	0.610	1.97
NARQ-R × Physical pain				0.03	0.31	0.759	2.30
NARQ-R × Anger				−0.13	−1.48	0.142	2.94
HSNS × Social pain				−0.14	−1.64	0.102	1.63
HSNS × Physical pain				−0.02	−0.31	0.759	1.46
HSNS × Anger				−0.00	−0.04	0.966	1.69

(Continued)

TABLE 2 | Continued

Variable	*F*	*p*	R^2	β	*t*	*p*	VIF
IGT 41-100							
Step 1: Narcissism, condition	2.60	0.019	0.07				
Social pain				0.15	2.13	0.034	1.15
Physical pain				0.04	0.53	0.598	1.18
Anger				0.16	2.26	0.025	1.15
NARQ-A				0.12	1.58	0.115	1.37
NARQ-R				0.08	1.03	0.305	1.46
HSNS				−0.02	−0.34	0.736	1.10
Step 2: Narcissism × Condition	1.22	0.258	0.08				
Social pain				0.15	2.06	0.041	1.19
Physical pain				0.02	0.27	0.787	1.27
Anger				0.16	2.23	0.027	1.17
NARQ-A				0.01	0.07	0.948	4.26
NARQ-R				0.13	0.99	0.324	3.95
HSNS				0.00	0.01	0.996	2.32
NARQ-A × Social pain				0.03	0.33	0.742	2.53
NARQ-A × Physical pain				0.14	1.32	0.189	2.47
NARQ-A × Anger				0.05	0.49	0.623	2.17
NARQ-R × Social pain				0.03	0.27	0.785	1.97
NARQ-R × Physical pain				−0.07	−0.67	0.506	2.30
NARQ-R × Anger				−0.06	−0.68	0.499	2.94
HSNS × Social pain				−0.06	−0.74	0.460	1.63
HSNS × Physical pain				−0.03	−0.32	0.751	1.46
HSNS × Anger				0.01	0.14	0.888	1.69

NARQ, Narcissistic Admiration and Rivalry Questionnaire; HSNS, Hypersensitive Narcissism Scale; BART, Balloon Analog Risk Task, average adjusted pumps per balloon; GDT, Game of Dice Task, net score; CCT, Columbia Card Task, average selections; IGT, Iowa Gambling Task, advantageous minus disadvantageous selections during early (1–40) and later (41–100) trials.

making (e.g., Cryder et al., 2008; de Vries et al., 2008; Buelow et al., 2013). Those in a more negative mood following the recall might attempt to repair mood by "winning" on the various tasks, leading to a strategy of focusing on the feedback to learn to decide advantageously. However, examination of the PANAS post-manipulation indicated only the anger recall condition led to a significant difference in positive or negative affect. Additional research is needed to both replicate this finding and determine what might be causing a post-pain recall improvement in decision making on the IGT but not the GDT. Our effect sizes for the ANOVAs fell in the small range and it is possible that our smaller sample size might have hampered our ability to detect significant small effects between pain recall groups.

We also predicted relationships between narcissistic admiration and rivalry (GN) and risky decision making (no prediction was made for VN). Specifically, we hypothesized higher GN would be associated with riskier decisions than lower levels of these characteristics. No support was found for this hypothesis. No narcissism variables were significantly related to decision making task scores at the $p < 0.01$ level. The narcissism and pain recall condition interactions all fell in the small to moderate range of effect sizes, and our smaller sample size may have also hindered our ability to detect significant but small effects. However, our limited findings are consistent with previous research showing both the assessment of narcissism and the behavioral task utilized can lead to varied relationships between narcissism and risky decision making (e.g., Crysel et al., 2013; Carre and Jones, 2016; Brunell and Buelow, 2017; Yang et al., 2018a,b). Some tasks rely more on explicit (GDT) versus implicit (IGT) information about the relative risks and benefits associated with each decision, leading to differing levels of effort and attention required to learn the optimal strategy. Still other tasks might better resemble real-world games (BART and GDT), leading participants to use previously learned information (that may or may not apply to the lab task) when making decisions. It is also possible that narcissism's effects on decision making and risk-taking behavior occur when there is a potential for others to learn about the outcomes, such as can occur in real-world decision making settings. Future research could examine how decisions change as a function of narcissists deciding individually versus in a group setting.

Several limitations exist which may have affected the results. As previously stated, the control group significantly preferred the disadvantageous decks, contrary to the IGT creator's intention but potentially reflecting the prominent Deck B phenomenon seen across studies (e.g., Lin et al., 2007). Although we assessed changes in positive and negative mood after the pain recall task, we did not include a measure of current pain experience. Our sample, though diverse, was comprised of undergraduate student participants and may not reflect decision making tendencies of non-student participants. We did not tie real financial incentives to participation in the study nor to performance on the tasks. Although this lack of financial incentives is common in psychological studies utilizing the BART, CCT, GDT, and IGT, research in economics points toward real incentives influencing and even improving decision making (e.g., Hertwig and Ortmann, 2001; Cohn et al., 2015; but see Scheres et al., 2010). Emotions can negatively affect decision making (e.g., Engelmann and Hare, 2018), but factors such as the type of behavioral task, how negative or positive affect are induced, and the strength of the mood induction method, in addition to the use of monetary payments, can affect this process. Our small sample size could negatively affect our power to detect small effects. In addition, we experienced a loss of data on several of the decision making tasks, which negatively affected our sample sizes for each analysis. It is possible the results would turn out differently if a different measure of narcissism was utilized, such as the Narcissistic Personality Inventory (NPI). It is also possible that narcissists are biased in their recall about themselves (consistent with Jones and Brunell, 2014), in that they strive to see themselves in positive agentic ways that are lacking in complexity and are self-aggrandizing (e.g., Rhodewalt and Morf, 1995). These biases may also limit how much self-related information they can store about themselves (e.g., Fukushima and Hosoe, 2011), which could negatively affect a recall task such as was used in the present study. It is also possible that the individual referenced in the socially painful experience was particularly impactful in that participants may have experienced ostracism by a familiar person as worse than ostracism by an unknown or casual acquaintance. Use of an experimental manipulation of pain, such as Cyberball (social pain; Williams et al., 2000)

and a cold pressor (physical pain), could offset some of these concerns. Future research should attempt to determine when narcissists take risks and why, as well as how the experience or avoidance of pain might affect this process. In addition, future research should begin to examine how performance on decision making tasks changes on each successive selection, and whether narcissists may show decision making patterns in behavioral models that do not appear when the standard scoring approaches are utilized.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Ohio State University Institutional Review Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Participants provided verbal consent.

AUTHOR CONTRIBUTIONS

MB designed the study, collected and analyzed data, and drafted the manuscript. AB designed the study and revised the manuscript.

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Behavioral and Neural Arguments of Motivational Influence on Decision Making During Uncertainty

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The scientific world is increasingly interested in motivation, primarily due to the suspected impact on decision-making abilities, particularly in uncertain conditions. To explore this plausible relationship, 28 healthy participants were included in the study and performed decision-making and motivational tasks while their neural activity was recorded. All participants performed the Iowa Gambling Task (IGT) and were split into two groups based on their score, one favorable group with 14 participants who performed advantageously and one undecided group with 14 participants who failed to develop the correct strategy on the IGT. In addition, all participants performed the Effort Expenditure for Reward Task (EEfRT), which defines the motivational level of each participant by the effort that participants agree to do in function of reward magnitudes and probabilities to receive these reward (10, 50, and 90%). The completion of both tasks allowed for the exploration of the relationship between the motivational level and decision-making abilities. The EEfRT was adapted to electroencephalography (EEG) recordings to explore how motivation could influence reward experience. Behavioral results showed no difference in EEfRT performances on the whole task between the two groups' performances on the IGT. However, there was a negative correlation between the difficulty to develop an optimal strategy on the IGT and the percentage of difficult choices at the 90% condition on the EEfRT. Each probability condition has been previously associated to different motivational and emotional states, with the 90% condition associated to the reward sensitivity. This behavioral result leads to the hypothesis that reward sensitivity may induce an inability to develop an optimal strategy on the IGT. Group analysis demonstrated that only the undecided group showed a P300 during the processing of the outcome, whereas the favorable group showed a blunted P300. Similarly, there was a negative correlation between the P300 amplitude and the ability to develop an optimal strategy on the IGT. In conclusion, behavioral and neuronal data provides evidence that the propensity to focus only on the immediate outcomes is related to the development of an inefficient strategy on the IGT, without influence of motivation.

Keywords: decision-making, uncertainty, motivation, IGT, EEfRT, P300, effort

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INTRODUCTION

The scientific world is increasingly interested in motivation, both as a function of the alteration in various neuropsychiatric disorders (Treadway et al., 2012, 2014) as well as through its influence on various cognitive processes, such as attention (Fan et al., 2002; Engelmann and Pessoa, 2007; Pessoa, 2009; Robinson et al., 2012; Oliveira et al., 2013), working memory (Taylor et al., 2004), long-term memory (Nielson and Bryant, 2005), and cognitive control (Chiew and Braver, 2014). It has been previously demonstrated that motivation plays an important role in the performance of various neurocognitive tests (Locke and Braver, 2008). While the Iowa Gambling Task (IGT) is a well-known laboratory task designed to assess decision-making ability during uncertain conditions and it has been used in multiple, various situations (Bechara et al., 1994, 1997), the influence of motivation on participant performances on the IGT has yet to be evaluated. The IGT was originally created to study decision-making impairments in patients with ventromedial prefrontal cortex damage, however, many IGT studies have shown large inter-individual variability regarding their performance in a healthy population. Several clinical reports have reported that, while a majority of healthy participants are able to develop an optimal strategy on the IGT, others do not acquire a preference for one deck over the others, indicative of a lack of learning. In fact, several studies have reported between 37 and 55% failure in healthy population in the IGT (Bechara et al., 2001; Bechara and Damasio, 2002; Bagneux et al., 2013; Mapelli et al., 2014; Giustiniani et al., 2015). The literature has suggested many factors that could account for this variability in IGT performance (e.g., low educational and intellectual levels), but cannot fully explain the variability. Motivation may be one element that explains the heterogeneity of the performance on the IGT. Motivation is identified indirectly (i.e., motivational levels can't be controlled) as an important element in the decision-making process in uncertain conditions (Singh, 2013; Giustiniani et al., 2015), therefore, many studies use monetary reward to improve the involvement in performing the task (Killgore et al., 2006). Additionally, Voss et al. (2008) used a color discrimination task to demonstrate that results in ambiguous situations were more influenced by the motivational level. Furthermore, both motivation and decision-making under uncertainty seem to be altered in the same neuropsychiatric (Cella et al., 2010; Treadway et al., 2012, 2014; Kim et al., 2016) and addictive disorders (Brevers et al., 2016), lending support for a link between these two concepts. Moreover, in an electrophysiological study using event-related potentials (ERPs), a P300 was observed following a loss of money in participants able to develop a correct strategy at the IGT (Giustiniani et al., 2015). The P300 is one of the primarily studied ERPs, known to play an important role in reward processing (Sutton et al., 1965; Wu and Zhou, 2009) and in a large number of cognitive and affective processes (Polich, 2007). Furthermore, the P300 has also been linked with motivational processes (Nieuwenhuis et al., 2005) and its amplitude was described to be proportional to the motivational level (Yeung and Sanfey, 2004). Although the link between motivation and decision making is currently suspected and indirectly made, the evidence of a direct relationship between these two processes has yet to be made (Giustiniani et al., 2017).

The role of motivation is complex and, subsequently, difficult to study (Ryan and Deci, 2000), therefore, it should be clearly defined and evaluated. The concept of motivation can be defined in terms of goal-directed behaviors, such as efforts engaged in the actions conducted to obtain the expected results (Braver et al., 2014). Motivation occurs during the triggering of one activity, but also occurs while the activity continues (Schunk, 2000). Motivation could be defined in cognitive neuroscience as the neural representations of expected outcomes that predict decisions regarding effort investment (Braver et al., 2014). Among the various methods to evaluate motivation, the Effort-Expenditure for Reward Task (EEfRT) (Treadway et al., 2009) appears to be the most relevant task, because it translates the concept of motivation in a behavior in terms of effort to obtain a reward (van den Bos et al., 2006). The EEfRT was originally developed to evaluate motivational dysregulation in clinical populations and its use has been validated on several different populations, such as those with mood disorders, schizophrenia (Whitton et al., 2015), obesity (Mata et al., 2017), and in cannabis users (Lawn et al., 2016), demonstrating its wide acceptability. More precisely, the EEfRT is a multi-trial task in which participants are asked to choose between two options (one easy and one difficult) as a function of the magnitude of the monetary reward and the probability of receiving this reward (between 12, 50, and 88%) if the task is completed. Each option is associated to a button press effort. In difficult options the participant is asked to make a large number of button presses with its no-dominant hand whereas in the easy option less presses are requested, this time with the dominant hand (Treadway et al., 2009). It is important to understand that effort is explained in terms of various costs such as physical effort, uncertainty, and delays to receipt reward. In addition, each probability condition (12, 50, and 88%) could be associated with motivational and emotional states. Indeed, subjects with more motivation made significantly more hard choices than easy choices when the probability to receive the reward is low (12%), in order to receive a greater final gain (Wardle et al., 2011). While the middle probability (50%) condition appears to be sensitive to the lack of motivation in an anhedonic population (Treadway et al., 2009), the high probability condition (88%) seems sensitive to the anticipation of pleasure (Yang et al., 2014).

Behavioral measures of motivation do not account for the dynamic construction of the motivational process. In its neuroscientific definition, motivation is indeed strongly associated with the reward experience and more precisely with neural representations of expected outcomes that predict decisions regarding effort investment (Braver et al., 2014). Moreover, reward experience is a construct characterized by distinct processes, categorized as outcome processing, reward learning, and reward anticipation (Berridge et al., 2009; Berridge and Kringelbach, 2015). To study the dynamic aspect of motivation, the use of neuroimaging with high temporal resolution appears to be one method of interest. Using the high-resolution electroencephalography (HR-EEG), whose high temporal resolution brings in a dynamic view the different

stages of the reward experience and whose spatial resolution gives the opportunity of localizing the neural structures involved in these processes (Nahum et al., 2011; Wahlen et al., 2011). In this context, we adapted the EEfRT to allow for the analysis of the ERP, thus providing the identification of various neurophysiological markers of motivation, such as the P300 and the stimulus preceding negativity (SPN). The SPN is a non-motor expectancy wave preceding a relevant stimulus, during which a non-motor response is required (Brunia and Damen, 1988). The SPN reflects reward anticipation, with a greater negativity when there is a possibility to receive desirable outcomes (Fuentemilla et al., 2013).

The aim of the current study was to investigate the relationship between motivation and decision-making under uncertain conditions. For that purpose, we selected 28 healthy participants, who performed versions of the IGT and the EEfRT adapted to study ERPs (Giustiniani et al., 2015, 2019). We hypothesized that the ability to develop an efficient strategy on the IGT could be explained by high motivational levels at the EEfRT. As a first step, the existence of a behavioral relationship between IGT and EEfRT performances was explored. In the next step, we measured ERPs resulting from the EEfRT in order to explore the influence of motivation during reward experience. We could therefore examine if the ERPs related to specific stages of the reward process, such as the SPN and the P300, were predictive of the IGT performances.

MATERIALS AND METHODS

Population

Thirty-two healthy, right-handed subjects, all males (mean age: 25 ± 5.29) participated in the current study. No participants had any previous medical history of psychiatric disorders, substance abuse, alcohol abuse, neurological diseases, traumatic brain injury or stroke, nor did they take any medication. Prior to participating in the study, participants received information regarding the aims and procedures of the experiment and gave their written informed consent to participate. The influence of real money playing a significant role in motivation, subjects received information that the monetary payment would be proportional to the global gain obtained in the IGT and the EEfRT. Due to ethical considerations, regardless of their performance, all participants received the maximum amount of 75€ at the end of the experiment. All methods were performed in accordance with the relevant guidelines and regulations and all methods were approved by the Ethics Committee of Besançon University Hospital [authorized by the General Health Administration (ANSM 2016-A00870-51)].

Experimental Tasks

All participants performed both the IGT and the EEfRT, in a randomized order.

Iowa Gambling Task

The task was an electronic version of the IGT, adapted for the study of ERPs and the analysis of brain activity sources. The aim of the task was to win as much money as possible by making successive selections between four decks.

The composition of decks, values, and schedules of reward/punishment were predetermined identically to the original form of the IGT (Bechara et al., 1994). While the back of each deck looked identical, they differed in composition. Decks A and B were the disadvantageous decks, they provided immediate reward, but in the long run yielded major economic losses. Decks C and D were the advantageous decks, they provided frequent small wins and smaller long term penalties, which resulted in long-term gain. The subjects were not informed of the number of trials they would be playing. To adapt the IGT to our French population, the money used to play was converted from US Dollars to Euros. At the beginning of the IGT, participants received a loan of 2,000€.

A few changes had to be made to adapt the IGT task to work with the EEG. First, to extend the electrophysiological recording from the hunch phase, no specific instructions were given to participants regarding the presence of advantageous or disadvantageous decks. In the absence of the instructions, the final performance usually worsened, therefore, the exploration phase was longer, and the optimal strategy was hardly found in the 100 trials. However, when more trials were allowed, many individuals performing poorly in the first 100 trials are able to achieve a good final performance. To that purpose, the number of trials was increased from 100 to 200. Each deck contained 200 cards. Second, the design of the trial process was modified to minimize ocular artifacts. For each trial, subjects were required to focus on a cross or a letter while making their selection by pressing a key. After the selection, a feedback of the deck chosen and the total credit amounts were displayed, followed by the amount of money involved in this trial. Then, a fixation point appeared to focus the eyes, followed by a green square if the money was won or a red square if the money was lost. Subjects received instructions to focus on the square and not to blink as long as they had not made their next selection. The choice to show a letter and not the amount of money and outcome simultaneously was made to avoid ocular movements induced by reading the amount. Before beginning the task, subjects were trained with a 5-trials short version of the game.

Effort Expenditure for Reward Task

The Effort Expenditure for Reward Task (EEfRT) was modified from the original version (Treadway et al., 2009) and adapted for ERP analysis. The goal of the EEfRT is to win as much money as possible by completing either easy or hard tasks. Each task is selected as a function of the amount of money that can be won if the task is completed as well as the probability of receiving the reward when the task is completed. This adaptation of the EEfRT was programmed in E-prime (Psychology Software Tools Inc., Sharpsburg, PA, United States). Both the probability, as well as the order of amounts, were randomized across participants. To ensure task comprehension, subjects received oral instructions and were provided with a series of task instructions, followed by a few practice trials prior to starting the experiment.

The experiment began with a calibration phase, consisting of determining the maximum number of button presses that

participants were able to perform in seven seconds with the index finger of their right hand and in fourteen seconds with the auricular finger of the left hand, allowing for personalization of the difficulty of the EEfRT.

In the adaptation used in the current study, the number of trials was fixed to 120. To complete the easy task, participants were required to execute 70% of their maximum number of buttons presses obtained with the right index finger in the calibration phase within seven seconds. When the easy task was completed, participants were eligible to win 1€. For the hard task, participants were required to execute 90% of their maximum number of buttons presses obtained in the calibration phase with the auricular finger of the left hand within 14 s. The time assigned for the completion of the hard task was reduced compared to the original task of 21 s, in order to compensate for the increased number of trials, which increase the study time. When the hard task was completed, participants were eligible to win either 1.5€, 3€, 4.5€, or 6€ (instead of a range of $1.24–$4.30 in the original version). The values were adapted to our French population with European money. Probabilities to win the money when the task was completed have been changed to 10, 50, or 90% (instead of 12, 50, and 88% in the original version). These probabilities applied to both the hard and the easy tasks and were distributed in equal proportions across the experiment. Effort was evaluated by the proportion of choice High Reward / High Cost (HR/HC) or Low Reward / Low Cost (LR/LC) choices on the whole task as function of each probability condition.

Group Assignment

According to their performance on the IGT, participants were separated into two equal groups, those able to develop a favorable strategy and those who were not.

The 200 trials were divided into 10 blocks of 20 trials and, for each block, the net score was calculated by subtracting the number of disadvantageous decks from the number of advantageous decks selected. In order to specifically examine the neural mechanisms underlying the elaboration of a successful long-term strategy on the current task, the net scores from the conceptual phase (i.e., from the last blocks at which the net score remained stable) were used to categorize participants.

The net score was considered to have remained stable when the overall performance was significantly different from a random choice of advantageous and disadvantageous selections. Bonferroni corrected *t*-tests were used to compare the evolution of the gambling performance from chance. From the 4th block on (i.e., 60th trial), participants' net score was significantly different from zero. Per previous studies, subjects were then classified, post hoc, into two groups differing in net score in blocks 4–10, favorable if the net score was higher than 10, unfavorable if the net score was less than –10 and undecided if the net score range was between 10 and – 10 (Bechara et al., 1994, 2000a; Bechara and Damasio, 2002; Giustiniani et al., 2015, 2019). In the pool of 32 participants, fourteen subjects were found to develop a correct strategy and were assigned to the favorable group (mean age: 25.4 ±/ 5.9). Therefore, fourteen participants were randomly selected on the 18 remaining participants unable to develop a correct strategy and were assigned to the undecided group (mean age = 23.8 ± 4.07). No significant differences were observed between each group concerning years of study ($p = 0.310$), marital status (single, couple, divorced) ($p = 0.159$), and the professional status (student, employment, unemployment) ($p = 0.275$). The term undecided was used to highlight that subjects from this group were unable to move toward a positive or negative strategy. These participants favored neither advantageous nor disadvantageous decks (Giustiniani et al., 2015, 2019). **Table 1** shows the net scores for both groups.

EEG Recording

EEG signals were recorded using a 256 channel Geodesic Sensor Net (Electrical Geodesics Inc., EGI, Eugene, OR, United States) during both the IGT and EEfRT. All channels were referenced to the vertex (Cz) and collected with a high impedance amplifier (Net Amp 300 amplifier, Electrical Geodesics) using Net Station 4.5 software (Electrical Geodesics). Data were continuously recorded using a high-pass filter at 1 Hz with a sampling rate at 1000 Hz. For both the IGT and the EEfRT, subjects were instructed to limit body movements, eye blinks, and muscular contractions during task selection and reward feedback.

Data Analysis

Behavorial Data Analysis

In addition to the IGT net score, which was calculated to separate the participants in two groups, several data were extracted from the EEfRT. Two categories of data were analyzed. First, overall motivation as the number of button presses (measured during the calibration phase) and the number of completed trials for the easy and hard tasks was analyzed. Second, parameters relative to the strategy developed at the EEfRT were analyzed as the number of difficult choices of the participant as a function of the different amounts of money and the probabilities of winning the money. Proportion's calculation of choices for the HR/HC or LR/LC was conducted on the whole performance task and in the second step on each probability. We have seen previously that each probability translated a motivational state (Treadway et al., 2009; Wardle et al., 2011; Yang et al., 2014).

EEG Data Analysis

EEG data analysis was performed using Cartool Software 3.55[1]. Raw EEG data were re-referenced offline to a common average reference.

Analyses were conducted for the EEfRT on two intervals around the reward screen. The main temporal interval of interest was following the reward. Epochs of 700 ms (100 ms prior to reward feedback – 600 ms following reward feedback) were extracted from the raw data and analyzed, with a baseline correction applied prior to the feedback through the onset of the feedback (100 ms – 0 ms). The P300 was defined as the mean voltage between 290 and 410 ms, based on grand averages of ERPs for the rewarded and not rewarded conditions. An additional analysis of the FRN, an ERP reflecting the early processing of the outcome, being defined as the mean voltage from 240 to

[1]http://brainmapping.unige.ch/Cartool.php

TABLE 1 | EEfRT and IGT scores in the favorable and undecided groups.

	EEfRT									IGT
	Probability (% difficult choices)			Amount (% difficult choices)				Amount of money	Button presses		net score (blocks 4–10)
	10%	50%	90%	1.5	3	4.5	6		Hard task	Easy task	
Favorable group	8%	41%	61%	2%	35%	50%	61%	135.32	82.07	40.14	16.87
Undecided group	8%	48%	75%	13%	42%	57%	61%	150.79	86.14	41.36	1.35

290 ms, was also conducted. The temporal interval preceding the reward, computed for easy and hard tasks, was also analyzed and related to the SPN. Epochs of 600 ms (500 ms prior to the outcome – 200 ms after) were extracted from the raw data, with a baseline correction of 100 ms applied prior to the participant selection of an easy or hard task. The SPN was defined as the mean voltage within 200 ms prior to the reward feedback. Due to a large number of artifacts, the SPN of three subjects from the advantageous group were removed from subsequent analyses.

For the IGT, the main interval of interest came following the reward screen. Epochs of 700 ms (100 ms prior to reward feedback – 600 ms following reward feedback) were extracted from the raw data and analyzed, with a baseline correction applied prior to feedback on the onset of the feedback (100–0 ms). The P300 was defined as the mean voltage between 290–440 ms, based on grand averages of ERPs for win and loss conditions.

For all ERPs, a band pass filter was applied between 1–30 Hz and a notch filter was applied at 50 Hz to remove environmental artifacts. A semi-automatic artifact rejection method was used, with a fixed criterion of $\pm 100\ \mu V$. Remaining epochs were visually inspected, manually removing any containing blinks, eye movements, or other sources of transient noise from the analysis. Electrodes with an aberrant signal (e.g., excessive noise due to malfunctioning or a bad signal during data collection) were interpolated using a 3-dimensional spline algorithm (average: 4.67% interpolated electrodes). Per previous literature on feedback processing, six central electrodes (Fpz, Fz, FCz, Cz, CPz, Pz) were chosen for the current analysis.

To visualize the brain regions accounting for the different ERPs, source localization was applied using a distributed linear inverse solution based on a Local AUto-Regressive Average (LAURA) model, comprising a solution space of 3005 nodes. Current distribution was calculated within the gray matter of the average brain, provided by the Montreal Neurological Institute (MNI).

Statistics

The overall motivation measured for the EEfRT (i.e., the number of button presses and the number of completed trials) was compared for the two groups of participants (advantageous/undecided) by using paired *t*-tests. The strategies developed at the EEfRT were analyzed by using partially repeated-measures analysis of variance (ANOVA) with three factors, namely group (advantageous/undecided), sum (1.5 to 6 euros), and probability (10, 50, and 90%). The ERPs measured for the EEfRT (P300, FRN) and for the IGT (P300) were also analyzed by using partially repeated-measures analysis of variance (ANOVA) with three factors, namely group (advantageous/undecided), electrodes (FPz, Fz, FCz, Cz, CPz, Pz) and outcome (win or loss). For the SPN, a partially repeated-measures analysis of variance (ANOVA) with three factors was used, namely group (advantageous/undecided), electrodes (FPz, Fz, FCz, Cz, CPz, Pz), and task (easy or hard). In all of these analyses, the threshold of significance was set to 5% and post hoc analyses were performed using a Bonferroni correction.

To evaluate whether the IGT net score and EEfRT parameters (behavior and ERP) were related, nonparametric Spearman rank-order correlations were used. Behavioral EEfRT parameters were the proportion of choices for each probability condition, as well as the total amount of money won by participants. Neural EEfRT parameters were mainly the amplitude of the 6 different electrodes during the P300, but also during the SPN (in a more exploratory approach). Similar correlations were used to compare P300 responses on the IGT and the IGT net score. To consider multiple comparisons, the threshold of significance was set to 1%. We performed the analyses using Statistica 11.0 for Windows (StatSoft, Inc., Tulsa, OK, United States).

RESULTS

Behavior at the EEfRT

Table 1 shows behavioral performances at the IGT for the favorable and undecided groups.

First, we wanted to evaluate whether the ability to develop a strategy for the IGT was related to the behavioral performance on the EEfRT. There were no difference in overall motivation, demonstrated by no differences between both groups in the number of button presses neither for the difficult task [$t(26) = -1.00$, $p = 0.39$] nor for the easy task [$t(26) = -0.58$, $p = 0.18$]. Similarly, there was no difference in completing the difficult task [$t(26) = 0.04$, $p = 0.97$] or the easy task [$t(26) = 0.92$, $p = 0.36$] for each group.

A 2 way partially repeated measures ANOVA with the factors group (favorable/undecided) and sum (1.5–6€) revealed that the decision-making differences on the IGT did not influence the strategy on the EEfRT (ANOVA partially repeated [$F(1,26) = 1.94$, $p = 0.18$)]. Similarly, a two way partially repeated measures ANOVA with the factors group (favorable/undecided) and probability (10, 50, and 90%) showed that decision-making differences on the IGT did not influence choices based on the probability of gain at the EEfRT [$F(1,26) = 2.02$, $p = 0.16$].

However, when looking at the relationship between the IGT and the EEfRT at the individual level, there was a strong

correlation between IGT performance and the percentage of difficult choices at a probability of gain of 90% ($r^2 = -0.59$, $p < 0.001$) (**Figure 1**).

Event-Related Potentials at the EEfRT

The analysis of the P300 revealed that the amplitude of the evoked potential related to the processing of the reward or the absence of the reward on the EEfRT differed significantly in function of the ability to develop a correct strategy or not at the IGT [$F(1,26) = 4.83$, $p < 0.05$]. More precisely, the mean P300 amplitude was larger in the undecided group after a gain compared to an absence of gain ($p < 0.01$). This difference was not present in the favorable group ($p = 1$) (**Figure 2**). No such effect was seen when analyzing the early processing of the outcome, with the FRN [$F(1,26) = 0.09$, $p = 0.77$].

To visualize from which neural structure the differences of P300 topography originated, source localization was performed on the P300 responses. A larger activity in the ventromedial prefrontal cortex was observed in the undecided group after a win (**Figure 3**).

A relationship between the strategies developed on the IGT and the amplitude of the P300 on the EEfRT was also observed on most of the frontal electrodes (**Figure 4**). Indeed, the more subjects developed an undecided strategy on the IGT, the higher the amplitude of the P300 during a gain on the EEfRT on the Fz ($r = -0.50$, $p < 0.01$) and FCz ($r = -0.55$, $p < 0.01$) electrodes.

We also performed an exploratory analysis of the anticipation of the reward. The analysis of the SPN did not show any influence of the decision-making strategy on its amplitude, either when waiting for the result after a difficult task or after an easy task [$F(1,23) = 0.14$, $p = 0.71$].

Event-Related Potentials at the IGT

In order to replicate previous results (Giustiniani et al., 2015), we examined whether IGT behavior also had an impact on the evoked potentials recorded during the IGT. The current results demonstrated that the amplitude of the P300 differed significantly as a function of the ability to develop a correct strategy or not on the IGT [$F(1,26) = 4.45$, $p < 0.05$], with a stronger amplitude for the undecided group. Similar to what was observed with the EEfRT at the individual level, a link between the amplitude of the P300 wave in the reward condition and the IGT score was observed, but on more posterior electrodes. The more subjects developed an undecided strategy on the IGT, the higher the amplitude of the P300 wave was during a gain on electrode Cz ($r = -0.48$, $p = 0.01$) and on neighboring electrodes at lower significance levels (FCz: $r = -0.42$, $p < 0.05$, and CPz: $r = -0.42$, $p < 0.05$).

DISCUSSION

In the current study, we evaluated the relationship between the motivational level measured at the EEfRT and decision-making abilities at the IGT. Healthy participants were separated into two groups based on their ability to develop a strategy on the IGT. Recording neural activity during the EEfRT execution allowed for the definition of neural activity differences between

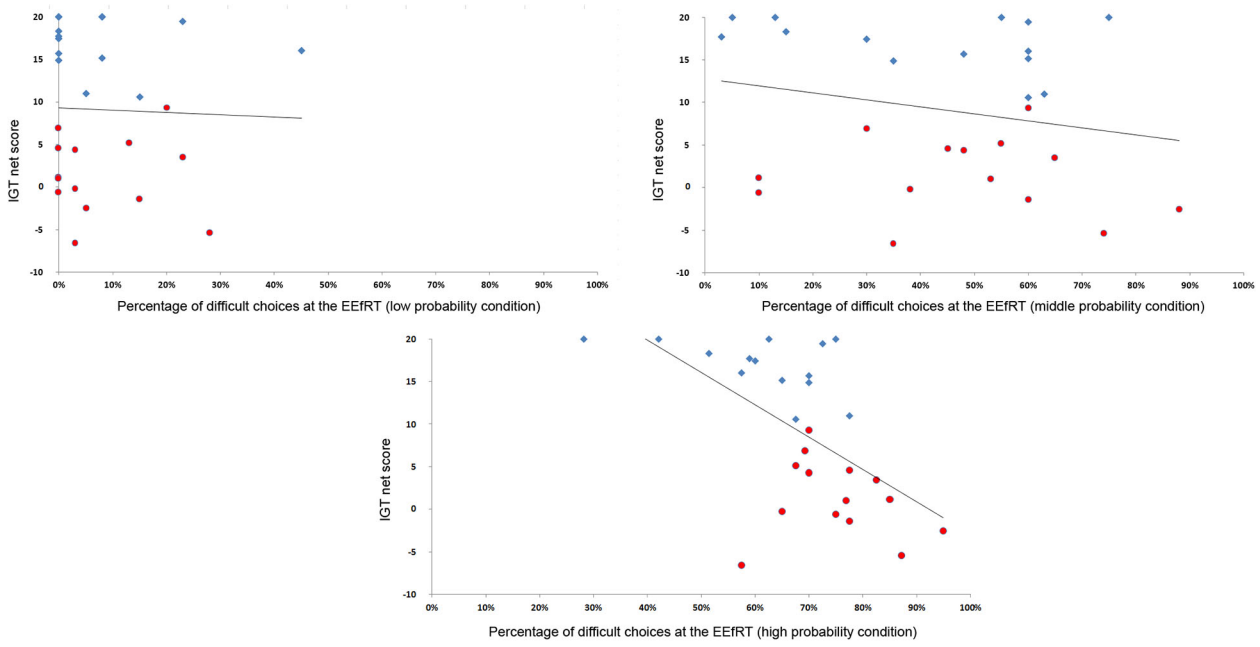

FIGURE 1 | Correlation between the netscore at the IGT and the percentage of difficult choices. The more participants developed a correct strategy at the IGT, the less they selected difficult choices at a probability of 90%. For visualization purpose, participants of the advantageous group are represented in blue diamonds and participants of the undecisive group in red circles.

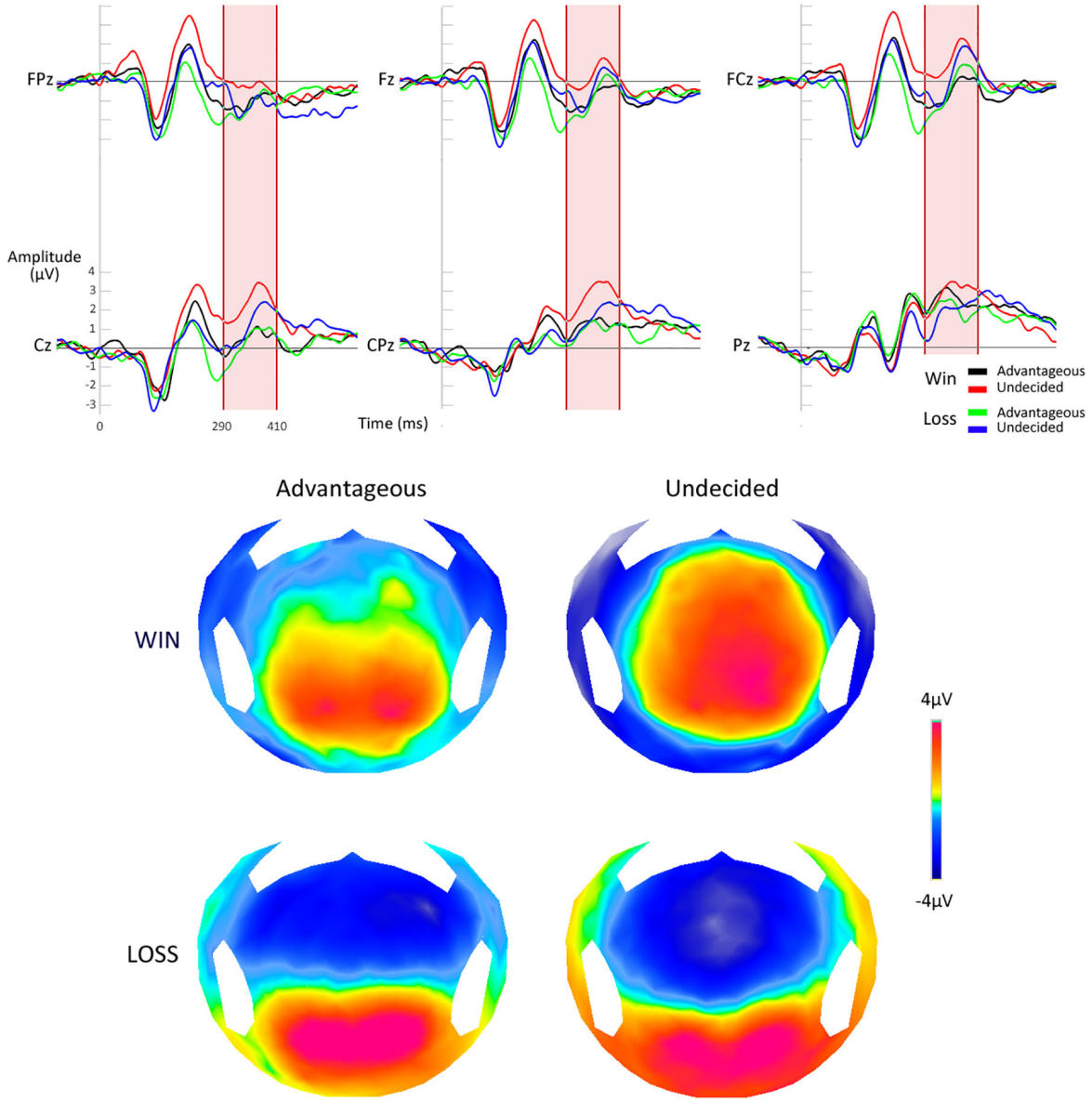

FIGURE 2 | Electrophysiological responses after the processing of a reward at the EEfRT. Top: ERPs on the six electrodes of interest. Down: topographic maps for the four conditions.

subjects who developed a successful strategy at the IGT and subjects who did not.

Relationship Between Decision-Making on the IGT and Behavioral Performances on the EEfRT

Behavioral analyses demonstrated that all participants, independently of their attribution groups, chose a mixture of HC/HR trials and LC/LR trials on the EEfRT. There was no difference between groups in the percentage of trials successfully completed, confirming that all participants were able to complete both the hard and easy tasks throughout the experiment. Therefore, the calibration of the number of presses did not negatively affect performance. Furthermore, there were no differences between favorable and undecided groups in the propensity to choose HC/HR or LC/LR trials. However, the pursuits of the analysis on the whole group showed a negative correlation between choosing HC/HR trials in the high probability condition to received gain (90%) and the netscore on the IGT. In other words, the more subjects make difficult choice in the high probability condition, the less likely they are to perform well on the IGT. Such a result suggests that the usual method of assigning participants into two or more groups according to their performance at the IGT may be somewhat artificial, and that decision-making

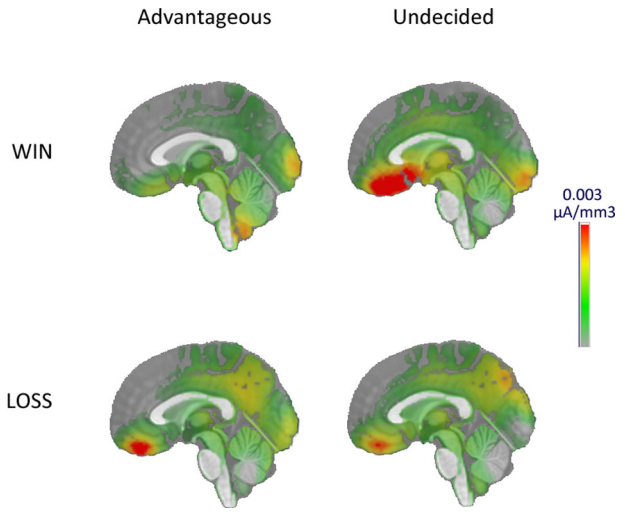

FIGURE 3 | Source imaging of the P300 at the EEfRT.

performance has to be analyzed as a continuum to understand the underlying processes.

The likelihood to choose HC/HR in the high probability condition has been previously associated with anticipatory pleasure (Yang et al., 2014). Appetitive pleasure was positively correlated with the likelihood to make hard choices in high probability conditions, however, this study was conducted on subjects with subsyndromal depression (Yang et al., 2014). The current participants declared having no previous medical history of psychiatric disorders, substance abuse, alcohol abuse, neurological diseases, traumatic brain injury or stroke, and did not take any medication. As the pleasure anticipation was not controlled for in the current study with an appropriate scale, we cannot affirm its role in decision-making. However, we pose a plausible hypothesis that more poor performance on the IGT was associated with a stronger pleasure anticipation and a stronger reward sensibility. In IGT, the emotional processing in addition to the cognitive processing allows the development of the optimal strategy (Bechara et al., 2005; Buelow and Suhr, 2009). To succeed, subjects must learn that two decks are advantageous with small reward and small punishments and that two other decks are disadvantageous with larger immediate reward but a larger long-term punishments (Bechara et al., 1994). Deck composition drives the hypothesis that a disadvantageous strategy was the consequence of reward hypersensitivity. To respond to this, Bechara et al. (2000b) developed variants of the IGT. The original IGT is structured on the reward distribution, whereas the variant is structured on the punishment distribution. Indeed, the magnitude and frequency of immediate reward and punishment, according to several authors, confound long-term decision making (Singh and Khan, 2012). Therefore, the variant of the IGT appears to affect different performances, with more subjects having an impaired decision-making on the reward variant compared to the punishment variant (Bechara and Damasio, 2002). In concurrence with our findings, immediate reward seem to generate greater difficulty in long-term decision-making ability. These data confirm our behavioral hypothesis that decision-making alteration is generated by a stronger reward anticipation and a stronger reward sensitivity.

Neural Mechanisms of Motivation

The ERP analysis was conducted to evaluate our hypothesis that motivation could influence reward sensitivity, which would result in poor decision-making abilities. Neural activity analyses were made on several ERPs, with the aim to describe and identify all elements that influence performance.

The P300 as a Neural Marker of Motivation

The P300 analysis during the EEfRT provides important elements for comprehension. First, the whole group analysis showed a result processing with a significant difference between the gain receptions and not receiving a gain. The gain reception induced a greater positive reaction compared to the absence of reception (Rigoni et al., 2010; Bland and Schaefer, 2011; Cui et al., 2013; Ferdinand and Kray, 2013; Mapelli et al., 2014).

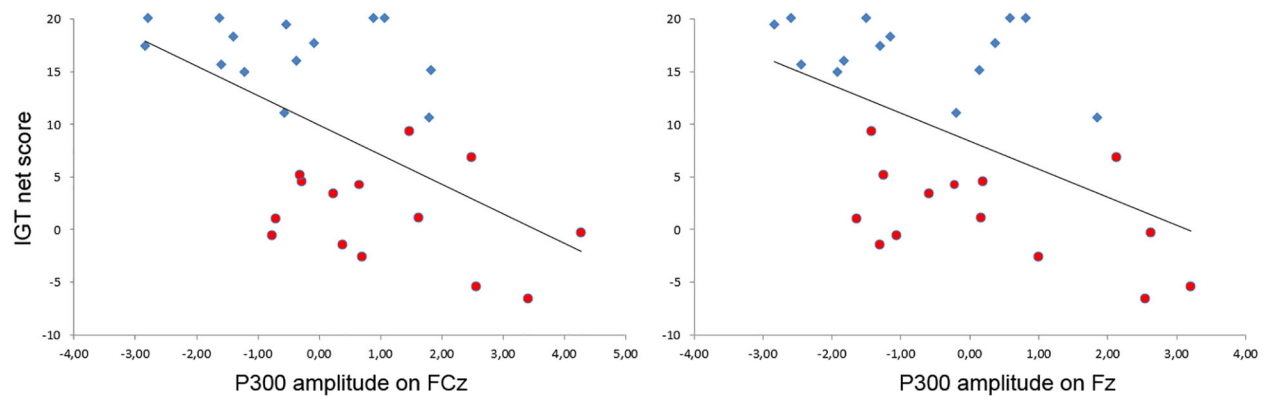

FIGURE 4 | Relationship between the amplitude of the P300 after a gain at the EEfRT and the development of a strategy at the IGT. A significant inverse correlation was observed on electrodes FCz (left) and Fz (right). For visualization purpose, participants of the advantageous group are represented in blue diamonds and participants of the undecisive group in red circles.

However, when this analysis was conducted on the groups, its presence appeared only on the undecided group. Indeed, surprisingly, only participants of the undecided group showed late outcome processing, with a greater sensitivity to the result. This observation is confirmed by the whole group analysis, which showed a significant negative correlation between P300 amplitude to the gain recording during the EEfRT and the net score on the IGT. However, we have previously demonstrated that P300 amplitude is proportional to the motivational level (Yeung and Sanfey, 2004). Per our hypothesis, it seems contradictory that the undecided subjects have the stronger motivational level and that its level is associated with poor decision-making abilities. However, when we reconsider this result by the prism of the various motivational concepts, this correlation appears more coherent. Indeed, the P300 amplitude represents a motivational state induced by the desire to obtain an immediate reward. Therefore, a greater sensitivity to the reward is translated by a greater P300 amplitude. The current participants exhibited a greater sensitivity to exogenous factors, causing a stronger extrinsic motivation (Ryan and Deci, 2000). The concepts of extrinsic and intrinsic motivation, proposed by Ryan and Deci (2000) and Ryan and Deci (2000), serve to distinguish between the interest originating from the activity itself and the interest caused by exogenous factors, two aspects of motivation that influence each other (Robinson et al., 2012). The entanglement between intrinsic and extrinsic motivation is still debated. However, exogenous factors could reduce the intrinsic motivation for the activity and could therefore have a negative impact on performance. It is plausible that the monetary incitation could negatively affect intrinsic motivation (Studer and Knecht, 2016). As a consequence, during IGT realization, participants with a stronger extrinsic motivation would favor more the decks with immediate gratifications, to the detriment of the future losses.

The P300 analysis during the IGT corroborates these observations. Indeed, P300 amplitude appears to be more important in the undecided group. Similarly, the P300 amplitude during the IGT realization is negatively correlated to the net score. This information could be reconciled with reward hypersensitivity and confirms our hypothesis on the behavioral analysis. However, if the P300 is sensitive to the outcome valence and amplitude, it is also a carrier of more complex cognitive information. Indeed, its amplitude is modified by the attention that the participant lends to the stimulus (Polich, 2007), without contradiction to its motivational aspect. The motivation increases, in a significant way, the interest for the stimulus with major consequences on attentional level. Therefore, based on these observations, it appears that the inability to develop an optimal strategy is associated with greater attention on the immediate outcome. Impacts on memory provides additional information to better comprehension, because the P300 is also assigned to the working memory updating after an unexpected event (Polich, 2004, 2007). In conclusion, the P300 reflects the attentional allocation process and the process of updating memory (Scharinger et al., 2017). Frequently, performance differences on the IGT could be explained by differences in cognitive abilities. More precisely, it was recognized that working memory played an important role on IGT performances (Bechara et al., 1998; Maia and McClelland, 2004). However, these observations were made on clinical populations, which could explain the discordance with our results. The updating of the working memory observed through the P300 was correlated with poor performance on the IGT. Decision-making ability seems to be influenced by the ability to filter the irrelevant distractors, rather than the ability to store immediate outcomes from decision-making in the working memory (Schmicker et al., 2017). This therefore explains why participants who developed an optimal strategy showed a blunted P300. This blunted P300 translates to less attention being paid to the immediate reward with a greater ability to filter distractors, in favor to an efficient long-term strategy.

The undecided group seemed to evaluate outcomes as more unexpected than the favorable group. As a consequence, the more they are sensitive to and surprised by the outcome, the more they take their decision as a function of the immediate outcome. This led to poor decision-making abilities with the immediate reward choice and negative consequences in the long term. This is in concurrence with a previous study, which showed a reward hypersensitivity induced inability to develop an optimal strategy (Bechara et al., 2002).

In the last step, source localization visually confirmed that one of the generators of the P300 wave was located in the ventromedial prefrontal cortex (vmPFC) (Horovitz et al., 2002; Polich, 2007; Wang et al., 2014). Indeed, comparison of vmPFC activity between groups showed a stronger activity during gain processing in the undecided group. This activity may reflect a processing in favor of the most appealing result (Rogers et al., 2004) in the undecided group. This confirms a reward sensitivity in the undecided group and that their behaviors are motivated by the reward perspective at the expense of punishments, compared to the favorable group.

Other ERPs Involved During the EEfRT

The exploratory analysis of the SPN during the EEfRT showed that, at the whole group level, the SPN was more negative for difficult compared to easy choices. This result suggests that difficult choices were linked to greater reward and, when participant made the choice of the difficulty, they were more hopeful to obtain the desirable outcome. This result is in line with a previous study in which the possibility to receive desirable outcomes induced greater anticipatory negativity (Fuentemilla et al., 2013).

Further exploratory analyses did not show any difference between groups. The lack of differences in the SPN analysis suggests the same level of commitment to the task between groups. However, the number of trials retained was too weak and did not allow for the processing of this information in any manner other than as an exploratory result. Indeed, we had to reject many trials during the ERP analysis due to artifacts induced by movement. It appears that following the task, subjects experience difficulties with being unable to move or blink.

Finally, we confirmed the presence of the FRN, with greater amplitude with a loss compared to a gain. The FRN did not differ between the groups, nor was its amplitude associated with the

proportion of difficult choices. This result is in agreement with the previous literature, which described the FRN in the early outcomes processing (Gehring and Willoughby, 2002; Yeung and Sanfey, 2004; Holroyd et al., 2006). Furthermore, the FRN is indifferently observed during the IGT and EEfRT. Cumulatively, this data provides information on the unique role of the FRN in the outcome processing.

CONCLUSION

Although we did not find that motivation directly influence decision-making performance at the IGT, behavioral and neuronal data provide evidence of a relationship between the propensity to focus only on the immediate outcomes and the development of an inefficient strategy on the IGT. Whether altered decision-making is a cause or a consequence of focusing on immediate outcomes remains to be explored. It is plausible that the behavioral differences on the EEfRT there were not significant in the current, healthy population could be observed in clinical population with important variation in their motivational level. Therefore, behavioral differences could provide categorical information, while ERPs bring a more dimensional approach, with a continuum between good and impaired decision-making abilities, as demonstrated by the correlation. The current investigation should be extended to a clinical population in order to verify this hypothesis.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of Besançon University Hospital [authorized by the General Health Administration (ANSM 2016-A00870-51)]. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JG, DG, MN, LP, PV, and EH conceived of and designed the experiments. JG, TC, and DG performed the experiments. JG, DG, NG, and TC analyzed the data. JG, DG, DB, JT, MN, CM, BT, MN, and EH contributed to writing of the manuscript.

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Iowa Gambling Task and Distortion in Perception of Body Image Among Adolescent Women With Eating Disorders

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The Iowa gambling task (IGT) is an instrument for the neuropsychological evaluation of cognitive and emotional decision making (DM) processes that was created to test the somatic marker hypothesis (SMH) described by Damasio in 1994. It was initially applied to patients with frontal lobe lesions due to its association with executive functions but was subsequently used on patients with a variety of disorders. Although the DM process is inherently perceptual, few studies have applied the IGT to examine DM processes in patients with eating disorders (EDs), and even fewer have associated the IGT to the perceptual distortion of body image (PDBI) in this population. People diagnosed with ED exhibit heightened control over their somatic responses—for example, they can delay digestion for hours—and DM may be affected in this condition. This study compares the performance of two samples of adolescent women—hospitalized patients with ED, and healthy controls with similar demographic characteristics—on the IGT using body image as a possible factor in the SMH. Seventy-four women with a mean age of 14.97 years (SD = 2.347) participated. To analyze their body self-image, we used the figure-rating scale and compared the results with their body mass index (BMI). Correlations between indices of the IGT and distortion in body image were then explored. The results revealed significant differences between the groups in terms of evolving performance on the partial IGT. Patients with ED performed worse than their healthy counterparts in the last 40 trials and exhibited greater distortions in their body image, especially in terms of overestimation. Indices of these distortions were negatively correlated with the total IGT. These results are compatible with the SMH because they suggest that patients with ED evinced blindness with regard to the future, as described by their authors. In addition, a negative correlation was found between the IGT and PDBI, showing that a more distorted body image was associated with lower IGT, that is, more disadvantageous or riskier decisions were made by the subjects with more distortion.

Keywords: adolescent women, decision making, distortion of body image, eating disorders, Iowa gambling task, perception

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INTRODUCTION

Decision making (DM) encompasses multiple and varied situations, ranging from the simplest choice of constant everyday decisions to the most complex situations at crucial points in our lives. In such situations, cognitive processes and neurological, somatic, and emotional structures are involved in initiating, supervising, controlling, and evaluating our behavior. These neurological systems are involved in executive functions (FFEE) and higher psychological processes. At the same time, the most basic psychological processes like attention, perception, memory-related, and motivational systems must function properly to enable complex or higher processes, such as DM (Fox et al., 2013; Patterson et al., 2014; Cowan, 2017; Padilla et al., 2018). Neuropsychological functioning enables human beings to adapt to their environment, to assume diverse responsibilities and tasks, display socially appropriate behavioral and emotional responses, overcome and learn from adversity, and formulate abstract thoughts of self-awareness and ethical and moral judgments (Pelegrín and Tirapu, 1995; Graham and Harris, 1996; Stelzer et al., 2010).

Recent neuroscientific studies have shown that emotions are crucial in the DM process. Decisions and their consequences imply emotions, and many of our choices are guided by past emotional experiences or their anticipation. This evidence has led to the hypothesis that emotions can play an important role in guiding our decisions, as described in the somatic marker hypothesis (SMH) proposed by Damasio (1994). To test this, the Iowa gambling task (IGT) (Bechara et al., 1994, 1997) was created. It was used initially on patients with frontal lobe damage and was subsequently administered to people with a wide variety of psychopathologies.

The IGT is designed to require more learning than is needed to simply indicate correct and incorrect long-term responses because it allows subjects to fine-tune their performance depending on feedback in the form of the consequences of their responses in prior trials (Pasion et al., 2017). Kovalchik and Allman (2006) used the IGT to study reverse learning conceptualized as the shift toward a more adaptive response (less attractive because of reduced gains) by inhibiting the prepotent response (more attractive because of large initial gains). This adaptive behavior of inhibiting the predominant response requires that participants learn to forgo high monetary rewards in favor of low to moderate monetary rewards. Likewise, non-inhibition would be comparable to the characteristic behavioral deterioration observed in patients with ventromedial prefrontal cortex (VMPFC) damage, addicts, psychopaths, and individuals with other self-destructive disorders who persist in previously gratifying behavior despite high long-term costs.

Therefore, the learning that can indicate the IGT is not the simple change from incorrect to correct answers but rather requires active inhibition of the instinctive response to choose the less attractive option.

Perception is fundamentally a psychological process that does not imply a copy of empirical reality but the interpretation made by the subject in an active and constructive way using content captured by the senses (Mohr et al., 2016; Felin et al., 2017). This interpretation is based on past perceptual experiences, their consequences, and personal expectations and predispositions (Biggs et al., 2015; Soto et al., 2015).

Adolescence is the stage of development in which one's identity, self-concept, and self-esteem are acquired, with the perceived body image as the main source of feedback. The body image is evolutionarily constructed by internalizing the experiences of his/her own body through interpersonal, social, and cultural mores that dictate personal attractiveness and competence (Rodgers et al., 2014; Rohde et al., 2015; Haynos et al., 2016). Therefore, it is not unusual that during this stage of higher vulnerability to sociocultural influence and peer group influence, teenagers assign a greater weight to their self-evaluation of their physical image than to other maturation-related factors of development, such as DM and its consequences, even though they also shape the emerging adult personality (Brosch et al., 2013; Hartley and Somerville, 2015).

Age and Performance in the IGT

IGT performance has been shown to increase significantly from early adolescence to adulthood. Hooper et al. (2004) compared IGT performance in groups of children and adolescents of various ages, obtaining significantly better results with older subjects. Participants ages 14–17 performed significantly better than participants ages 9–10 in the 100 computerized IGT trials. This was also shown with the 5-block analysis (20 cards/block). In Block 4, the 14- to 17-year-old group performed better than the two younger groups (9–10 and 11–13 years old). In Block 5, the 14- to 17-year-old group performed better than the 9- to 10-year-old group. Overman and Pierce (2013) confirmed these results but also observed that once subjects reached young adulthood (mean age of 19 years), they no longer differed in performance compared to older adults (mean age of 59 years).

This steady increase in IGT performance from adolescence through young adulthood has been interpreted in different ways, one of which is that increases in performance are related to ongoing neuroanatomical and neurochemical development of the frontal lobe.

During adolescence there are substantial brain changes, especially in the PFC (Giedd et al., 1999), making IGT an optimal task to use with this population. The hypotheses that attribute poor decision making among adolescents to neuroanatomical changes in areas within the PFC indicate that optimal IGT performance depends on the integrity of several PFC regions: the orbital PFC (ORBPFC) (Bechara et al., 1994), dorsolateral PFC (Fellows and Farah, 2005), and/or dorsomedial PFC (Manes et al., 2002). Damage to any of these areas impairs IGT performance and, in adolescence, these and other areas of the brain undergo changes.

Gender and IGT Performance

Recent studies on gender differences in IGT performance show that males perform better than females. This gender difference is the result of women's preference for high-gain-frequency cards, either from the disadvantageous Deck B (van den Bos et al., 2013) or from the summation of the two decks, B and D (Reavis and Overman, 2001; Overman et al., 2006). In addition, men declared

the correct rule significantly earlier on the task (75th test on average) than women (97th test on average). That is, men and women learn to choose advantageous cards in the task, but men choose more cards from decks C and D and women choose more cards from decks B and D.

Different etiological hypotheses are proposed for these results. Some authors proposed that hypersensitivity to loss may be driving female performance in risk-taking tasks (Deakin et al., 2004; Lee et al., 2009; van den Bos et al., 2012, 2013), while other authors have interpreted that the IGT gender difference is driven by a male aversion to loss and a female preference for reward (Overman et al., 2006; Overman and Pierce, 2013). This second hypothesis is based on the results of Bolla et al. (2004), who reported differential activation in ORBPFC subregions, measured with PET imaging, between men and women while performing the IGT. Men showed increases in activation in the lateral ORBPFC (BA 47), and females showed increases in activation in the medial ORBPFC (BA 11).

Regarding the hypothesis of hypersensitivity to loss in women, van den Bos et al. (2013) reported that they focus on both win-loss frequencies and long-term pay-off of decks, while men focus on long-term pay-off. In addition, women may be more sensitive to occasional losses in long-term advantageous decks than men. Therefore, women need more trials (40–60) to reach the same performance level as men.

This proposal is based on the psychological mechanisms and neurobiological substrates underlying sex differences in IGT-type decision-making: serotoninergic activity and left-right hemispheric activity, as well as differences in the dorsolateral prefrontal cortex. Sex differences in ORBPFC activity may be due to the organizational effects of gonadal hormones. Thus, the behavioral and neurobiological differences in IGT between men and women would be an expression of more general sexual differences in emotional regulation.

ORBPFC involvement in IGT performance leads to the promptly assumption that enhanced IGT performance is based on functional maturation of ORBPFC and related networks. However, it should not be forgotten that there are numerous social and environmental changes that occur concomitantly with IGT improvement during this time period (He et al., 2012; Overman and Pierce, 2013).

Perceptual Distortion in Adolescent Women With Eating Disorders (ED)

Alterations of cognitive processes involved in DM, such as perception, have a direct impact on a person's ability to develop independent, autonomous, and adaptive personal and social lives (Rolls, 2004; Brooks et al., 2016). Thus, distortions in perception, particularly those related to body image, are considered to be among the main clinical symptoms of eating disorders (EDs). Alterations in perception have been observed in other psychological disorders, such as body dysmorphic disorder, hypochondria, and psychosomatic delusions, and have been noted in the general or non-clinical population. Perceptual distortion of body image (PDBI) is also common in adolescents of control groups). The literature suggests that ∼60% of adolescent females are dissatisfied with their bodies, and desire to change their shapes or sizes (Balluck et al., 2016; Coelho et al., 2016; Duchesne et al., 2017; Japil et al., 2018; Quittkat et al., 2019). It also calls attention to the increasing trends in these factors across the world (Smink et al., 2012; Mond et al., 2013; Ganesan et al., 2018; Fuller-Tyszkiewicz, 2019).

Research on sociocultural influences on body image development has had extensive media impacts (Rodgers et al., 2014). However, little attention has been paid to describing the basic psychophysiology of body image and analyzing its components in the context of personal health and well-being. It is also important to consider the aesthetic industry, with an objective to make money from people who are unhappy with their bodies (American Society of Plastic Surgeons [ASPS], 2018; British Association of Aesthetic Plastic Surgeons, 2014; Department of Health (UK), 2013; Grogan, 2017).

In 2009, the International Society of Aesthetic Plastic Surgery (International Society of Aesthetic Plastic Surgery [ISAPS], 2009) published its first survey of interventions in plastic and cosmetic surgery. A survey of registered interventions in 20 countries, featuring 20,000 plastic surgeons of the 32,000 registered in these regions, yielded a total of 17,295,557 interventions. The most common surgery performed was liposuction, accounting for 18.9% of the total (3,268,860.273), at an average cost of $6000 US/intervention, with a total annual cost of $19,613,161,638. In 2018, the largest increases in surgical procedures was recorded in liposuction and abdominoplasty, and cases of each increased by >9.7% compared with 2017 statistics (available at: http://www.isaps.org). It is also necessary to consider these figures in light of interventions that were performed but not registered on official accounts, non-surgical treatments (medication and body creams for fat absorption, herbal treatment, slimming clothes, and cosmetics), and records that were inaccessible due to doctor–patient confidentiality agreements.

In general, the above trend aims at a social and cultural model encouraging the "beauty of slimness" or a "thin-ideal" as well as "weight phobia." This has pernicious consequences for health and leads to an increase in eating disorders, and has led to a collective obsession with body image (Smith et al., 2018; Grave et al., 2019). Furthermore, Suisman et al. (2012, 2014) concluded that most variance in the internalization of the thin ideal can be accounted for by environmental factors, and twin models showed no significant differences in etiological effects across development, suggesting that the thin ideal is independent of genetic influences.

Neurologically, functional magnetic resonance imaging now allows us to identify areas of the brain that are over- or under-active in patients when they are exposed to controlled stimuli, such as those related to EDs. Diffusion tensor imaging allows for the dynamic mapping of circuits that connect key areas involved in executive functions: The ventromedial prefrontal cortex (VMPFC) is critical for weighing risks and rewards, learning from experience, and emotion regulation. The dorsolateral (DLPFC) is responsible for impulse inhibition and future orientation, and is connected to the anterior cingulate cortex (ACC, surrounding the corpus callosum), which is in turn connected to limbic system regions that handle reward and

task anticipation, attention, detection of errors, DM, empathy, emotional modulation, and the autonomic control of pulse and blood pressure (Starr and Kreipe, 2014).

However, the frontal cortex is heterogeneous, and its development is extremely complex because not all subareas develop simultaneously during adolescence. There is specific regional development with some areas being pruned while others show increases in synapses (Giedd et al., 1999). Some researchers have suggested that changes in the dorsolateral PFC are more correlated with adolescent decision-making behavior patterns (Lewis, 1997; Sowell et al., 2001; Paus, 2005), while others have suggested that changes in the ventromedial PFC are more highly correlated with such patterns (Hooper et al., 2004; Schwartz et al., 2010).

The review by Chen et al. (2018) on the neurocognitive basis of ED in relation to decision-making indicates that activity in these brain systems is comparable to the literature knowledge on addictive and problematic behaviors. It proposes an integrative triadic neural model to give etiology to the components and altered neuropsychological functioning of compulsive food consumption based on three systems: (a) an impulsive system (fast, autonomous, and subconscious) of processing and anticipation of hyperfunctional reward (dependent on amygdala-striatum) in response to food-related cues; (b) a reflective (slow, deliberative, and conscious) system of reflective control and functional inhibition (dependent on the PFC) that cannot adequately anticipate and weigh future results; and (c) an altered interoceptive consciousness system (dependent on the insular cortex). That third system would be incorporated into the traditional dual vision and constitutes the basis of the triadic model, whose function is to integrate homeostatic signals. When it is violated, it translates into a strong desire to consume that hijacks the inhibitory system and excites the reward system.

The tripartite model of decision-making regarding food cues reveals that food-related stimuli can trigger habitual involuntary bottom-up desire mediated by the amygdala-striatal system. The goal-directed reflective system may fail to anticipate future results of excessive food consumption and/or failure to inhibit excessive food consumption. This imbalance may be exacerbated by an altered interoceptive awareness system that hijacks inhibition/reflection resources and excites the impulsive system (Chen et al., 2018).

A review by ter Steege and Kolkman (2012) indicated that during physical exercise, the increased activity of the sympathetic nervous system redistributes blood flow from the splanchnic organs to the working muscles. With prolonged duration and/or intensity of exercise, splanchnic blood flow may decrease by 80% or more. In this respect, and in search for the ideal of the body image, people with eating disorders usually practice intense physical exercise, exhibiting high control of their somatic responses, and, in extreme cases, can even delay their digestion for hours (Dubois et al., 1979; McCallum et al., 1985). They can also decide to vomit to lose weight as a short-term reward to achieve the ideal of the body image, neglecting long-term consequences (e.g., malnutrition, death).

The risky decisions made by adolescents with EDs may indicate that they have altered cognitive processes: in eating restrictions of anorexia nervosa (AN) with abnormal activity in the ventromedial PFC (Cavedini et al., 2004; Tchanturia et al., 2007; Danner et al., 2012; Chan et al., 2014) and in abusive and compulsive eating in obesity, with neuronal changes in the key neuropsychological systems involved in habits, decision-making and self-control processes (Madrigal et al., 2000; He et al., 2014, 2015; Suchan et al., 2015; Chen et al., 2018). The cognitive impairment underlying perceptual distortion of body image in EDs has also been extensively studied, as the most important component and criterion for the diagnosis of AN of DSM-V (American Psychiatric Association [APA], 2013). Studies have reported alterations in the perceptual process, decreased parietal cortex activity, and altered somatosensory integration (Hebebrand et al., 2004; Uher and Treasure, 2005; Steinglass et al., 2006; Cucarella et al., 2012), as well as increased activation in bilateral frontal structures including the medial frontal gyrus and left medial temporal gyrus covering the striatum (Hodzic et al., 2009). However, the relationships between the perceptual distortion of body image and the neuropsychological process of decision making have not been systematically explored, although both seem to concur alterations on these cortical areas.

The main objective of this study was to analyze the relationship between the perceptive distortion of one's own body image and risk decision making using the IGT (Bechara et al., 1994). We compared a group of adolescents with ED (g. clinic) with a group of healthy and demographically similar women (g. control). The following secondary objectives were specified in the form of hypotheses to be tested: (a) the clinical and control groups will differ in the total IGT performance, but both will be negative due to their young age; (b) IGT learning will show differences between groups in the two last blocks; (c) PDBI will show greater overestimation of body image in the ED group compared to control; and (d) PDBI will correlate with IGT.

MATERIALS AND METHODS

Participants

Seventy-four female volunteers with a mean age of 14.97 years (SD = 2.347) participated in this study. They were separated into two groups: an ED group, consisting of women hospitalized with EDs (n = 23), with an average age of 15.13 years (SD = 2.528), all ED group patients were hospitalized by anorexia nervosa except for one patient with bulimia. The control group included healthy women (n = 51), and the mean age was 14.9 years (SD = 2.283). We enrolled twice the number of healthy subjects as controls based on a recommendation of the ethics committee for clinical trials of the Juan Ramón Jiménez (JRJ) Hospital of Huelva (Spain). Age was not significantly different between groups [$t_{(74)} = 0.385$, $p = 0.701$].

All subjects in the ED group were undergoing the same medical and psychological treatment according to JRJ Hospital protocol.

The ED group inclusion criteria were hospitalization or having been cited as an out-patient for medical follow-up after recent hospital discharge. Subjects in the control group were students of a secondary education center with parental confirmation of no

ED diagnosis. The exclusion criteria were: (i) drug consumption, including the intake of more than 12 g of ethanol per day; (ii) any psychiatric diagnosis (apart from ED); and (iii) any psychophysiological condition that could have altered the results of the questionnaire, including chronic illness and sensory or cognitive disability.

The participants were individually evaluated while ensuring the privacy of their data. ED patients usually ask physicians for study results, even though this is contrary to the course of clinical intervention. Thus, the evaluators did not inform the participants about the data obtained from these measures.

All participants and their legal tutors provided informed consent. This study was configured according to the protocols established by the PEIBA (Portal de Ética de la Investigación Biomédica de Andalucía). Ethical approval was obtained based on the relevant legislation and the national and institutional guidelines, and was in accordance with the ethical rules of the Helsinki Declaration.

Decision Making: Iowa Gambling Task

Total IGT

To assess the participants' DM, the IGT was applied using the Cartas software (Palacios et al., 2010), a computerized version of the IGT proposed by Bechara et al. (1994): the "ABCD" version. The total IGT over 100 trials of each participant was calculated as follows:

$$\text{Total IGT} = (\text{C} + \text{D}) - (\text{A} + \text{B})$$

A higher IGT score reflected better decision making while lower ones indicated riskier DM or disadvantageous choices.

The IGT consists of four decks of cards presented on a screen from which participants must choose one card in every trial for a total of 100 choices, each displaying a certain gain or loss, and the cards were distributed in four decks of 40 each. The decks were shown to the participants in the follow order: A, B, C, and D. The choice of a card was locked within 2 s of the participants clicking on it. However, participants could freely think before making a new decision without any maximum time restriction to click on the next card.

The participants started the test with €2000 in virtual currency, which was shown on the screen and automatically updated with gains or losses after each selection. The goal of each participant was to win as much money as possible. The best strategy was to choose two advantageous decks, C and D, with long-term gains, but each card in these decks had a small value (of gain or loss). On the contrary, the two disadvantageous decks, A and B, incurred long-term losses because each card had a large value (of gain or loss). A few cards offered a substantial gain (€100), but others led to large loss (-€1250).

Partial IGT

The partial IGT was calculated by analyzing the results of five partial blocks (20 trials per block) of the task from b1 to b5: b1 (cards 1–20), b2 (cards 21–40), b3 (cards 41– 60), b4 (cards 61–80), and b5 (81–100). The learning phase of the IGT was composed of the first three blocks, and the task execution phase was constituted by the last two blocks of the tests.

Disadvantageous decks are more attractive owing to their high rewards, and as a consequence initially attracted a prepotent response. In adaptive learning for the IGT, inhibition or curbing these initially predominant choices (decks A and B) in favor of lower monetary rewards in the short term (decks C and D) is required to obtain long-term benefits. This curbing is conceptualized as a reversal of the effect of learning (Kovalchik and Allman, 2006). During the learning phase of the IGT, implicit feedback is comparable to uncertainly experienced in real-life decisions (Bechara, 2007; Brevers et al., 2013). In its execution phase, the reversal learning effect may highlight the time at which the participants learn the advantageous strategy (Pasion et al., 2017).

Perceptual Distortion of Body Image (PDBI)

Anthropometric

We first calculated the real body mass index (BMI), measuring the weight in kilograms and height in meters, using the following formula:

$$\text{BMI} = \frac{\text{weight } (\text{kg})}{\text{height}^2 \ (\text{m}^2)}$$

Body Image

The silhouettes test (ST) was used to analyze each participant's self-estimated body image using an adaptation of figure-rating scale proposed by Stunkard et al. (1983). In this test, graphic representations of nine rank-ordered human female figures that incrementally increased in size from underweight to obese (from F1: BMI < 18, to F9: BMI > 32) were provided to the participants. The original ST also included nine human male figures that were not used here.

The participants were instructed to select the figure perceived as representative of their own at the time of the study, and this choice was designated as the perceived BMI (pBMI). The previously measured real BMI values were classified into nine categories corresponding to the Stunkard figures as follows: F1 (BMI < 18), F2 (BMI 18–20), F3 (BMI 20–22), F4 (BMI 22–24), F5 (BMI 24–26), F6 (BMI 26–28), F7 (BMI 28–30), F8 (BMI 30–32), and F9 (BMI > 32). We refer to these results as the "current BMI" (cBMI).

Perceptual Body Image Distortion Index

To calculate the PDBI index, the following formula was applied:

$$\text{PDBI} = \text{pBMI} - \text{cBMI}$$

We also adjusted the PDBI as the cPDBI to include the closest upper and lower ST figures in relation to the figure selected by each participant ($\pm$ 1 Fx), according to a principle of visual similarity, to reduce the possibility of false positives. For example a patient selecting F7 and having a cBMI of F4 would present a PDBI of 3 points (F7 minus F4) but a cPDBI of 2 points because we include F6 and F8 since they are the closest figures to F7, and the difference will take the figure closer to cBMI (F6, the closest figure from the range F6-F8 minus F4). In other words, we subtract 1 point to the absolute value of the PDBI except for cases with no distortion (0 points of PDBI).

The correlations between variables of the IGT and those of ST (PDBI) were calculated using Kendall's τb non-parametric contrast test, also pBMI and cBMI were correlated. All p values were two-sided, with $p < 0.05$ considered statistically significant.

Statistical Analysis

The Student's t-statistic was used to compare mean values of the variables. To compare the mean socioeconomic levels of the groups, we used the non-parametric Mann–Whitney's U contrast test. The Student's t-test for independent samples was used to examine possible differences between groups in terms of overall DM during the test (IGT). It was also used to establish differences in anthropometric measures between groups. Repeated measurements analysis of variance (ANOVA) followed by planned comparisons of groups (ED vs. control) was used to confirm differences in the number of choices depending on the type of deck (advantageous vs. disadvantageous) and to compare group differences in terms of partial IGT (b1, b2, b3, b4, b5) to observe their evolution in performing the task across blocks. ANOVA was also used to examine the cBMI, ST, PDBI, and cPDBI. The correlations between variables of the IGT and those of ST (PDBI) were calculated using Kendall's τb non-parametric contrast test. All p values were two-sided, with $p < 0.05$ considered statistically significant. Finally, we performed linear regression of the correlated variables.

RESULTS

Demographic and Socioeconomic Variables

No significant differences were observed between the groups in age [$t_{(74)} = 0.385$ and $p = 0.701$] or socioeconomic level [$U_{(74)} = 553.5$; $p = 0.658$] in a questionnaire administered to parents included a scale of three options: (1) Rental housing/VPO, (2) mortgaged home, and (3) home ownership. It also asked: Is your family economy on the Andalusian per capita income average, and can you make ends meet without financial difficulties? The answer was YES or NO. Both groups were in the range of the Andalusian average per capita income.

The education levels of all participants were identical due to their age, which placed them along compulsory schooling at the secondary level (ESO) and furthermore, none of them was in a higher or lower grade than in the one corresponding to them by age.

Decision Making

Total IGT: Hypothesis (a)

The normality goodness-of-fit test of the IGT variables was performed using the Kolmogorov-Smirnov statistic, and they were not significant ($p > 0.05$), indicating that the variables analyzed were normally distributed. There were no significant differences between the ED group ($M = -4.78$, SD = 15.08) and control group ($M = -0.39$, SD = 13.49) in terms of total IGT [$t_{(74)} = -1.249$, $p = 0.216$]. Although this index was lower in the ED group, both groups had negative values, indicating risky DM in both.

Partial IGT: Hypothesis (b)

In terms of partial IGT, we analyzed differences between the ED and control groups for each block separately, and we found an evident group effect in b4 [$F_{(1,\ 72)} = 8.949$, $p = 0.004$] and b5 [$F_{(1,\ 72)} = 4.109$, $p = 0.046$]. Student's t-tests revealed significant differences in blocks b4 ($t = -2.991$, $p = 0.004$) and b5 ($t = -2.027$, $p = 0.046$). These differences between groups in terms of DM task evolution reflected significantly disadvantageous execution in the last 40 trials by the ED group, with more advantageous choices made by the control group (**Figure 1**).

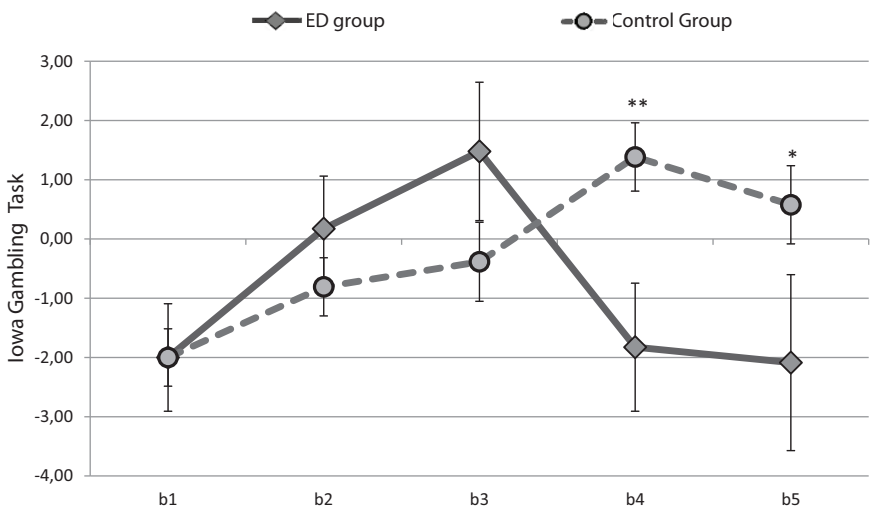

FIGURE 1 | Mean IGT scores through the five trial blocks of the IGT for the ED and control groups. $^{**}p < 0.01$, $^{*}p < 0.05$.

These results indicate that more disadvantageous choices were made by members of both groups in the first 20 trials (first block). However, advantageous decisions increased in the second block. Only in the last two blocks of the task were significant differences observed between the groups: advantageous decisions by members of the control group increased, but such decisions decreased for the ED group, and its number of disadvantageous decisions increased. Thus, performance in different task blocks revealed differences between the ED and control groups in the last two blocks (b4, b5), without differences in the first three blocks (b1, b2, b3).

Perceptual Distortion of Body Image: Hypothesis (c)

Anthropometric Measures

To estimate the PDBI, we calculated the mean anthropometric indices for each group and compared them using Student's *t*-tests (**Table 1**). Weight (p = 0.004), and BMI (p = 0.002) were significantly different between the control and ED groups. Height was similar between groups (p = 0.405), which was expected owing to the sociodemographic similarities of the samples (**Figure 2**).

Body Image

The ED and control groups did not differ in the choice of the ST figure independently of the current BMI [$F_{(1,\ 72)}$ = 0.281; p = 0.597] of their members. The absence of significant differences in ST between the ED and control groups contrasted with the previously reported results of the "real BMI," which supported the hypothesis of perceptual distortion in the ED group (**Table 2**).

Perceptual Body Image Distortion Index

The ED group showed significantly higher rates of perceptual distortion of body image (PDBI) [$F_{(1,\ 72)}$ = 5.021; p = 0.028], particularly in the sense of overestimation (M = 2.52, SD = 1.675) compared to the control group (M = 1.59, SD = 1.651). The same calculations were made to obtain cPDBI and yielded similar results [$F_{(1,\ 72)}$ = 4.758; p = 0.032]. This also highlights greater overestimation among the ED group (M = 1.61, SD = 1.559) compared to the control group (M = 0.86, SD = 1.265).

The results of PDBI showed statistically significant differences between groups (p = 0.028). The results of our modification, described in Section "Materials and Methods" (cPDBI), were also significant (p = 0.032). This PDBI estimated using the indices showed a 91.7% distortion of the body in the ED group compared to 84.3% in the control group (**Figure 3A**). The values of the cPDBI were 65.2 and 54.9% for the ED and control groups, respectively (**Figure 3B**).

TABLE 1 | General anthropometric measures in the ED and control groups.

Anthropometry	Group	*N*	Mean	SD	*t*	**p*
Weight (kg)	Control group	51	56.388	8.930	−3.008	0.004
	ED group	23	49.253	10.519		
Height (cm)	Control group	51	160.010	8.001	−0.837	0.405
	ED group	23	158.330	7.968		
BMI	Control group	51	22.074	3.190	−3.171	0.002
	ED group	23	19.481	3.395		

**p values were calculated with Student's t-tests.*

Associations IGT–PDBI: Hypothesis (d)

The correlations between the IGT and variables of body image distortion were analyzed. A negative correlation was obtained between the IGT and PDBI (τ_b = −0.175; p = 0.045) and between the IGT and the cPDBI (τ_b = −0.207; p = 0.021). Thus, the greater the distortion in body image, the smaller the IGT, which means that participants with more PDBI made riskier decisions (**Figure 4**). In the regression analysis, the independent variable "total IGT" explained 5.5% of the variance (R2) of the dependent variable "PDBI" (β = −0.234, 95% confidence interval, −0.056 to −0.001, p = 0.044) and it also explained 8% of the dependent variable "cPDBI" (β = 0.283, 95% confidence interval, −0.051 to 0.006, p = 0.014).

Furthermore, pBMI and cBMI showed a positive strong correlation (τ_b = 0.399; $p < 0.001$) indicating that their self-body perception reflect the body reality. This correlation was stronger for the control group (τ_b = 0.431; $p < 0.001$) than for the ED group (τ_b = 0.381; p = 0.025), suggesting that control group perceived self-body images more accurately than subjects with ED. In the regression analysis, the independent variable "pBMI" explained 19.8% of the variance (R2) of the dependent variable "cBMI" (β = 0.457, 95% confidence interval, 0.225–0.604, $p < 0.001$).

DISCUSSION

The IGT is a useful test to assess the characteristics of everyday uncertainty in decisions and their consequences. Perception and cognitive and emotional DM processes might be affected in people suffering from ED. In this study, we hypothesized that the DM process is altered in young women with EDs.

The results supported our hypothesis and revealed significant differences between the ED and the control groups in the last two blocks of the computer-based version of the IGT. These differences were found in the last two blocks (after 60 trials), when members of the ED group tended to ignore long-term implications and made disadvantageous choices, making decisions contrary to those in previous trials in the first three blocks. This change in the direction of decisions produced economic losses. The control group tended to make more advantageous decisions, but they were still risky, as the total IGT for this group was also negative. This can be explained by the low mean age of both groups (teenagers), as well as the fact that all subjects were female.

The low mean age of both groups (teenagers) could be the explanation for this low total IGT, because as we mention in Introduction, IGT performance significantly improves from adolescence to adulthood (Hooper et al., 2004). Performance levels off after reaching the beginning of adulthood (approx. 19 years) (Overman and Pierce, 2013).

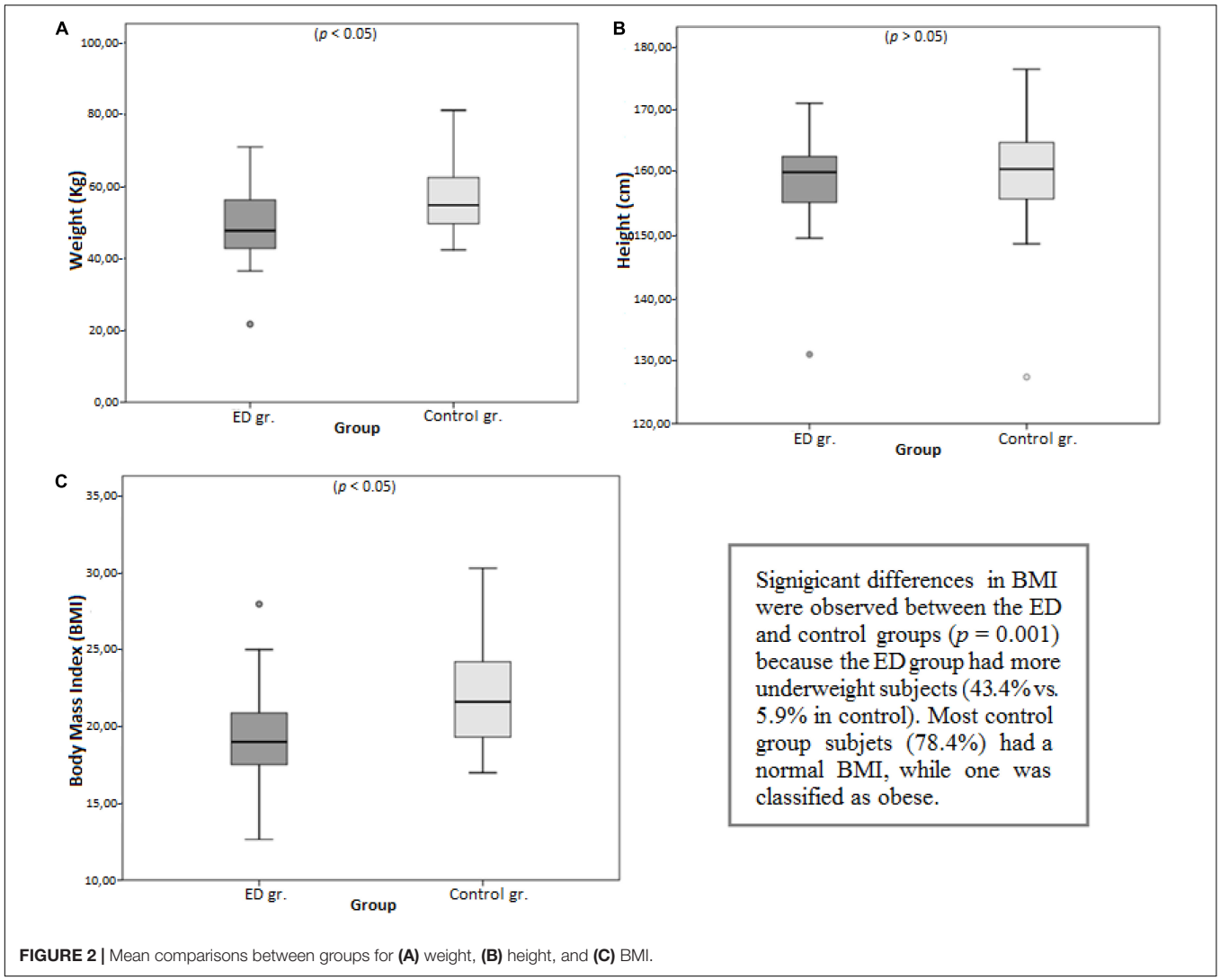

FIGURE 2 | Mean comparisons between groups for **(A)** weight, **(B)** height, and **(C)** BMI.

Regarding sex, the study by van den Bos et al. (2013) indicated that women perform at lower levels than men. The authors proposed that women are hypersensitive to loss based on their greater preference for high-frequency payout cards (B and D decks) and the fact that they need 40–60 more trials than men to achieve the same performance level. Therefore, in our sample, both circumstances would explain the negative results in the total IGT: the young age (14.97 years) and that they would need up to 60 trials to improve performance.

In the results of the IGT per block, there were no significant differences between our groups in the first three blocks in accordance with previous research (Brand et al., 2007; Brogan et al., 2010; Chan et al., 2014), although slightly higher scores were found for the ED group. Another similarities with previous studies lies in the performance deficits obtained in the last two blocks of the IGT by ED patients. This suggests that members of the ED group learned the task better but showed worse execution; perhaps they could not or did not want inhibit the prepotent response of make a riskier choice. However, we did not find significant differences between the groups in terms of total IGT, as has been previously reported.

The mean age of participants in both groups in our study was 15 years. The mean age of participants in work by Brogan et al. (2010) was significantly different among the four groups and was higher than that of our sample. The mean ages reported in other studies were slightly different among groups, and were higher than our groups. Guillaume et al. (2010) tested participants with a mean age of 23 years for the ED group and 28 years for the control group. Chan et al. (2014) employed subjects with similar mean ages for the ED and control groups (∼26 years), as did Danner et al. (2012) (25 years). Consequently, the older ages of subjects in these studies and their heterogeneity between groups differ from ours, so they are not be comparable with regard to IGT execution. We consider the young age of our sample (approx. 15 years) and the similar age, educational and socioeconomic levels between groups as strengths of the present study. We understand that these similarities are key to establishing that possible differences

TABLE 2 | Distribution of self-perceived figure (ST) and "current BMI" by group.

ST Figure		Self-perceived Figure		Current BMI	
		Control group	ED group	Control group	ED group
1	Count	0	0	2	9
	Group%	0.0%	0.0%	3.9%	39.1%
2	Count	3	3	16	4
	Group%	5.9%	13.0%	31.4%	17.4%
3	Count	7	1	9	5
	Group%	13.7%	4.3%	17.6%	21.7%
4	Count	8	7	10	3
	Group%	15.7%	30.4%	19.6%	13.0%
5	Count	8	4	8	1
	Group%	15.7%	17.4%	15.7%	4.3%
6	Count	14	2	3	1
	Group%	27.5%	8.7%	5.9%	4.3%
7	Count	9	4	2	0
	Group%	17.6%	17.4%	3.9%	0.0%
8	Count	2	2	1	0
	Group%	3.9%	8.7%	2.0%	0.0%
9	Count	0	0	0	0
	Group%	0.0%	0.0%	0.0%	0.0%

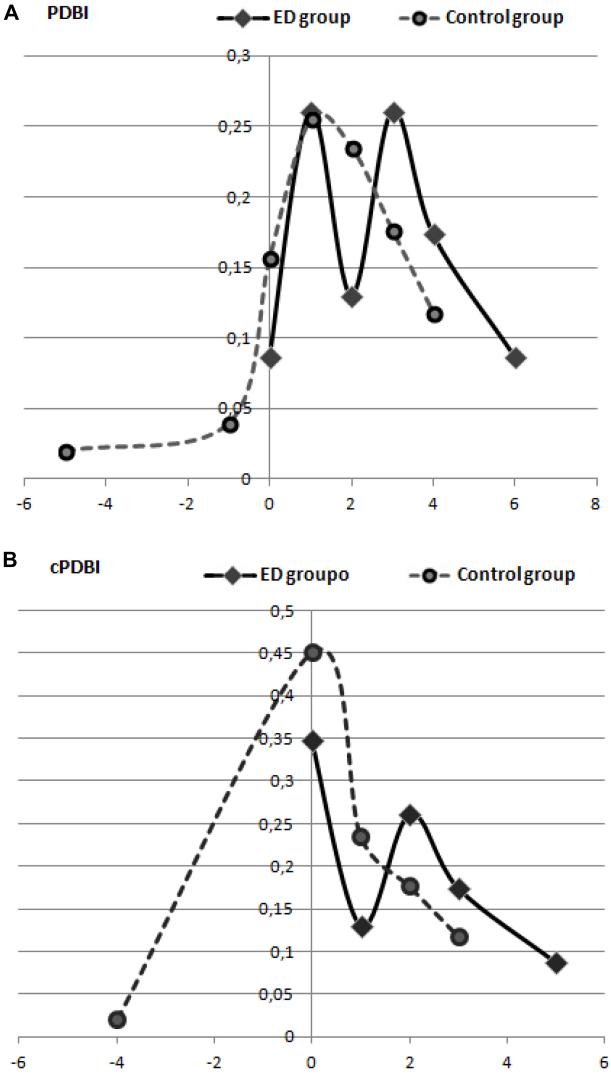

FIGURE 3 | Percentage of representation of perceptual distortion of body image (PDBI) in the ED and control groups **(A)**, and adaptation using cPDBI **(B)**.

in the IGT between groups should indeed be due to ED group main difference: PDBI.

As mentioned in the Introduction in the Age and Gender sections in relation to IGT performance, the age effect is useful for explaining discrepancies between the above-mentioned studies and our present work. They can be attributed to the maturation status of the PFC, specifically, structural changes and connection maturation after synaptic pruning occur in this brain region, which is involved in neurobiological decision-making processes (Overman and Pierce, 2013; van den Bos et al., 2013; Hartley and Somerville, 2015; Dumontheil, 2016). Active PFC development occurs throughout adolescence and is associated with seeking new experiences and engaging in risky behavior, which minimized the differences in terms of total IGT between our groups, but not in other studies with older subjects (Feinberg, 2017). However, our research on IGT performance during adolescence was not designed to determine the underlying neural bases for behavior changes. Rather we studied behavioral changes in IGT performance between two groups of adolescents: ED and control.

In terms of learning or evolution throughout blocks of the IGT, our results were in accordance with previous results reported by Brogan et al. (2010), who also found significant differences between ED patients and controls in the last two blocks of the test. Furthermore, Chan et al. (2014) observed differences in the third and fourth blocks (b3 and b4), with a tendency toward significant differences in the fifth block (b5). These consistencies, even with different mean ages among the studies, suggest that DM deficits in ED patients can be detected in adolescence, and support the concept proposed by Brogan et al. (2010) regarding ED progression. Thus, our findings significantly contribute to knowledge of the relationship between EDs and DM, with possible implications for preventing some characteristics of this disorder. In summary, in terms of total IGT, the small differences found between our adolescent groups would be exacerbated over time due to PFC maturation.

Consistent with Damasio's theory (1994), the results of this study suggest that during the first 60 trials, the somatic markers of the consequences of each choice were created, and the subsequent 40 choices were guided by this past learning (psychophysiological memories of its consequences or secondary emotions) and fundamentally according to their objectives. Fuglset (2019) review indicates that the use of different imaging tests (e.g., embedded figures, fragmented images, and the Rey Complex Figures Test) suggests that patients with AN have weak central coherence or global integration difficulties, suggesting that these patients have greater local processing or a bias

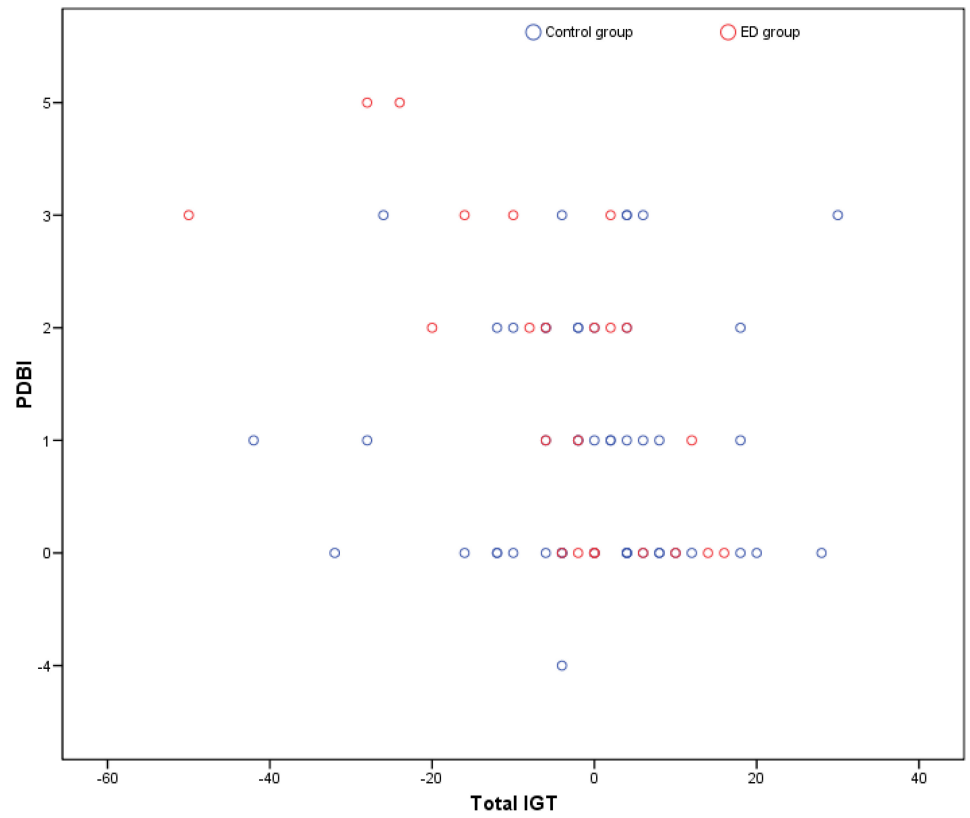

FIGURE 4 | Scatter plot for the correlation between PDBI and total IGT score.

toward detail processing (Lang et al., 2014). It also refers to the few studies that have used the IGT to investigate decision making in AN already recovered (AN-REC). The results are contradictory since Tchanturia et al. (2007) did not find differences with the control group, while Danner et al. (2012) observed poorer decision-making than in controls. Therefore, it is still unknown whether ED neuropsychological deficits are related to predisposing traits or are a consequence of this disease. Thus, our results represent an advance in the knowledge of ED patient performance in relation to risk decision making and self-perception of their own body image. This might also explain the discrepant results between the groups in terms of partial IGT.

As Damasio (1994, 1996) hypothesize, somatic markers have positive or negative associations based on personal experience (hypothetical or imagined) of the consequences perceived as pleasant or aversive. The results suggest that for the ED group, risk decisions are somatically marked with pleasant emotions because they continue to take risks in the following trials despite their losses. This might be similar to the increase in adrenaline before vomiting, even if it has an initially unpleasant body sensation or momentary displeasure, which is surpassed by their pleasure to achieve their main objective: weight loss. As a result, they ignore the long-term negative consequences of their decisions (malnutrition/death). In the control group, risky decisions may be initially pleasant or attractive, as in the ED group (due to their similar ages, novel sensation seeking, and risk), but these subjects may consider long-term adverse consequences, which leads them to inhibit this attraction and make more advantageous choices.

CONCLUSION

The inter-group differences obtained in the last two blocks task performance of this study suggest a kind of blindness toward the future in the ED group, as described by the developers of the SMH. Finally, the negative correlations found between the IGT and PDBI indicate that high distortions in body image are related to a lower gambling index, that is, these distortions are related to more disadvantageous or riskier decisions.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee for clinical trials of

the "Juan Ramón Jiménez" Hospital of Huelva (Spain), PEIBA (Portal de Ética de la Investigación Biomédica de Andalucía). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

All authors contributed substantially to the design and planning of the study, as well as in making decisions on the data provided by the legal guardians of the participants. They also contributed equally to the data analysis and interpretation and to writing and reviewing the manuscript. All authors approved the final version of the manuscript.

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Expected Valence Predicts Choice in a Recurrent Decision Task

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There is empirical evidence that expected yet not current affect predicts decisions. However, common research designs in affective decision-making show consistent methodological problems (e.g., conceptualization of different emotion concepts; measuring only emotional valence, but not arousal). We developed a gambling task that systematically varied learning experience, average feedback balance and feedback consistency. In Experiment 1 we studied whether predecisional current affect or expected affect predict recurrent gambling responses. Furthermore, we exploratively examined how affective information is represented on a neuronal level in Experiment 2. Expected and current valence and arousal ratings as well as Blood Oxygen Level Dependent (BOLD) responses were analyzed using a within-subject design. We used a generalized mixed effect model to predict gambling responses with the different affect variables. Results suggest a guiding function of expected valence for decisions. In the anticipation period, we found activity in brain areas previously associated with valence-general processing (e.g., anterior cingulate cortex, nucleus accumbens, thalamus) mostly independent of contextual factors. These findings are discussed in the context of the idea of a valence-general affective work-space, a goal-directed account of emotions, and the hypothesis that current affect might be used to form expectations of future outcomes. In conclusion, expected valence seems to be the best predictor of recurrent decisions in gambling tasks.

Keywords: affect, decision, predecisional, expected valence, anticipation, goal-directed emotion, fMRI, Iowa Gambling Task

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INTRODUCTION

According to Prospect Theory (Kahneman and Tversky, 2013), human decision-making is not solely rational but rather subject to inherent biases that influence judgement, decision-making, and human behavior. Other authors have also suggested an affective involvement in decision-making and behavior regulation (Mellers et al., 1997; Loewenstein and Lerner, 2003; Lerner et al., 2015; DeWall et al., 2016). However, the exact role of emotions in decision-making and behavior regulation is the subject of ongoing debate. One important issue in this context is how to conceptualize different components of emotions. In our opinion, there are two dimensions that need to be separated. First, it appears useful to differentiate between pre- and post-decisional emotions (Mellers et al., 1997). *Predecisional emotions* are present before the decision is made while *postdecisional emotions* arise after the decision when experiencing the feedback. Second, Loewenstein and Lerner (2003) broadly distinguished expected from immediate emotions.

Expected emotions refer to the prediction of future emotional consequences depending on the respective decision or action while *current/immediate emotions* refer to emotions that are present while the decision is made.

In our view, distinguishing between expected and current emotions also benefits research concerning the role of predecisional emotions in recurrent decision-making. This distinction mirrors dual process accounts that have been proposed in the decision-making literature (Lerner et al., 2015; Beer, 2017). These accounts propose that decision-making consists of two kinds of processes. First, cognitive processes that require time, deliberation, and cognitive resources; and, second, automatic processes that work in a quick and dirty fashion and thereby incorporate current emotions as a mediating variable between stimulus and response. In a meta-analysis, DeWall et al. (2016) examined whether during the anticipation period current emotions or expected emotions (they called it anticipated emotions) guide decisions and behavior. They concluded that there is weak evidence to support the claim that current emotions cause decisions but stronger preliminary evidence that expected emotions do so. This contradicts the default assumption of the described dual process accounts which assume that current emotions directly cause behavior (e.g., Loewenstein et al., 2001). However, DeWall et al. (2016) did not pit each theory against each other but rather tested them separately. Furthermore, they included studies in their analysis that asked about distinct emotion categories and, therefore, for conscious emotions. We think that this level of analysis might neglect causal mechanisms among emotion components. Thus, we propose to look at emotion components and causal mechanisms among them. For example, it could be fruitful to examine subjective feelings and how they relate to decisions as, for example, Charpentier et al. (2016) did. They showed that feelings could predict choices in a gambling task better than a value-based prediction model. However, they did not use a two dimensional feelings model but just measured expected valence. Barrett and Bliss-Moreau (2009) argued that the core of generating subjective feelings relies on two affect dimensions: *valence or pleasantness* and *arousal or activation* (Feldman and Russell, 1998). Thus, they suppose that humans continuously monitor how pleasant and arousing something is and use this to construct an emotional episode. In sum, Charpentier et al. (2016) have not taken a two-dimensional perspective on feelings as they neglected arousal in their experiments. Moreover, they did not investigate? how predecisional current affect and expected affect relate to one another and the respective decision.

Decision Affect Theory offers a theoretical foundation for the role of anticipated pleasure in choice prediction (Mellers et al., 1999; Mellers and McGraw, 2001). Simply put, this theory posits that ". . . when making decisions, people anticipate the pleasure or pain of future outcomes, weigh those feelings by the chances they will occur, and select the option with greater average pleasure" (Mellers and McGraw, 2001, p. 210). In several experiments they have identified several contextual factors which influence anticipated pleasure ratings. They used pie charts and, therefore, fully displayed associated probabilities and outcomes. Moreover, participants received information about their unchosen options. Each decision participants made referred to a new gambling situation with different probabilities and outcomes. Hence, participants knew probabilities in advance, could not learn from feedback, and could not avoid gambling. Based on this experimental paradigm, the authors identified four effects which influenced anticipated pleasure ratings. First, outcome effects (the higher the outcome, the higher anticipated pleasure ratings and vice versa). Second, suprise effects (the less probable an outcome the more pronounced are outcome effects). Last, regret and disappointment effects can be subsumed under comparison effects which show that the unobtained outcomes or unchosen outcomes also influence anticipated pleasure ratings. Finally, the authors could show that expected pleasure ratings were correlated with decisions participants made (Mellers and McGraw, 2001).

Another common method to investigate the role of emotions in decision-making is the Iowa Gambling Task (IGT; Aram et al., 2019). Participants have to draw a card from one of four decks. They do not know that there are good and bad decks. Bad decks produce high wins in the short term but on average losses in the long term as possible losses are also higher. However, good decks result in small wins in the short term but on average wins in the long term as possible losses are even smaller. Participants have to figure this out via trial and error. Patients with damaged prefrontal brain regions performed worse in the IGT and did not show increased anticipatory autonomous activity before making their decision. In contrast, neurologically healthy adults displayed an increase in electrodermal activity prior to a decision that was present even before participants gained conscious insight into the task structure (Bechara et al., 1997). Consequently, results suggest that electrophysiological correlates, which could be termed as current affect or somatic markers, as Bechara and Damasio (2005) call it, are essential to advantageous decision-making. At the same time, the interpretation of results and the task design have been criticized and alternative explanations have been proposed (Dunn et al., 2006). We want to highlight two major points regarding IGT's task design: decks are not presented in a counterbalanced order and all four decks are presented simultaneously which makes it impossible to see which deck is attended. If feelings guide choices, knowing which deck participants focus attention on, is crucial as several expected and current feelings might be present at the same time.

Taken together, previous research in choice prediction has neglected the two-dimensional nature of affect (Mellers and McGraw, 2001; Charpentier et al., 2016) or used only clustered data for choice prediction (Schlösser et al., 2013). As described, research has produced inconsistent findings. Additionally, some experiments conducted in this area of research used gambling tasks with fully displayed probabilities for each choice option and did not incorporate learning experience. In more ecologically valid tasks like the IGT, choice prediction based on predecisional subjective feelings has to our knowledge not been employed. As we wanted to understand causal mechanisms among emotional components on a subjective and neuronal level of analysis, we measured both dimensions of affect (arousal and valence) and examined both expected and current affect. To get an understanding of how contextual factors translate into emotion components and neural activations in a recurrent decision task,

we designed two experiments. In Experiment 1 we examined how the proposed constructs are influenced by contextual factors and which feeling constructs predict choice best. In Experiment 2 we tried to replicate Experiment 1's main findings regarding contextual influences on predecisional affective constructs. At the same time, we exploratively looked at brain activity of our gambling task to get a preliminary understanding of how contextual factors might influence brain activity and predecisional affect ratings.

EXPERIMENT 1

We designed a gambling task that was similar to the IGT in the way that participants had to make recurrent decisions and did not know gambling probabilities in advance. We did so to address the previously mentioned shortcomings of the IGT. At the same time our task had a similar ecologically valid structure as the IGT as outcome probabilities were unknown in advance (like most times in real life), participants could avoid certain outcomes, and they had to adapt their behavior based on previous experiences.

Thus, our task presented only one choice option at a time and allowed to vary contextual factors like feedback consistency, learning experience (time), and feedback balance in a systematic way. Feedback consistency refers to the probability of certain outcomes (see **Table 1**), feedback balance refers to the average outcome that could be obtained (see **Table 1**), and learning experience refers to three different time points we took measurements of predecisional affect. Four different symbols were used in the task. Each symbol had a unique pay-off schedule that was unknown to the participants. For each symbol, participants could decide whether they wanted to gamble or not. If participants decided not to gamble, their current balance remained unaffected. Thus, participants had the option of avoiding certain actions. If participants decided to gamble, however, they could win or lose points. Two symbols returned consistent positive or negative feedback while the other two symbols returned inconsistent feedback. Furthermore, the overall balance was positive for two symbols and negative for the other two symbols.

To better understand the affective involvement in our task and how affective components develop with task experience, we measured different kinds of affect at three different time-points. We took a two-dimensional perspective and, therefore, measured current valence and current arousal. Additionally, we looked at the expected valence and expected arousal for each option (gambling, passing). In a first step we analyzed whether the proposed affect constructs were sufficiently different from one another. Second, we wanted to show that contextual factors like feedback balance, feedback consistency, and learning experience had an effect on self-reported affect constructs. Finally, we hypothesized in line with the previously presented research (Mellers and McGraw, 2001; Dunn et al., 2006; Charpentier et al., 2016; DeWall et al., 2016) that expected affect and especially expected valence are better predictors for decision-making than current affect.

TABLE 1 | Example of Symbol-Feedback contingencies depending on the average feedback balance and the feedback consistency in Experiment 1.

Average feedback balance	Feedback consistency	Symbol	$P_{(+15points)}$ (%)	$P_{(-15points)}$ (%)
Positive	Consistent	■	100	0
	Inconsistent	▲	66.6	33.3
Negative	Consistent	●	0	100
	Inconsistent	✚	33.3	66.6

$P_{(+15points)}$ refers to the probability of winning 15 points and $P_{(-15points)}$ to the complementary probability of losing 15 points if the participant decided to gamble. Please note that symbol-feedback condition mapping was randomly assigned for each participant.

Materials and Methods

Participants

Data were collected from 25 healthy adults (M_{age} = 24.1 years, *SD* = 3.6 years, 10 men). Participants had normal or corrected to normal vision; 21 participants were right-handed, four were left-handed; all participants were students at the University of Bamberg and received course credit for participation. The study was conducted in accordance with the Declaration of Helsinki. Participants gave their written informed consent and were told that they could refrain from the study at any point without consequences. The study protocol was approved by the local ethics commission.

Materials

The experiment consisted of two types of blocks: Learning Blocks and Predecisional Affective Questionnaire (PAQ) Blocks. For stimulus presentation, we used the software NBS Presentation[1]. For answer collection, we used a two keyed Cedrus Response Box (RB-380) and paper-pencil questionnaires.

Gambling task in the learning blocks

The main goal of the gambling task for participants was to maximize points. Each participant started with a balance of 500 points. By making advantageous decisions participants could accumulate wins and avoid losses. In each trial of the gambling task, one of four symbols (circle, triangle, square, cross) was displayed (see **Table 1**). The presented symbol served as a clue for the possible feedback based on previous experience the participants made with this symbol (see **Figure 1** for timing parameters, ITI = 500 ms, and **Figure 2A** for trial structure). Thus, in each trial the participant had to decide whether she wanted to gamble or have a pass on the symbol. If the participant decided not to gamble (pass), the feedback was always ± 0 points irrespectively of the previously presented symbol. If the participant decided to gamble, feedback was determined based on constant symbol dependent winning and losing probabilities

[1]http://www.neurobs.com

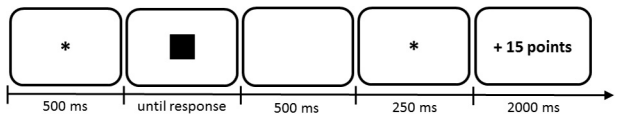

FIGURE 1 | Example trial to illustrate the timing of the Gambling Task. Numbers characterize presentation durations in ms. In this case the participant would have chosen to gamble and subsequently won 15 points. ITI = 500 ms. * Indicates a fixation dot.

(see **Table 1** for an example). Moreover, participants were not told a symbol's objective winning probability. They were rather instructed to figure out via trial and error for which symbol they expected a positive point balance. Symbol–probability pairings depended on two factors (average feedback balance, average feedback consistency) and were randomly assigned for each participant (see **Table 1** for an example and **Table 2** for an overview). The factor feedback balance coded whether symbols yield positive or negative feedback on average. The factor feedback consistency coded whether symbols returned consistent or inconsistent/mixed feedback. Hence, there were three possible outcomes depending on the previously presented symbol and the decision. In our example from **Table 1**: the square had a 100% probability of winning 15 points (and 0% losing probability); the circle had a 66.6% probability of winning 15 points (33.3% losing probability); the cross had a 33.3% probability of winning 15 points (66.6% losing probability); the circle had a 0% probability of winning 15 points (100% losing probability). Thus, to maximize gains, participants should gamble when experiencing an overall positive balance (square and triangle) and should avoid gambling when experiencing an overall negative balance (circle and cross). In each block the two symbols producing consistent feedback (100 and 0% winning probability) were each presented 14 times; inconsistent symbols (66 and 33% winning probability) were each presented 27 times. Symbols were presented in a randomized order.

TABLE 2 | Overview of experimental factors, number of symbols, procedure, and dependent measures in examining affective constructs and BOLD (Blood Oxygen Level Dependent) response for both experiments.

	Experiment 1	Experiment 2
Factors	Average feedback balance (positive/negative) Feedback consistency (consistent/inconsistent) Time (Questionnaire Block 1/2/3)	Average feedback balance (positive/negative) Feedback consistency (consistent/inconsistent)
Number of symbols	Four (see **Table 1** for more details)	Five (see **Table 1** + control symbol)
Procedure	Practice Block (8 trials) Learning Block 1 (82 trials) PAQ Block 1 (4 trials) Learning Block 2 (82 trials) PAQ Block 2 (4 trials) Learning Block 3 (82 trials) PAQ Block 3 (4 trials)	Behavioral Practice Block (10 trials) Learning Block 1 (52 trials) Learning Block 2 (52 trials) Learning Block 3 (52 trials) fMRI Practice Block (5 trials) fMRI Block 1 (50 trials) fMRI Block 2 (50 trials) PAQ Block (4 trials)
Dependent measures	Current valence, current arousal, expected valence difference, expected arousal if gambling, expected arousal if passing	Current valence, current arousal, expected valence difference, expected arousal if gambling, expected arousal if passing; BOLD response

PAQ, Predecisional Affect Questionnaire; fMRI, functional Magnet Resonance Imaging.

Predecisional affect questionnaire block

Questionnaire blocks measured self-reported predecisional affect. In the questionnaires blocks, after looking at the symbol and

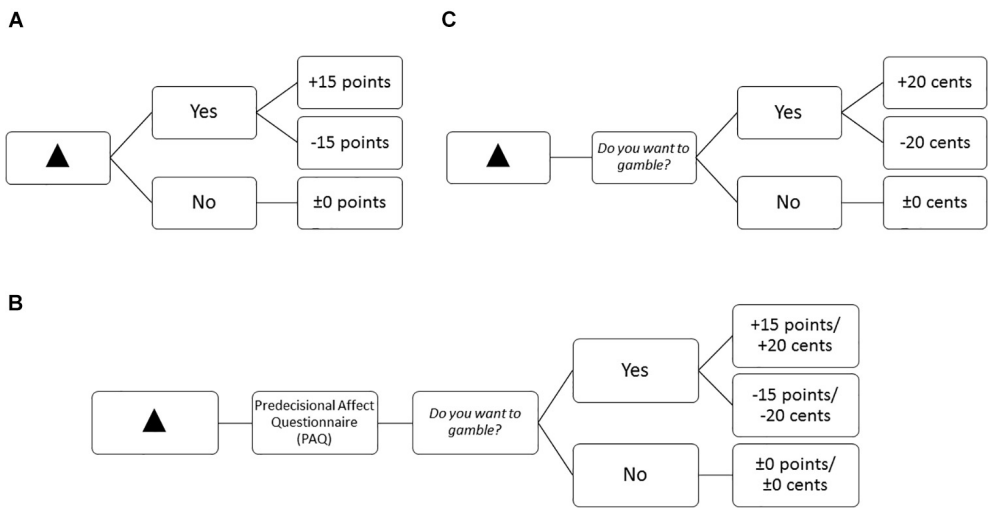

FIGURE 2 | Example of the trial structure and possible feedback depending on gambling decision for a positive-inconsistent symbol **(A)** in the learning blocks in Experiment 1, and **(B)** the questionnaire blocks for both experiments (Participants could win or lose points in Experiment 1 and cents in Experiment 2), and **(C)** the learning and fMRI blocks in Experiment 2.

before deciding for or against gambling, participants filled in a paper-pencil questionnaire (see **Figure 2B** for an example trial structure). In this questionnaire they rated their affective state from three different perspectives each on the dimensions of *valence* and *arousal* using a 9-point Self-Assessment Manikin Scale (SAM; Bradley and Lang, 1994). The first perspective asked participants to rate their current affective state: *"Please rate how you are feeling now."* The second perspective asked them to rate their expected affective state if they would decide to gamble: *"Please rate how you would feel if you decided to gamble."* The third perspective asked them to rate their expected affective state if they decide not to gamble: *"Please rate how you would feel if you decided not to gamble."* Below each question we presented a SAM Valence Scale and a SAM Arousal Scale. Hence, we asked one question for each perspective but collected two ratings (valence, arousal) per perspective resulting in six variables: Current Valence/Arousal, Expected Valence/Arousal if gambling, and Expected Valence/Arousal if passing (see **Table 2**). In the questionnaire blocks each symbol was randomly presented once, resulting in four trials. For every symbol participants filled in the above mentioned questionnaire in a paper-pencil format. Taken together, we collected 24 ratings per questionnaire block. Question presentation was not randomized: they were first asked to rate their current affective state, then their expected affective state if gambling, and last their expected affective state if passing.

Procedure

At the beginning, participants were welcomed, filled in a demographic questionnaire, and gave their written informed consent to the experimental procedure. For an overview of experimental factors, dependent variables, and the chronological procedure (see **Table 2**). Participants could gain or lose points in the gambling task. They were informed that the 10 highest scoring participants would win 10 euros each. Each participant started the experiment with a balance of 500 points. The current score was presented after each block. Thus, participants got an immediate feedback after each block on how much points they won or lost in the preceding block. First, participants completed a practice block of eight trials which did not affect their balance. Then they started the first of the three learning blocks (for more details see section "Materials"). Participants indicated their gambling decision by pressing the assigned yes- or no-button. Key assignment was counterbalanced across participants. After each learning block there was a PAQ block (for more details see section "Materials"). Hence, we measured predecisional affect at three different time points which constituted the factor time (see **Table 2**). Participants could take a short self-timed break between blocks if they wanted to. At the very end, participants were debriefed.

Results

First, we show that the experimental factors impact the self-report ratings. In a second step, we want to examine which self-reported affect variables predict gambling choices best. To begin with, we analyzed how the proposed valence constructs were correlated with one another. We used the rmcorr package in R (Bakdash and Marusich, 2017). Both expected valence variables (expected gambling and expected passing) were highly correlated ($r = -0.53$, $p < 0.001$), however, all other constructs were only moderately correlated ($< r = 0.35$). Therefore, we decided to compute a difference score for the expected valence perspectives (Expected Valence Difference = "Expected Valence if gambling"–"Expected Valence if passing") as Charpentier et al. (2016) did to avoid collinearity in the analysis.

Expected Valence

We submitted the difference scores of self-reported expected valence ratings for the three TIMES and each symbol to a 3 × 2 × 2 repeated measures ANOVA. The factor BALANCE had two levels: positive, for symbols that won on average, and negative, for symbols that lost on average. The factor CONSISTENCY also had two levels, consistent, for symbols that returned consistent positive or negative feedback, and inconsistent, for symbols that returned mixed feedback. The three-way interaction TIME × BALANCE × CONSISTENCY was non-significant, $F(2, 48) = 22.19$, $p = 0.07$. However, the interaction BALANCE × CONSISTENCY turned out to be significant, $F(1, 24) = 8.96$, $p = 0.006$, $\eta_p = 0.272$ (see **Table 3**). As it was a semi-disordinal interaction only the main effect BALANCE was interpretable, $F(1, 24) = 22.19$, $p < 0.001$, $\eta_p = 0.480$. Symbols which had a positive balance, $M = 1.273$, $SE = 0.307$, had significantly higher difference scores than symbols which had a negative balance, $M = -0.973$, $SE = 0.307$, $p < 0.001$. Thus, the effect of a positive balance on expected valence ratings was even more pronounced for symbols returning consistent positive feedback in comparison to symbols returning inconsistent positive feedback.

Current Valence

We submitted the self-reported current valence ratings to a 3 × 2 × 2 ANOVA for repeated measures. As in the expected valence analysis, we used the factors TIME, BALANCE, CONSISTENCY. The three-way interaction TIME × BALANCE × CONSISTENCY was significant, $F(2, 48) = 6.49$, $p = 0.003$, $\eta_p = 0.213$ (for means and other statistics see **Table 4**). For resolving this interaction we conducted three additional 2 × 2 ANOVAs for repeated measures with the factors BALANCE and CONSISTENCY, one for each time point. For time 1, there were no significant differences between current valence ratings. However, for time 2, there was a significant CONSISTENCY × BALANCE interaction effect, $F(1, 24) = 8.29$, $p = 0.008$, $\eta_p = 0.257$. *Post-hoc* Bonferroni corrected *t*-tests indicated that current valence ratings were smaller for consistent negative

TABLE 3 | Estimated Marginal Means, Standard Errors (SE), and 95% Confidence Interval for the two-way interaction BALANCE × CONSISTENCY in the Analysis of Expected Valence Difference ratings.

				95% Confidence Interval	
Balance	**Consistency**	**Mean**	**SE**	**Lower**	**Upper**
Positive	Consistent	1.91	0.350	1.2082	2.605
	Inconsistent	0.64	0.350	−0.0585	1.338
Negative	Consistent	−1.08	0.350	−1.7785	−0.382
	Inconsistent	−0.87	0.350	−1.5651	−0.168

TABLE 4 | Estimated Marginal Means, Standard Errors (SE), and 95% Confidence Interval for the threeway-way interaction TIME × BALANCE × CONSISTENCY in the Analysis of Current Valence ratings.

					95% Confidence Interval	
Time	**Balance**	**Consistency**	**Mean**	**SE**	**Lower**	**Upper**
Time 1	Positive	Consistent	6.24	0.285	5.67	6.81
		Inconsistent	6.60	0.285	6.03	7.17
	Negative	Consistent	6.52	0.285	5.95	7.09
		Inconsistent	6.40	0.285	5.83	6.97
Time 2	Positive	Consistent	6.92	0.285	6.35	7.49
		Inconsistent	6.24	0.285	5.67	6.81
	Negative	Consistent	6.08	0.285	5.51	6.65
		Inconsistent	6.56	0.285	5.99	7.13
Time 3	Positive	Consistent	7.12	0.285	6.55	7.69
		Inconsistent	6.68	0.285	6.11	7.25
	Negative	Consistent	6.28	0.285	5.71	6.85
		Inconsistent	6.28	0.285	5.71	6.85

symbols compared to consistent positive symbols, $p < 0.016$. For time 3, there was a significant main effect for BALANCE, $F(1, 24) = 11.45$, $p = 0.002$, $\eta_p = 0.323$. Symbols with an overall positive balance, $M = 6.90$, $SE = 0.265$, had higher current valence ratings than symbols with an overall negative balance, $M = 6.28$, $SE = 0.265$, irrespective of feedback consistency.

Expected Arousal

Analogous to the expected valence analysis, we submitted the difference scores of self-reported expected arousal ratings for the three TIMES and each symbol varying in CONSISTENCY and BALANCE to a 3 × 2 × 2 repeated measures ANOVA. All interaction and main effects were non-significant.

Current Arousal

For self-reported current arousal we performed a 3 × 2 × 2 ANOVA for repeated measures with the factors TIME, BALANCE, and CONSISTENCY. All three- and two-way interactions were non-significant, however, the main effect of BALANCE was significant, $F(1, 24) = 7.97$, $p = 0.009$, $\eta_p = 0.249$. Symbols with a positive balance, $M = 4.39$, $SE = 0.29$, had higher self-reported current arousal ratings than symbols with a negative balance, $M = 3.97$, $SE = 0.29$.

Choice Prediction

To test which affect variables predicted choice best, we ran a generalized mixed effects model using the glmer function from the lme4 package in R (Bates et al., 2015). As correlation analysis showed that both expected valence variables were highly correlated, we decided to compute a difference score to reduce collinearity. All other variables were only mildly correlated which is why we entered them separately into the model. We modeled the Participant ID as a random intercept and entered each affect variable as a fixed effect into the model resulting in the formula: Choice ∼ Difference Expected Valence + Current Valence + Expected Gambling Arousal + Expected Not Gambling Arousal + Current Arousal + (1| Participant ID). Significance was assessed via model comparison with an Alpha of 0.05. Expected Valence was the only significant predictor for gambling choice, $\beta = 1.19$, $SE = 0.17$, $X^2(1) = 150.2$, $p < 0.001$. This means, the higher the difference score of expected valence ratings (gambling—not gambling) were, the more likely participants chose to gamble. For more details regarding fixed and random effect structure (see **Table 5**).

TABLE 5 | Generalized linear mixed effect estimates for the choice prediction model including the proposed affective predictors.

Predictors	**Odds ratios**	***CI***	***p***
(Intercept)	0.37	0.03–4.15	0.419
Difference expected valence (gambling–passing)	3.28	2.37–4.54	**<0.001**
Expected gambling arousal	1.05	0.76–1.45	0.760
Expected not gambling arousal	1.21	0.87–1.67	0.256
Current valence	1.24	0.92–1.68	0.156
Current arousal	0.80	0.55–1.16	0.233
Random effects			
σ^2	3.29		
$\tau_{00\ Participant}$	0.40		
ICC	0.11		
$N_{Participant}$	25		
Observations	300		
Marginal R^2/Conditional R^2	0.733 / 0.762		

Fixed Effects: Odds Ratios, Confidence Intervals (CI), and p-values. Random Effects: σ^2 = within-person residual variance, $\tau_{00\ Participant}$ = between-person variance, ICC = Proportion of variance explained by between-person differences; Marginal R^2 = variance explained by fixed effects, Conditional R^2 = variance explained by fixed and random effects. Significant results are printed in bold.

Discussion

In Experiment 1, we wanted to examine how subjective feelings are part of the decision process in a recurrent gambling task with unknown outcome probabilities. Hence, we developed a gambling task that was similar to the Iowa Gambling Task. However, our task varied feedback consistency, average feedback balance, and the learning experience in a systematic, controllable way. For measuring subjective feelings we took different classifications into account. Thus, we measured valence and arousal under the perspective of current and expected feelings. Our most important research question studied which of the proposed subjective feeling construct would predict choice. We found that expected valence was the only predictor for choices participants made. All other constructs were non-significant. Hence, the difference of expected valence ratings but not current valence or arousal constructs predicted choices which is in line with our hypotheses and previous research (Mellers et al., 1997; Charpentier et al., 2016; DeWall et al., 2016). At the same time, our findings challenge a decision guiding function of arousal. We found that self-reported current arousal indeed varied between good and bad symbols, however, it did not predict subsequent choices. As self-reported arousal ratings might be unreliable, it might be useful to simultaneously assess physiological arousal measures to enhance predictive power (Asutay et al., 2019). Future studies should further examine these findings and include

physiological measures of autonomous activity instead of self-reported arousal in their choice prediction models.

Furthermore, we examined whether the measured variables were sufficiently different from one another. We found that most constructs correlated only mildly or moderately and, therefore, differed sufficiently. However, expected valence ratings of the two choice options were highly correlated which is why we computed a difference score for expected valence ratings (for a similar procedure, see Charpentier et al., 2016). Moreover, we examined how contextual factors like feedback consistency, learning experience, and average feedback balance influence the proposed subjective feelings variables. In general, we found that most self-reported ratings were influenced by contextual factors, yet, in different ways. Most constructs, except for current valence, were insensitive to time of measurement which implies a relatively early manifestation of constructs. As predicted, expected valence ratings distinguished between symbols with a positive and negative balance and for positive balanced symbols also between consistent and inconsistent symbols. This was the case over all measurement points, indicating an early manifestation of expectancy constructs. The impact of contextual factors on current valence ratings changed over time. After the first block there was no significant difference between ratings, at time 2 consistent positive symbols were rated higher than all other symbols, at time 3 positive balanced symbols (consistent and inconsistent) had higher current valence ratings than negative balanced symbols. In other words, current valence changed as participants learned symbol-feedback contingencies. This posits that current valence manifests over time as learning takes place. The difference of expected arousal ratings was not affected by contextual factors. Taken together, contextual factors influenced most of the proposed constructs but not expected arousal ratings.

EXPERIMENT 2

In Experiment 1 we found that self-reported affect ratings were influenced in different ways by feedback consistency, feedback balance, and learning experience. As a next step, we wanted to examine how these contextual factors determine predecisional affective brain activity. Lindquist et al. (2016) tested three competing hypotheses regarding neural representation of affect in a meta-analysis of the human neuroimaging literature. The bipolarity hypothesis assumes that pleasant and unpleasant feelings are endorsed by a brain system that monotonically increases and decreases along the valence dimension. Second, the bivalent hypothesis posits two independent brain systems for positive and negative affect. Last, the affective workspace hypothesis suggests that valence is best represented on a neuronal level as a valence general neural workspace which recruits a flexible set of valence-general areas. Results clearly favored the affective workspace hypothesis while evidence for both other theories was rather weak. Valence-general activations were found in the bilateral anterior insula, thalamus, dorsal ACC, bilateral lateral orbitofrontal cortex, supplementary motor area, bilateral amygdala, the ventral striatum, dorsomedial prefrontal cortex, bilateral ventro-lateral prefrontal cortex, and lateral portions of the right temporal/occipital cortex. At the same time, the authors acknowledge that it might be a possibility that the arousal component of affect might contribute to valence-general activation patterns as separating arousal from valence is both a statistically and theoretically complex endeavor.

As in Experiment 1, our task design varied the symbol's balance and its feedback consistency. In accordance with the hypothesis of a valence-general affective workspace, we expected that all symbols, which varied in contextual factors and therefore also in affect ratings, recruit the same brain regions. In line with the presented evidence we supposed to find brain activity in the anterior cingulate cortex, the accumbens area, the thalamus, the amygdala, the insula, and the prefrontal cortex. In addition to that, we hypothesized that the symbol's balance or its feedback consistency would have a rather small or no effect on observed brain activity as valence-general brain regions work together to produce different valence intensities.

Materials and Methods

Participants

Data were collected from 22 adults of which five (M_{age} = 50.4 years, SD = 2.7 years, two men) were excluded because they had not learned the symbol-feedback contingencies after the third block. Exclusion criteria were set at a gambling rate below 70% for the 100% chance condition as well as a gambling rate above 30% for the 0% chance condition. The final sample consisted of 17 adults (six men) aged between 20 and 57 (M_{age} = 35.5 years, SD = 12.0 years). Hence, the dropout seems to be age-related, meaning that older participants had difficulties learning the symbol-feedback contingencies. Furthermore, after the MRI block one participant decided to end the study. Therefore, the sample for the questionnaire block comprised 16 adults (six men) aged between 20 and 57 (M_{age} = 36.4 years, SD = 11.8 years). Participants had normal or corrected to normal vision; 16 participants were right-handed, one was left-handed; six participants had at least an educational degree of a German high school diploma, whereas the others had a German Middle School Degree.

The study was conducted in accordance with the Declaration of Helsinki. Participants gave their written informed consent and were told that they could refrain from the study at any point without consequences. The study protocol was approved by the ethics committee of the Hannover Medical School with the study ID 7416.

Materials

The general materials did not change much in comparision to Experiment 1, however, we adapted the procedure and timing parameters to the needs of the fMRI setting. In all blocks (learning, fMRI, and PAQ Block) participants did not respond to the symbol directly but rather to the question *"Do you want to gamble?"* as presented in **Figure 2C**. We thought that it would be easier for participants to have a consistent task structure. Moreover, we introduced a control symbol to the gambling task, which regardless of choice did not affect participants' score. As we wanted to isolate affect-related brain activity, we needed

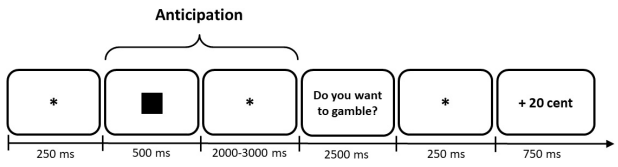

FIGURE 3 | Example trial to illustrate the timing of the fMRI Monetary Gambling Task. Numbers characterize presentation durations in ms. In this case the participant would have chosen to gamble and subsequently won 20 cents. Only the anticipation period was used for analysis of brain activity. *Indicates a fixation dot.

the control symbol to compute difference contrasts (see "Data Analysis" section for more details). Finally, we decided to use real money instead of points because we hoped this would result in stronger neural activations. Participants could win or lose 20 cents in each trial. "Gamble" and "Pass" key assignment was counterbalanced over participants. For stimulus presentation, we used the software NBS Presentation[2].

The learning blocks consisted of 52 randomized trials: eight consistent-positive feedback symbols, eight consistent-negative feedback symbols, eight control symbols, 14 inconsistent-positive feedback symbols and 14 inconsistent-negative feedback symbols. We decided to present more inconsistent symbols to make it easier for participants to learn these contingencies. Each trial had the following timing parameters: fixation asterisk (250 ms), symbol (500 ms), fixation asterisk (500–800 ms), choice ("*Do you want to gamble?*," until response), feedback depending on the decision and the symbol's winning probability (750 ms), inter trial interval (ITI; 500–800 ms).

The fMRI blocks consisted of 50 randomized trials (10 repetitions of each symbol). We also adjusted the timing parameters to fit the fMRI method (see **Figure 3**). The inter trial interval (ITI) and the anticipation period were both jittered with an average duration of 2,500 ms, ranging from 2,000 to 3,000 ms. Participants could answer within 2,500 ms when they were requested to indicate their decision (see **Figure 3**). If they did not respond within this time frame, *"XXX"* appeared as feedback which did not affect their momentary balance. However, participants were still asked to give an answer although a no-decision would have yielded a similar result for the participant's overall balance. We did so to reduce missed trials, which cannot be used in analysis, to a minimum.

Last, in the PAQ Block we did not change trial structure (see **Figure 2B**). However, we presented five symbols instead of four, as we had one additional control symbol in Experiment 2. Again, participants indicated their predecisional affective states on a paper-pencil questionnaire. Hence, the PAQ Block consisted of five trials (see **Table 2**).

Procedure

For an overview of experimental factors and the procedure in comparison to Experiment 1 (see **Table 2**). First, participants were welcomed, filled in a demographic questionnaire, and gave their written informed consent to the experimental procedure. We placed five euros in front of each participant to underline that they could win and lose real money during the experiment. Each participant started the experiment with a balance of five euros. The participant's current money balance was presented after each block. Thus, participants got an immediate feedback after each block how much they won or lost in the respective block. Practice blocks did not affect the participants' balance in any part of the experiment. After completing the practice block consisting of 10 trials (each symbol was presented twice), they started the three learning blocks. Participants could indicate their gambling decision by pressing the assigned gamble or pass button on a two keyed Cedrus Response Box (RB-380). In the learning phase, participants could take a short self-timed break between blocks if they wanted to. Before each task change, participants completed a practice block to get used to the procedure or the changed trial timing. After the fMRI practice block (five trials), they completed two fMRI blocks starting with a 6 s fixation trial. Between both blocks a 50 s break was inserted and the balance of monetary gains or losses in the preceding block was presented. In this phase we used NordicNeuroLab's VisualSystem for stimulus presentation in the MRI scanner and ResponseGrip to collect their answers. The VisualSystem goggles were placed on the head coil where participants could adjust the visual acuity depending on their visual condition. Participants were instructed to use their right and left thumb to indicate their decision. After the fMRI phase, participants completed the PAQ Block. At the very end, participants were debriefed and got paid their overall balance.

fMRI Data Acquisition

Data were collected using a 1.5 T Magnetom Avanto scanner (Siemens Medical Systems, Erlangen, Germany) with an 18-channel head coil. Functional images were obtained using a T2*-weighted echo planar imaging (EPI) sequence with TR = 2,000 ms, TE = 35 ms and flip angle = 80°, 498 volumes, resulting in a duration of 16.6 min. Each functional image consisted of 23 axial slices, with 64 × 64 matrix, 200 mm × 200 mm field of view (FOV), 5 mm thickness, 1 mm gap, and 3.125 mm × 3.125 mm inplane resolution. Structural images were obtained using a 3D structural sagittal T1-weighted MPRAGE image. Each structural image consisted of 192 contiguous slices, with 256 mm × 250 mm matrix size and 1 mm slice thickness.

Data Analysis

Behavioral

Behavioral data were analyzed by computing a repeated measures ANOVA for each dependent variable of interest as we did in the behavioral analysis of Experiment 1. As we had a small sample size and just one measurement for each affect construct, we decided to skip the choice prediction analysis.

fMRI

Data were preprocessed and analyzed using SPM12[3]. The first three volumes were discarded due to longitudinal magnetization equilibration effects. First, structural and functional images were roughly reoriented using the EPI-derived MNI template (ICBM

[2]http://www.neurobs.com

[3]http://www.fil.ion.ucl.ac.uk/spm/

305, Montreal Neurological Institute). After realignment, the structural images were coregistered to the EPI images, and the six movement parameters (x, y, z, pitch, yaw, roll) saved to include them as covariates in the first level analysis. Then EPI images were time shifted to the middle slice to correct differences in slice acquisition timing. In a further step, both structural and functional images were directly normalized to the MNI template. The normalized EPI images were smoothed with a Gaussian kernel of 8 mm full-width half-maximum (FWHM) and filtered with a high-pass filter of 128 s.

In the first level analysis, we specified conditions, estimated parameters, and computed contrasts for each participant using the canonical hemodynamic response function (HRF) and a general linear model. Therefore, we defined the time-locked anticipation periods (see **Figure 3**) of the five symbols as regressors and included the six motion parameters as covariates to reduce signal-corrected motion effects. Regardless of the later gambling decision, anticipation periods of the symbols were each modeled as a separate regressor. Response, feedback, and between-block pause periods were still modeled but not included in the analysis. Additionally, anticipation periods of missed trials were treated the same way, the ITI serving as implicit baseline. Then, we applied classical parameter estimation with a one-lag autoregressive model and a masking threshold of 0.8 to minimize false positive voxels. Finally, we computed the t-contrasts of the symbols compared to the control symbol to isolate brain activity of potential wins and losses in the anticipation period. Thus, we computed the contrasts "positive-consistent > control," "positive-inconsistent > control," "negative-inconsistent > control," and "negative-consistent > control" to take them to the second level group analysis.

In the second level group analysis, we defined a 2 × 2 full factorial design for repeated measures with the factors BALANCE and CONSISTENCY while AGE was included as a covariate due to the previously discovered age related dropouts caused by learning difficulties. We assigned the factor levels in the same way as in the behavioral analysis. For computation, we entered each participant's t-contrasts of each symbol in comparison to the control condition which were calculated in the first level analysis. For each factor, variances were assumed to be unequal and independence was not given. Furthermore, we applied implicit masking and carried out a classical parameter estimation.

Results

Behavioral

Expected valence

We submitted the difference scores of self-reported expected valence ratings for each symbol to a 2 × 2 repeated measures ANOVA as in Experiment 1. The interaction BALANCE × CONSISTENCY turned out to be significant, $F(1, 15) = 4.98$, $p = 0.041$, $\eta_p = 0.241$. As it was a semi-disordinal interaction, only the main effect BALANCE was interpretable, $F(1, 15) = 13.63$, $p = 0.002$, $\eta_p = 0.476$. Symbols which had a positive balance, $M = 2.06$, $SE = 0.558$, had significantly higher difference scores than symbols which had a negative balance, $M = -1.16$, $SE = 0.558$. Thus, the effect of a positive balance on expected valence ratings was even more pronounced for symbols returning consistent positive feedback in comparison to symbols returning inconsistent positive feedback.

Current valence

We submitted the self-reported current valence ratings to a 2 × 2 ANOVA for repeated measures. The main effect CONSISTENCY proved to be significant, $F(1, 15) = 6.05$, $p = 0.027$, $\eta_p = 0.287$, with consistent symbols, $M = 7.44$, $SE = 0.334$, having significantly higher current valence ratings than inconsistent symbols, $M = 6.72$, $SE = 0.334$. The main effect BALANCE was only marginally significant, $F(1, 15) = 4.45$, $p = 0.052$, $\eta_p = 0.229$.

Expected arousal

As before, we submitted the difference scores of self-reported expected arousal ratings for each symbol varying in CONSISTENCY and BALANCE to a 2 × 2 repeated measures ANOVA. All interaction and main effects were non-significant.

Current arousal

For self-reported current arousal we performed a 2 × 2 ANOVA for repeated measures with the factors BALANCE and CONSISTENCY. The two-way interaction was non-significant, $F(1, 15) < 1$, however, the main effect BALANCE reached significance, $F(1, 15) = 11.50$, $p = 0.004$, $\eta_p = 0.434$. Symbols with a positive balance, $M = 4.16$, $SE = 0.447$, had significantly higher self-reported current arousal ratings than symbols with a negative balance, $M = 3.31$, $SE = 0.447$.

fMRI

Results of the full factorial analysis are presented in **Table 6** and **Figures 4**, **5** at $p < 0.001$ (uncorrected) and a minimum voxel cluster of 40. Despite the possibility of false positive results, we decided to conduct the analysis to give an idea of potentially activated brain regions. Main and interaction effects which are not reported did not approach significance. For all symbols,

TABLE 6 | Group maximum *T*-values and MNI Coordinates of activation foci for the t-contrast Condition (general activation averaged over anticipation periods of the four symbols; $p < 0.001$, uncorrected; $n = 17$) and the t-contrast Balance (negative > positive; $p < 0.001$, uncorrected; $n = 17$).

Region	H	*x*	*y*	*Z*	*t*	Size
Condition						
Cerebellum exterior	R	12	−46	−20	4.45	49
Accumbens area	L	0	4	−4	4.40	49
Thalamus proper	R	2	−2	6	4.05	44
Anterior cingulate	L	−10	40	−4	4.25	43
Medial superior frontal	R	4	40	24	4.07	60
Superior frontal	R	18	20	56	3.73	56
Balance						
Superior temporal	L	−54	−20	0	4.80	91
		−64	−48	16	4.79	52
Middle temporal	L	−48	−60	4	4.47	65
		−52	−60	12	3.53	45

Size, number of activated voxels; L, left; R, right; H, hemisphere.

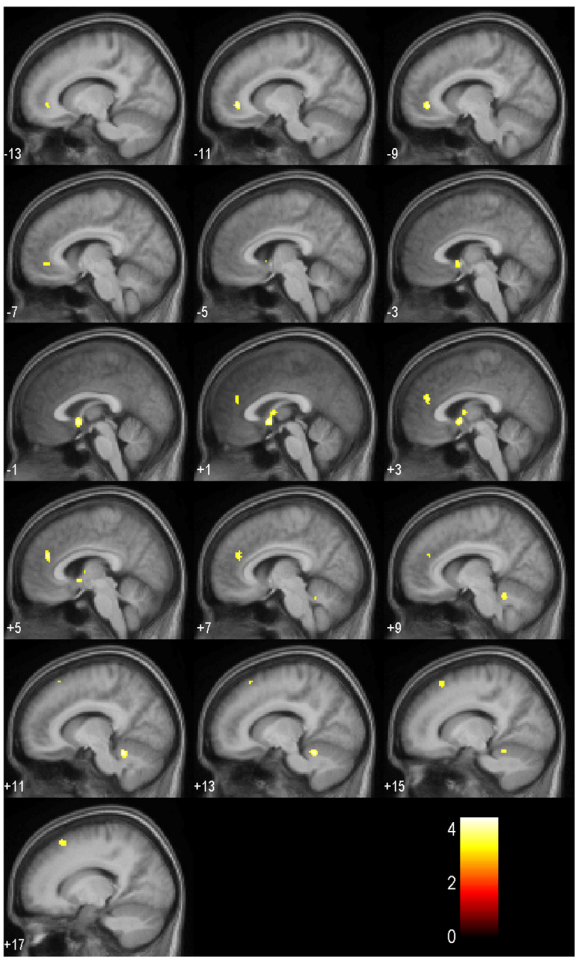

FIGURE 4 | Activation patterns in the anticipation period as listed in **Table 6** for all symbols in comparison to the control symbol ($p < 0.001$, uncorrected; $n = 17$). Positive values represent the number of sagittal slices from the center to the right hemisphere. Negative values indicate the number of sagittal slices from the center to the left hemisphere. The colored bar specifies the respective *t*-value's magnitude.

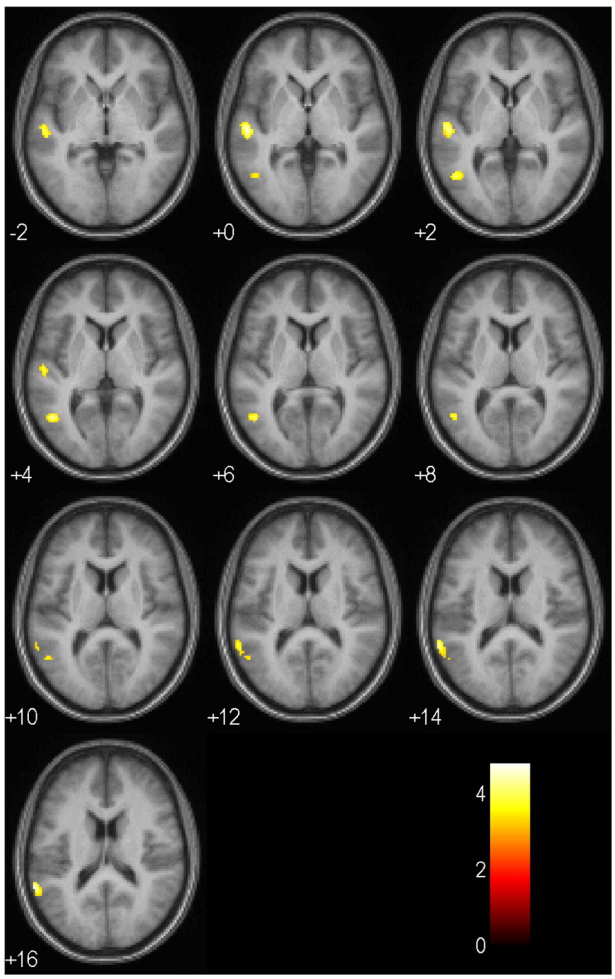

FIGURE 5 | Activation patterns in the anticipation period as listed in **Table 6** for negative balanced in comparison to positive balanced symbols (main effect balance, no > yes; $p < 0.001$, uncorrected; $n = 17$). Positive values represent the number of axial slices from the center downwards. Negative values indicate the number of sagittal slices from the center upwards. The colored bar specifies the respective *t*-value's magnitude.

which returned positive or negative feedback in comparison to a control symbol, which regardless of choice returned a null feedback, we found general activations in the anticipation period. As presented in **Figure 4**, symbols associated with positive or negative feedback showed more activity in the anticipation period in the Cerebellum Exterior, the Accumbens Area, the Thalamus Proper, the Anterior Cingulate Cortex, the Medial Superior Frontal Cortex, and the Superior Frontal Cortex. Furthermore, we found that negative balanced symbols produced stronger activations in the Superior Temporal and Middle Temporal Cortex in the anticipation period in comparison to positive balanced symbols (see **Figure 5**).

Discussion

In Experiment 2 we adapted the gambling task from Experiment 1 to the fMRI environment. We were interested in predecisional affect in the anticipation period of a complex decision-making task. Therefore, we wanted to exploratively examine affective brain-activity and varied feedback consistency and average feedback balance. We could only show brain activity for uncorrected *p*-values which is due to our small sample size. Nevertheless, we think that our exploratory results are still worth reporting since future hypothesis testing research can use our findings as a starting point. In line with previous research (Lindquist et al., 2016), we could observe most activity in the valence-general condition which indicated activity independent of experimental factors in the accumbens area, thalamus proper, anterior cingulate cortex, medial superior frontal cortex, superior frontal cortex, and the cerebellum exterior. A negative average feedback balance produced activity in the superior temporal and middle temporal gyrus. Analysis of expected valence ratings replicated findings from Experiment 1 meaning that expected valence ratings differed between positive and negative

balanced symbols and for positive balanced symbols between consistent and inconsistent symbols. Findings of current arousal could also be replicated with positively balanced symbols having higher arousal ratings than negatively balanced symbols. Findings of expected arousal and current valence could only partially replicate findings from Experiment 1. Overall, the presented evidence suggests that valence-general regions are also recruited in the anticipation period of our decision-making task. During the anticipation period self-reported expected valence and current arousal ratings are robustly influenced by contextual factors.

Our results indicate some overlapping activity with results of the meta-analysis by Lindquist et al. (2016). However, there is still a considerable difference between valence-general active regions as we did not find activity in the amygdala, the insula, and prefrontal regions, for example. The absence of activity in prefrontal regions could be explained by findings from Oldham et al. (2018). They conducted a meta-analysis on fMRI studies that used the monetary incentive delay task. This task makes it possible to disentangle the anticipation period from the feedback period as well as gains from losses. Their findings suggest that there is great overlapping neural activity between the anticipation of gains and losses including the amygdala, thalamus, striatum, and insula which is in line with Lindquist et al.'s (2016) findings and the affective work-space hypothesis. Furthermore, activity in orbitofrontal/ventromedial prefrontal regions was only observed during the reward feedback period which could explain the absence of activity in our findings. In general, Wilson et al. (2018) replicated the findings in another meta-analysis and analyzed active brain regions in more detail. This resulted in similar activations like we found adding activity in the cerebellum, the superior frontal gyrus, and the medial superior frontal gyrus to the meta-analytic evidence. However, we could not observe activity in the insula and the amygdala which has been a robust finding in the presented meta-analyses (Lindquist et al., 2016; Oldham et al., 2018; Wilson et al., 2018). Both brain areas have been identified as key nodes of the so called salience network which appears to serve the function of detecting novel stimuli across different modalities (Uddin, 2015). As we examined neural activity in relation to a control symbol, this could be the reason why we did not observe neutral activity in these areas of the salience network. Participants continuously viewed different symbols intermitted by fixation asterisks and the feedback presentation. We argue that the recognition of the control symbol, like all other symbols, also elicited a salience response. Hence, the control symbol was as novel as the other symbols in our experimental design which resulted in no greater or lesser neural activity in the salience regions.

GENERAL DISCUSSION

In two experiments, we examined the involvement of subjective feelings in the decision-making process. We studied how contextual factors influence current and expected subjective feelings and which constructs predict choice behavior best. We addressed the problems of common research designs like the IGT (Dunn et al., 2006) by developing a recurrent decision task that can vary contextual factors (feedback consistency, average feedback balance, learning experience) in a systematic way. Furthermore, we presented only one symbol at a time and could, therefore, solve the previously mentioned problem of the IGT without losing ecological validity. To our knowledge this is the first study that took a two-dimensional affect approach (valence, arousal) for measuring self-reported expected and current affect in a recurrent decision task. This provides a fuller picture of involved affective processes in recurrent decision-making. Furthermore, we exploratively looked at neural activations depending on contextual factors. Our results suggest that expected valence is the main and only self-reported subjective feeling component that predicts decisions. Hence, self-reported expected valence yet not self-reported current affect predicted decisions. Additionally, we observed valence-general neural activity in Experiment 2 while participants' self-reported expected valence depended on contextual factors. Although self-reported current affect ratings also depended on contextual factors, the observed effect size and effect consistency for expected valence was substantially bigger. In sum, we observed valence-general activity in line with the presented meta analyses (Lindquist et al., 2016; Oldham et al., 2018; Wilson et al., 2018) and observed inconsistent and smaller contextual effects for self-reported current valence than for self-reported expected valence.

We carefully interpret our findings in the way that based on past experiences symbols induced current affect (fMRI findings, self-report current affect ratings) which in turn prompted further cognitive processes like expectancies of future outcomes (expected valence). If this is the case, participants would feel something and use this feeling to build their expectancies upon this feeling which is reflected in differential expected affect ratings. However, we did not find clear self-reported current affect patterns and no high correlation between current valence and expected valence which limits our interpretation. The reason for this contradiction could be the way we asked for current affect. Västfjäll and Slovic (2013) suggest, additionally to the proposed dimensions, to distinguish *incidential affect*, which is unrelated to the decision problem, from *integral affect* which is inherently linked to the decision problem. Hence, to get a more sensitive measure of incidential current affect we might have asked participants how they felt while seeing the symbol. This might have led to more consistent findings and a bigger predictive power of current affect. Keeping this in mind, we should be careful with this interpretation as our findings have limitations that make it impossible to draw final conclusions. Future research should focus on how current and expected affect interact or do not interact with each other. Experimental designs would have to make sure that the measurement of current affect is more precise and should examine whether it is even possible to separately manipulate expected affect and current affect. If it is not possible, this will provide more evidence for the described interpretation.

Complementing our interpretation, Moors and Fischer (2019) suggest that from a theoretical perspective there is no need to assume an intervening emotion variable to cause behavior. Even cases incorporating maladaptive emotions can be reinterpreted in a goal-directed way. For example, a student is paralyzed

during her presentation in class as she is afraid. Her goal could be not to make a mistake which she tries to control through increased self-monitoring (Clark and Wells, 1995). This limits her cognitive resources which makes committing mistakes more likely. Thus, she tries to control the first mistake with increased self-monitoring. This results in a vicious cycle which eventually paralyzes her. In her logic, if she stops speaking, she cannot make mistakes which is her overarching goal. Consequently, in this model of explaining the student's behavior, there is no need of a mediating emotion variable. The authors conclude that "emotions may point in imprecise ways to other factors (values and expectancies) that do the actual causal work. If so, it may be time to replace explanations in terms of emotions with explanations in terms of these other factors" (Moors and Fischer, 2019, p. 98). In our findings we can also see that expectancies are a much better predictor than current affect. Incorporating subjective feelings and expectancies of subjective feelings into one model shows that there is no predictive power of current affect as a goal-directed account of emotions would predict.

As mentioned before, there are some limitations to our study we would like to address now. First, in the fMRI analysis we report uncorrected *p*-values. Hence, cumulated alpha errors could have led to false positive results. However, we conducted an explorative fMRI analysis which is useful for generating hypotheses and should not be taken as conclusive knowledge. Adding to that, we would like to point out that we had a relatively small sample size in both experiments which underlines the robustness of effects regarding expected valence. However, it is still possible that we missed smaller effects due to the low power of our study. Future research should replicate the main findings with a larger sample size. Moreover, we did not present questions in a randomized order which could have led to systematic biases in affect ratings. Future research should counterbalance or randomize question presentation to make sure that there is no hidden bias. We expect though that findings regarding affect ratings will not change in a meaningful way. Taken together, our findings can only be preliminary due to the described limitations. Nevertheless, we still think that our results make a valuable contribution to inspire future research and neurocognitive decision theories.

Future research should also measure current affect in a more sensitive way as we proposed before. This would be the first step to further study how current and expected affect might work together. Furthermore, experimental designs should try to separately manipulate current affect and expected affect. We have two ideas how this could be accomplished. First, we could present symbol-feedback contingencies in the beginning and start with a questionnaire block. This would mean that participants have not experienced any outcome but draw on their knowledge and should therefore report differential valence expectancy ratings. Following reinforcement learning models (Holroyd and Coles, 2002), having not experienced an outcome before, might eliminate current affective experiences when viewing the symbol. A second option would be to switch symbol-feedback contingencies after a learning phase and before a questionnaire phase. Participants should be told which symbols have changed, so that they could adjust their expectations accordingly. This way participants would have current affect ratings based on their learning history and expected valence ratings based on the new information they received. Studying how these changes in experimental design affect subsequent gambling decisions could elucidate how current and expected affect work together and which is causal for decisions. Moreover, we would like to point out that self-reported arousal might not be the best way to measure an emotional arousal component as it produces inconsistent results (Asutay et al., 2019). It might be better to additionally use physiological arousal measures.

CONCLUSION

Examining the relations among current and expected affective constructs in causing decision is a sensible way for future theorizing and empirical research on the affective involvement in decision-making.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the ethics committee of the Hannover Medical School. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DJ, JR, and MB designed the study. DJ and MB collected and analyzed the data, DJ, MB, JR, and JDR wrote the manuscript. All authors approved the final version of the manuscript.

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BRIEF RESEARCH REPORT
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Recollecting Cross-Cultural Evidences: Are Decision Makers Really Foresighted in Iowa Gambling Task?

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The Iowa Gambling Task (IGT) has become a remarkable experimental paradigm of dynamic emotion decision making. In recent years, research has emphasized the "prominent deck B (PDB) phenomenon" among normal (control group) participants, in which they favor "bad" deck B with its high-frequency gain structure—a finding that is incongruent with the original IGT hypothesis concerning foresightedness. Some studies have attributed such performance inconsistencies to cultural differences. In the present review, 86 studies featuring data on individual deck selections were drawn from an initial sample of 958 IGT-related studies published from 1994 to 2017 for further investigation. The PDB phenomenon was found in 67.44% of the studies (58 of 86), and most participants were recorded as having adopted the "gain-stay loss-randomize" strategy to cope with uncertainty. Notably, participants in our sample of studies originated from 16 areas across North America, South America, Europe, Oceania, and Asia, and the findings suggest that the PDB phenomenon may be cross-cultural.

Keywords: iowa gambling task, IGT global map, foresight, prominent deck B phenomenon, gain-loss frequency, gain-stay loss-randomize decision strategy, cross-cultural, dynamic decision-making

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INTRODUCTION

In recent decades, the Iowa Gambling Task (IGT; Bechara et al., 1994) has gradually become a classic experimental paradigm of dynamic decision making (Dunn et al., 2006) and has even been used to clinically assess patients with ventromedial prefrontal cortex (vmPFC) dysfunction related to brain lesions (Bechara, 2007, 2016). The IGT is a dynamic task that simulates the uncertain conditions of a real-life situation. In the task, four decks are displayed with a pseudorandomized and symmetrical gain-loss schedule that is not disclosed to the participants. Based on the schedule developed by Bechara et al. (1994), decks A and B are defined as "bad decks" due to their long-term disadvantageous outcome despite a large gain (e.g., $100) in each selection, while decks C and D are scheduled with a small gain (e.g., $50) in each selection and defined as "good decks" due to their long-term advantageous outcome. Furthermore, decks A and C contain five times as many losses, while decks B and D contain an average of only one loss for every 10 trials. Compared

to patients with vmPFC lesions, Bechara et al. (1994) theorized that control participants would form a "somatic marker" (Damasio, 1994) when making deck selections and that the gut feeling related to the somatic marker would lead to foresighted and rational decision making—that is, choosing "good decks" (C and D) in the IGT. Moreover, a series of studies by Bechara et al. (1994; 1997; 1998; 1999; 2000) replicated these results.

However, Dunn et al. (2006) undertook a review of IGT-related studies and noted several possible issues, including the possibility that the inconsistencies identified between prior studies' findings were due to variability of the normal (control) participants. Recently, though, others have shown that the IGT participants in control groups typically favor bad deck B not only more than deck A, but also more than good decks C or D (Wilder et al., 1998; Toplak et al., 2005; Fernie and Tunney, 2006; Lin et al., 2007, 2013; Steingroever et al., 2013), which is inconsistent with the basic assumption proposed by Bechara et al. (1994). This finding has been defined as the "prominent deck B (PDB) phenomenon" (Lin et al., 2007), and researchers have inferred that the selection preference is due to a "gain-loss frequency effect"—that is, like good deck D, bad deck B features nine gains and one loss across 10 trials, in terms of net value (Lin et al., 2007; Chiu et al., 2008). The PDB phenomenon has been acknowledged as a critical issue in IGT-related research (Chiu et al., 2018), yet, few studies (Chiu et al., 2012; Steingroever et al., 2013) have fully examined whether it exists in relation to prior IGT-related findings.

Some researchers have attributed a preference for a particular IGT deck with high-frequency gain to cultural differences (Ekhtiari et al., 2009; Bakos et al., 2010). For example, Bakos et al. (2010) found that culture or birth country could partially influence participants' behavior in the IGT. However, a similar finding regarding high-frequency gain preference in the IGT was also observed in a sample of Iranian participants. Ekhtiari et al. (2009) attributed the demonstration of the phenomenon in this example to the restriction on gambling within Islamic culture and the country's relatively late development of a bourgeois class.

Chiu et al. (2012) undertook a review of the PDB phenomenon and found that out of 16 studies, 13 (81.25%) obtained results for individual deck selections (i.e., the mean selection number with respect to each deck was presented in the study) that demonstrated the PDB phenomenon. Steingroever et al. (2013) published the results of two reviews related to the IGT: the first examined 17 studies that utilized data regarding selections from four decks (479 normal participants in total); the second review examined 39 groups and the corresponding mean selections from good and bad decks (1,427 normal participants in total). The research team then sent emails requesting the raw data. After receiving responses from seven authors, the researchers collected data from 162 normal participants and analyzed the 8 data sets. Ultimately, both reviews concluded that the normal participants had a preference for low-frequency loss deck B, and the selections persisted until the end of the IGT (Steingroever et al., 2013). The issue of cultural difference, however, was not clearly specified in these review studies.

Following the findings of Chiu et al. (2012) and Steingroever et al. (2013), but in contrast to the observations made by Ekhtiari et al. (2009) and Bakos et al. (2010), we hypothesized that the PDB phenomenon (i.e., a preference of normal participants for the high-frequency gain bad deck B in the IGT) exists cross-culturally. That is, cultural difference may not be a critical factor for interpreting decision-making behavior in the IGT. To test this hypothesis, we reviewed past studies that were identified through a PubMed search of the MEDLINE biomedical database and further integrated the findings of review studies (Chiu et al., 2012; Steingroever et al., 2013) to examine the geographical distribution of IGT-related studies that found individual deck selections in the IGT and plot a global map of the PDB phenomenon.

METHODS

Procedure

A search for IGT-related studies dating from 1994 to March 31, 2017 was performed on the MEDLINE biomedical database using the PubMed search engine and the keywords "Iowa gambling" and "Bechara card task." We found 945 articles that featured "Iowa gambling" and 18 articles using "Bechara card task" as keywords. Once we had excluded 12 overlapping IGT-related studies, 951 IGT-related studies were individually reviewed.

Inclusion and Exclusion Criteria

We ultimately identified 140 articles that presented deck decisions in the main text, tables, or figures. Regarding the version of the IGT, testing procedure consistencies, and the ages of participants, we excluded 22 studies that used revised versions of the IGT (e.g., the Hungry Donkey task, the inverted IGT, the simple IGT, the net-value IGT, and the Soochow Gambling Task), 9 studies that manipulated testing procedures, 9 studies that did not present the control group data, 9 studies that included participants younger than 17 years of age, 7 studies that presented the results of fewer than 100 trials, 3 studies that only presented representative data, and 2 studies in which the data for deck selection were unclear even though each selection of every participant was presented. Consequently, 79 studies that used the original IGT's gain-loss structure and presented data for individual deck choices were further analyzed.

Table 1 presents the deck selection data of control participants in 100 IGT trials (namely, over 100 IGT trials were not depicted here) that we extracted from these 79 studies. For studies that presented figures without precise means and standard deviations, we measured and estimated the values based on the scale of the figures.

To increase the integrity of reviewing IGT-related studies, we investigated the studies originally reviewed by Chiu et al. (2012) and Steingroever et al. (2013) that had focused on the issue of high-frequency gain deck preference in the IGT (see **Table 2**). Six studies were selected after we excluded repeated articles from the database mentioned above. The original selection data of 100 trials in a concurrent IGT condition published in Chiu et al. (2012) were also obtained and included in the present research.

TABLE 1 | Data of normal participants in Iowa Gambling Task (IGT)-related studies from PubMed search, which showed individual deck selections.

Authors	Sample size (sex)	$Mean_{age}$ (SD)	Source of study	Mean number of card selection				Note
				Deck A	Deck B	Deck C	Deck D	
Petry et al., 1998	59 (26F, 33M)	35 (10)	US	16.80	26.20	28.50	32.20	≈
Petry, 2001	21 (21M)	36.1 (11.5)	US	15.50	24.80	27.80	32.70	≈
North and O'Carroll, 2001	20 (4F, 16M)	30.8 (1.91)	GB	9.80	19.90	36.60	34.90	≈
O'Carroll and Papps, 2003	11 (5F, 6M)	20.0 (3.1)	GB	15.00	26.70	20.80	35.60	≈Placebo
Overman, 2004	101 (54F, 47M)	F: 21.1, M: 19.1	US	13.00	29.25	25.50	32.25	% ≈ +Adult Female, Weather Task First Reavis and Overman, 2011
				13.00	29.70	22.10	35.25	% ≈ +Adult Female, Card Task First Reavis and Overman, 2011
				11.65	21.30	29.10	38.00	% ≈ +Adult Male, Weather Task First Reavis and Overman, 2011
				13.90	25.80	32.10	28.70	% ≈ +Adult Male, Card Task First Reavis and Overman, 2011
Shurman et al., 2005	10 (5F, 5M)	32.1 (4.5)	US	15.70 (4.1)	18.50 (6.4)	34.00 (9.0)	31.80 (6.3)	
Bark et al., 2005	26 (14F, 12M)	29.81 (9.39)	DE	22.30	29.10	24.30	24.00	≈ +
Rodriguez-Sanchez et al., 2005	22 (10F, 12M)	26.09 (6.49)	ES	16.91 (5.51)	32.05 (13.22)	20.50 (8.55)	30.55 (14.04)	
Fernie and Tunney, 2006	20 (not reported)	Not reported	GB	18.80 (1.45)	31.60 (2.25)	21.05 (1.73)	28.55 (2.22)	Session 1 Hint-Fascimile group
	20 (not reported)	Not reported	GB	20.45 (1.31)	32.65 (2.02)	21.65 (1.44)	25.25 (1.65)	Session 1 No Hint-Fascimile group
Northoff et al., 2006	14 (7F, 7M)	28.7 (19–34)	DE	15.19	26.61	18.78	38.84	= +
Kester et al., 2006	25 (11F, 14 M)	17.1 (1.8)	US	20.70 (5.1)	25.20 (6.5)	25.60 (10.3)	28.40 (10.3)	
Sevy et al., 2007	20 (8F, 12M)	33 (10)	US	18.00 (5)	31.00 (8)	23.00 (6)	27.00 (6)	
Lee et al., 2007	28 (13F, 15M)	26.9 (3.6)	KR	17.60 (6.2)	23.60 (7.7)	25.50 (10.9)	33.10 (13.5)	
Martino et al., 2007	15 (9F, 6M)	34.96 (10.93)	AR	15.20 (3.74)	26.66 (10.46)	21.13 (9.25)	37.00 (8.75)	
Zamarian et al., 2008	33 (22F, 11M)	36.1 (13.7)	AT	12.50 (4.2)	21.40 (8.0)	25.60 (10.8)	40.40 (11.9)	Young adults
	52 (34F, 18M)	69.3 (7.0)		15.20 (5.4)	26.60 (9.0)	22.50 (8.4)	35.70 (9.5)	Old adults
Ahn et al., 2008	36 (18F, 18M)	22.0 (18–33)	US	13.28	24.30	31.60	30.82	% ≈ +
Viswanath et al., 2009	25 (10F, 15M)	27.44 (6.40)	IN	20.68 (7.23)	22.84 (7.24)	26.04 (6.54)	31.24 (8.40)	
van den Bos et al., 2009	10 (10M)	24.7 (0.5)	NL	16.80 (2.5)	24.00 (2.8)	27.80 (3.0)	31.40 (2.6)	Male control subjects
	12 (12F)	22.3 (0.4)	NL	21.30 (1.9)	25.20 (1.5)	26.40 (1.9)	27.10 (1.1)	Female control subjects
Kim et al., 2009	55 (26F, 29M)	28.8 (7.5)	KR	16.90	26.95	24.30	33.90	≈
van Toor et al., 2011	31 (15F, 16M)	36.32 (12.36)	NL	15.26 (6.78)	24.23 (9.29)	21.97 (7.87)	38.55 (15.70)	
Martino et al., 2011	34 (22F, 12M)	40.0 (12.9)	AR	14.70 (6.3)	27.10 (12.1)	20.40 (10.9)	37.80 (12.5)	
Adida et al., 2011	150 (75F, 75M)	38.8 (10.6)	GB FR	17.10	24.70	25.70	32.80	≈
Kim et al., 2011	21 (21M)	30.52 (2.98)	KR	18.05 (8.29)	20.19 (7.52)	29.67 (12.13)	32.10 (12.93)	
Tchanturia et al., 2012	61 (41F, 20M)	22.2 (5.68)	GB ES	17.29 (6.94)	25.37 (9.04)	25.39 (10.77)	31.95 (11.57)	Female
		25.45 (7.63)		12.45 (6.71)	27.15 (14.85)	29.75 (12.54)	30.65 (15.21)	Male
Gansler et al., 2011	214 (123F, 91M)	54.65 (17.44)	US	15.52 (6.23)	28.69 (11.68)	20.87 (8.73)	34.92 (14.68)	
Visagan et al., 2012	30 (16F, 14M)	22.2 (3.7)	GB	11.00	28.00	23.00	33.10	≈ +

(Continued)

TABLE 1 | Continued

Authors	Sample size (sex)	$Mean_{age}$ (SD)	Source of study	Mean number of card selection				Note
				Deck A	Deck B	Deck C	Deck D	
Mogedas Valladares and Alameda-Bailen, 2011	33 (18F, 15M)	29.91 (9.45)	ES	14.48 (5.149)	26.94 (7.905)	29.30 (6.502)	29.27 (5.986)	
Escartin et al., 2012	31 (14F, 17M)	50 (11.1)	ES	17.97 (6.98)	26.45 (12.05)	25.39 (13.31)	30.13 (11.15)	
Gansler et al., 2012	124 (65F, 59M)	54.9 (16.4)	US	15.94 (6.62)	29.18 (11.20)	20.46 (7.99)	34.43 (13.99)	Same subjects as Gansler et al., 2011 but exclude Connecticut subjects.
Upton et al., 2012	27 (5F, 22M)	35 (10.44)	AU	16.64	34.88	17.76	31.26	% ≈ +
Gescheidt et al., 2012	20 (5F, 15M)	49.95 (9.03)	CZ	20.50	24.40	25.30	29.80	≈ +
Horstmann et al., 2012	119 (66F, 53M)	F: 25.2 (4.9) M: 24.7 (3.1)	DE	13.92	33.59	21.71	30.79	= +
Alameda-Bailen et al., 2012	41 (14F, 27M)	25.17 (5.652)	ES	15.95 (5.731)	24.49 (6.874)	29.61 (7.334)	29.95 (6.618)	
Carvalho et al., 2012	40 (22F, 18M)	25.50 (4.70)	BR	14.75 (6.27)	30.90 (13.43)	20.88 (10.06)	34.28 (11.18)	Young adults
	40 (30F, 10M)	67.40 (5.02)		18.90 (6.77)	29.23 (11.14)	22.30 (6.72)	29.85 (11.52)	Elderly adults
Steingroever et al., 2013	162 (82F, 80M)	25.56 (4.86)	NL	15.00	35.00	20.00	30.00	
Worthy et al., 2013a	41 (30F, 11M)	21.29 (18–29)	US	14.78	34.24	25.36	25.72	% ≈ +
van den Bos et al., 2013	213 (140F, 73M)	Not reported	NL	18.70	26.90	27.00	27.20	≈Female (the reconstruct data)
				18.60	25.20	27.80	28.20	≈Male (the reconstruct data)
Miller et al., 2013	77 (77F)	17–25	US	14.10 (5.02)	31.84 (14.02)	20.99 (11.61)	33.06 (13.85)	
Le Berre et al., 2014	45 (7F, 38M)	44.76 (7.78)	FR	20.31 (7.87)	20.22 (6.07)	30.69 (6.86)	28.78 (7.18)	
Kim et al., 2012	33 (17F, 16M)	27.8 (3.0)	KR	17.10 (7.1)	24.40 (9.7)	27.50 (13.8)	30.80 (14.0)	
Penolazzi et al., 2013	84 (44F, 40M)	26.47 (7.14)	IT	14.60	30.80	22.30	33.90	≈
Lin et al., 2013	72 (37F, 35M)	Not reported	TW	18.69	30.53	22.99	27.79	
Vassileva et al., 2013	12 (12F)	33.5 (8.5)	US	16.90	33.10	22.50	27.70	≈HIV-seronegative/no crack cocaine and/or heroin use history
Kloeters et al., 2013	28 (12F, 16M)	64.2 (4.4)	AU	12.30 (4.5)	28.20 (12.9)	20.30 (10.1)	39.20 (13.6)	
Buelow and Suhr, 2014	70 (48F, 22M)	18.94 (1.21)	US	18.16	29.22	22.19	30.44	% +
Lavin et al., 2014	10 (5F, 5M)	23.4 (2.4)	CL	21.30	34.80	20.00	23.90	≈ +
Beitz et al., 2014	17–29 y/o: 664 (485F, 179M) 30–59 y/o: 281 (211F, 70M)	17–89	US	14.90	25.30	25.80	35.10	≈ +17–59 y/o group
	60–89 y/o: 293 (202F, 91M)			15.40	29.00	21.80	34.90	≈ +60–89 y/o group
Cotrena et al., 2014	55 (27F, 28M)	33.4 (17.4)	BR	17.00	25.80	23.00	36.50	≈
Wolk et al., 2014	17 (8F, 9M)	36.53 (12.10)	DE	16.44 (10.10)	35.25 (11.70)	20.31 (11.60)	28.00 (14.50)	
Cardoso et al., 2014	18 (14F, 4M)	59.28 (10.25)	BR	16.00 (6.48)	22.61 (7.49)	25.61 (6.58)	36.65 (12.36)	
LeGris et al., 2014	41 (41F)	31.2 (9.0)	CA	13.40 (5.2)	26.05 (12.3)	23.34 (13.4)	37.20 (14.5)	
Lee et al., 2014	52 (26F, 26M)	21.39 (3.64)	TW	15.28 (5.75)	31.98 (8.32)	25.54 (11.32)	27.20 (9.25)	
Alameda-Bailen et al., 2014	63 (26F, 37M)	25.11 (6.01)	ES	15.60	23.80	30.50	30.50	≈+
Hong et al., 2015	30 (6F, 24M)	29.1 (7.6)	CN	19.70	21.60	31.40	29.00	≈
Seeley et al., 2014	92 (76F, 16M)	Not reported	CA	18.15	33.10	21.10	29.05	% ≈ +Session 1
Matsuzawa et al., 2015	50 (17F, 33M)	31.9 (7.8)	JP	20.90	29.10	26.10	24.40	≈
Evans and Hampson, 2015	93 (48F, 45M)	19.69 (17–28) 19.54 (17–32)	CA	15.60 17.00	31.10 34.80	21.80 23.30	34.20 27.10	≈ +Male ≈ +Female

(Continued)

TABLE 1 | Continued

Authors	Sample size (sex)	$Mean_{age}$ (SD)	Source of study	Mean number of card selection				Note
				Deck A	Deck B	Deck C	Deck D	
Hori et al., 2014	51 (26F, 25M)	36.7 (9.9)	JP	17.70 (6.9)	26.00 (12.2)	30.70 (12.6)	25.20 (8.9)	
Ma et al., 2015	24 (24M)	21.7 (1.8)	CN	19.70	31.50	24.70	24.10	≈ +
Bull et al., 2015	50 (30F, 20M)	21.44 (3.79)	NZ	16.10	21.30	30.80	31.80	≈
Brown et al., 2015	43 (17F, 26M)	41.1 (11.8)	US	15.00	29.40	24.60	31.70	≈
Zhang et al., 2015c	88 (41F, 47M)	19.17 (1.29)	CN	25.00	30.40	21.40	23.90	≈Low trait anxiety group
	119 (57F, 62M)	19.17 (1.29)	CN	23.90	24.60	21.80	30.00	≈Medium trait anxiety group
	97 (45F, 52M)	19.17 (1.29)	CN	30.00	23.10	19.60	27.70	≈High trait anxiety group
Smart and Krawitz, 2015	25 (10F, 15M)	69.88 (3.36)	CA	11.77	27.11	17.86	41.39	% ≈ +
Besnard et al., 2015	17 (2F, 15M)	44.1 (9–76)	FR	12.40 (7.9)	19.60 (5.3)	29.90 (6.4)	38.00 (10.1)	
Huang et al., 2015	65 (42F, 23M)	24.50 (3.79)	US	15.80	34.10	17.80 (10.28)	31.20 (14.74)	≈Younger adult
	65 (47F, 18M)	75.28 (6.40)		16.70	34.40	21.49 (9.72)	26.86 (11.64)	≈Older adult
Zhang et al., 2015b	80 (13F, 67M)	19.2 (2.96)	CN	24.30	24.30	22.70	29.00	≈
Alarcon et al., 2015	40 (Not reported)	Not reported	ES	18.60	32.90	19.80	28.70	≈ +Original IGT group
Zhang et al., 2015a	115 (55F, 60M)	27.32 (7.81)	CN	24.40	23.70	22.80	29.10	≈
Seeley et al., 2016	13 (Not reported)	Not reported	CA	20.36	36.10	16.81	26.46	% ≈ +Session 1
Okdie et al., 2016	30 (Not reported)	Not reported	US	16.90	31.14	22.60	28.26	% +Study 1: control group
	30 (Not reported)	18.18 (0.48)		15.96	33.70	20.04	30.30	% +Study 2: control group
Piper et al., 2016	47 (28F, 19M)	18.8 (0.3)	US	16.20 16.80	32.80 33.00	24.60 21.50	25.90 29.00	≈PAR version ≈PEBL version
Besnard et al., 2016	30 (22F, 8M)	55.1 (22.6)	FR	16.00 (6.2)	21.30 (6.8)	29.00 (8.4)	33.70 (6.2)	
Hawthorne and Pierce, 2015	30 (Not reported)	18–29	US	13.90	28.90	29.60	28.10	≈Full attention group
Pedersen et al., 2017	38 (16F, 22M)	40 (13.8)	DE	19.10 (6.4)	30.70 (10.1)	19.60 (11.3)	30.60 (10.0)	
Lin et al., 2016	145 (43F, 102M)	18.6 (0.97)	TW	17.39	32.47	24.73	25.41	
Yechiam et al., 2016	130 (65F, 65M)	23.5 (18–28)	IL	12.50	26.30	26.30	34.40	Study 2
Visser-Keizer et al., 2016	59 (22F, 37M)	43.50 (1.90)	NL	14.90 (7.7)	29.30 (14.1)	25.20 (19.6)	30.60 (18.1)	
Wright et al., 2017	36 (Not reported)	Not reported	GB	17.50	23.80	25.60	30.90	≈ +
Jollans et al., 2017	20 (9F, 11M)	24.9 (4.8)	GB	18.82	34.49	21.10	25.96	% ≈ +

Note: AR, Argentina; AT, Austria; AU, Australia; BR, Brazil; CA, Canada; CL, Chile; CN, China; CZ, Czechia; DE, Germany; ES, Spain; FR, France; GB, United Kingdom; IL, Israel; IN, India; IT, Italy; JP, Japan; KR, South Korea; NL, Netherlands; NZ, New Zealand; TW, Taiwan; and US, United States of America. The abbreviation codes were based on the "ISO 3166-1 alpha-2" (https://en.wikipedia.org/wiki/List_of_ISO_3166_country_codes).

Note: The first step of data redrawn from the figure is to measure the length (mm) of a single unit of the Y-axis. Accordingly, the second step is to convert each data point in the figure to how many card selections. Notably, there are some potential small errors (e.g., the length of the first unit is not totally equal to that of the second unit of Y-axis in the same figure) in the procedure of estimation, so we have to make a note here; some of the estimated data sets were summed into 100 and some are not.

≈Data were transcribed from figures.

≈ +Data of average deck selection in blocks were transcribed and summed.

= +Data of average deck selection in blocks were summed.

% +Data of average deck selection percentage in blocks were calculated and summed.

% ≈ +Data of average deck selection percentage in blocks were transcribed, calculated, and summed.

Note without special signs above: numerical deck selection data were obtained from original studies.

In total, there were seven studies sourced from Chiu et al. (2012) and Steingroever et al. (2013).

Study Selection and Data Extraction

Two authors (W-KL and C-JL) independently retrieved the studies that presented individual deck selections (i.e., in the main text, tables, or figures). They independently reviewed each study to extract the data and measured the average selection numbers (i.e., based on the scale of the figures). Any disagreement with respect to the process of study selection or data extraction was resolved through consensus via repeated measurements and discussion. All average numbers of choice obtained through measurement by two researchers were controlled under the difference $\leq$1 selection approach.

TABLE 2 | Data of normal participants in IGT-related studies included in Chiu et al. (2012) and Steingroever et al. (2013).

Authors	Sample size (sex)	$Mean_{age}$ (SD)	Source of study	Mean number of card selection				Note
				Deck A	Deck B	Deck C	Deck D	
Bechara et al., 1994	44 (21F, 23M)	Not reported	US	14.00	16.00	35.00	35.00	≈
Wilder et al., 1998	30 (18F, 12M)	30.2 (9.7)	US	20.20 (5.8)	26.80 (7.0)	24.10 (7.9)	28.90 (7.6)	
Tomb et al., 2002	10 (5F, 5M)	Not reported	US	15.00	19.00	34.00	32.00	≈
Ritter et al., 2004	15 (15M)	47.1 (10.2)	US	18.00	25.00	24.00	33.00	≈
Caroselli et al., 2006	141 (73F, 68M)	21.7 (4.6)	US	22.00	35.00	20.00	23.00	≈
Fum et al., 2008	Not reported	Not reported	IT	14.87	32.84	17.09	35.19	Experiment 1 standard condition
Chiu et al., 2012	24 (12F, 12M)	Not reported	TW	18.13	31.50	25.71	24.67	100 trials selection data obtained from authors

Note. IT, Italy; TW, Taiwan; and US, United States of America.
≈Data were transcribed from tables of the review studies.

Data Analysis

Data analysis was performed on a total of 86 studies, 79 of which were retrieved from the MEDLINE biomedical database and 7 from the 2 review studies noted above (Chiu et al., 2012; Steingroever et al., 2013). Notably, each experimental condition performed by normal participants in the 86 studies was considered as a single data set, even though there may in fact have been 2 (Fernie and Tunney, 2006; Zamarian et al., 2008; van den Bos et al., 2009, 2013; Carvalho et al., 2012; Tchanturia et al., 2012; Beitz et al., 2014; Evans and Hampson, 2015; Huang et al., 2015; Okdie et al., 2016; Piper et al., 2016), 3 (Zhang et al., 2015c), or 4 experimental conditions (Overman, 2004) in the original study (experimental conditions are marked in the note of **Table 1**). In total, 102 data sets obtained from 86 studies were subsequently analyzed.

To verify whether a "gain-stay loss-randomize" decision strategy was demonstrated in the different data sources, we conducted a decks-by-groups repeated measures analysis of variance (ANOVA) using IBM SPSS Statistics (version 22) and analyzed individual deck selection data. To visualize whether the PDB phenomenon is cross-cultural, all studies that presented each of four deck selections obtained from the database search and review studies were marked on an IGT global map according to the source and origin of the study's participants (**Figure 1**). We defined selections of bad deck B equal to 25 or more (i.e., higher than the randomized choices of 100 trials, or chance level), as being a "PDB phenomenon."

This standard was strictly applied while we were identifying whether the PDB phenomenon existed in the 86 studies—specifically, every experimental condition performed by normal participants had to consistently exhibit the PDB phenomenon, even in studies that featured more than one experimental condition (as discussed above). As a result, there were four studies (Overman, 2004; Zamarian et al., 2008; van den Bos et al., 2009; Zhang et al., 2015c) that we were unable to classify due to the phenomenon existing inconsistently across different experimental conditions: the PDB phenomenon existed in only three of the four experimental conditions in Overman (2004), one of the three experimental conditions in Zhang et al. (2015c), and one of the two experimental conditions in Zamarian et al. (2008) and van den Bos et al. (2009; see **Table 1** and **Figure 1**). Although unclassifiable in the global map (see gray circles in **Figure 1**), the data sets from the four studies were still included in the following analysis.

RESULTS

The repeated measures ANOVA showed that the interaction effect of groups (studies retrieved from the database search and review studies) and decks was nonsignificant, F (2.377, 237.73) = 0.445, p = 0.676 (Greenhouse–Geisser correction). The main effect of the decks was significant, F (2.377, 237.73) = 39.141, $p < 0.001$, $\eta^2 = 0.281$, but that of the groups was not, F (1, 100) = 0.123, p = 0.726. In short, the results indicated no difference between the data obtained from the MEDLINE database and the review studies (Chiu et al., 2012; Steingroever et al., 2013).

As there was no difference between the two data sources, we combined the data obtained from the two sources (86 studies in total) and further conducted a repeated measures ANOVA to test for differences between decks. The results showed a significant difference with respect to the selections of individual decks, F (2.379, 240.293) = 171.702, $p < 0.001$, and $\eta^2 = 0.63$ (Greenhouse–Geisser correction). The selection of deck B was significantly higher than that of decks A, $p < 0.001$, and C, $p < 0.001$. Moreover, the selection of deck C was higher than that of deck A, and the selection of deck D was higher than those of all other decks, ps < 0.001. These results suggest that the PDB phenomenon was common in the reviewed studies (**Figure 2**).

Combining the results of the studies from the MEDLINE database and the review studies, we found that 67.44% (58 of 86) featured a selection of the disadvantageous deck B $\geq$ 25 times, and this preference corresponded to our definition of the PDB phenomenon (detailed above). As shown in **Figure 1**, the normal participants in these 58 studies originated from 16 regions of North America, South America, Europe, Oceania, and Asia: specifically, Argentina, Australia, Brazil, Canada, Chile, China, Germany, Israel, Italy, Japan, Netherlands, South Korea, Spain, Taiwan, United Kingdom, and the United States.

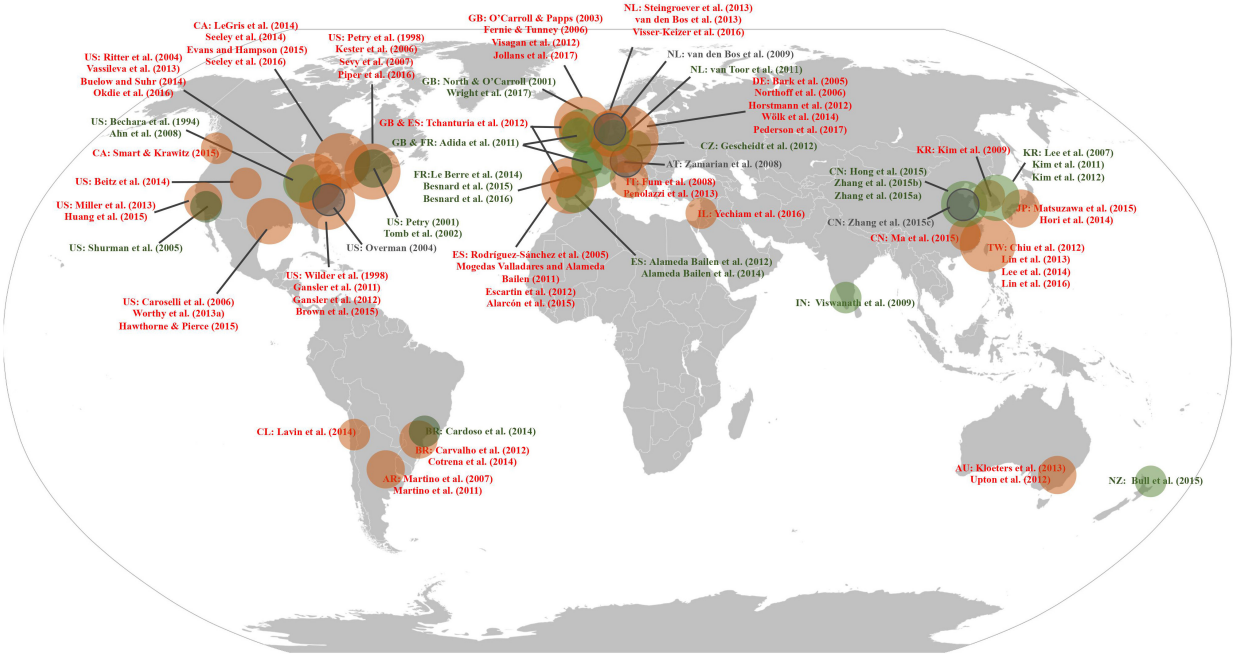

FIGURE 1 | The Iowa Gambling Task (IGT) global map. The figure illustrates the geographical distribution of IGT-related studies that showed individual deck selections. Red circles indicate studies demonstrating the PDB phenomenon, green circles indicate studies that support the original IGT assumptions, and gray circles indicate studies that were unclassifiable. AR, Argentina; AT, Austria; AU, Australia; BR, Brazil; CA, Canada; CL, Chile; CN, China; CZ, Czechia; DE, Germany; ES, Spain; FR, France; GB, United Kingdom; IN, India; IT, Italy; JP, Japan; KR, South Korea; NL, Netherlands; NZ, New Zealand; TW, Taiwan; and US, United States of America. Adapted from "Robinson projection, national borders, areas grouped" (https://en.wikipedia.org/wiki/Wikipedia:Blank_maps#/media/File:BlankMap-World.svg) in the public domain.

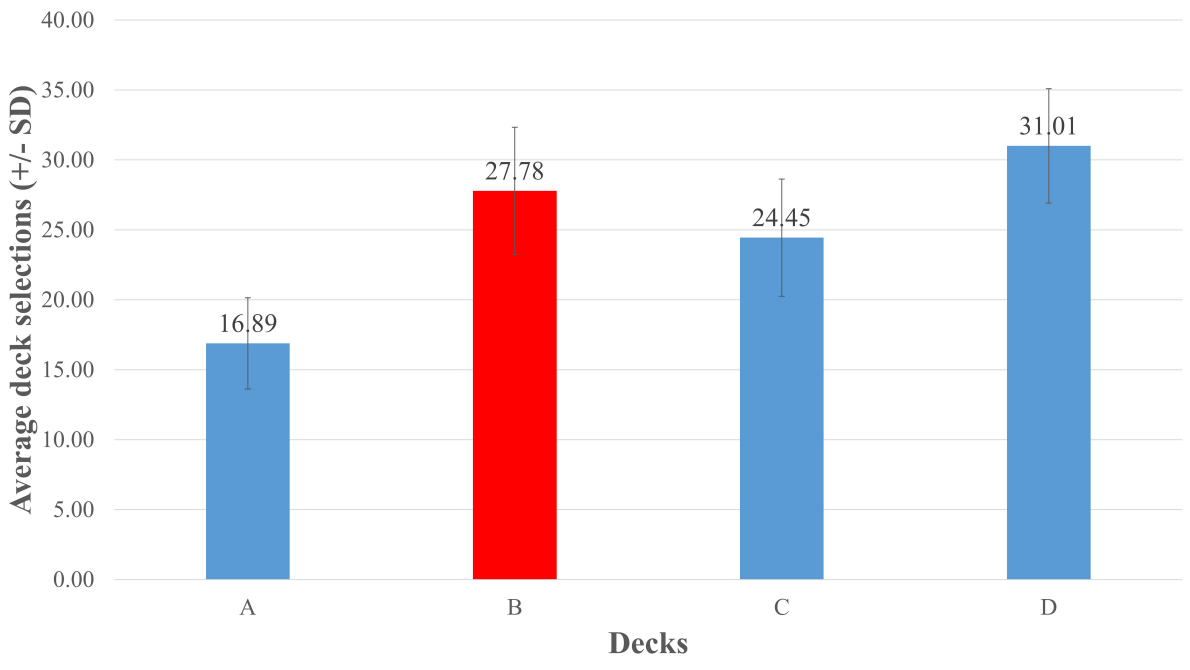

FIGURE 2 | Mean number of card selections in 86 IGT-related studies. The figure was produced by averaging the numbers of the four decks chosen across the 86 IGT-related studies. Selections of deck B were relatively higher than those of decks A and C, demonstrating that the PDB phenomenon was present. This finding is consistent with those obtained in a growing number of other IGT-related researches.

DISCUSSION

Most IGT-related studies have used the calculation (C + D) − (A + B) to define decision-making performance. Correspondingly, the basic assumption of the IGT (Bechara et al., 1994, 1997) posited that normal (control group) participants could perform advantageously and make rational decisions guided by implicit emotion, in contrast to participants who were unable to access an emotional system due to a vmPFC lesion. However, the present article found that in 67.44% (58 out of 86) of the IGT-related studies that showed individual deck selection data, a preference for the disadvantageous deck B was observed. The participants in these 58 studies originated from 16 different areas across North America, South America, Europe, Asia, and Oceania. Therefore, we infer that the PDB phenomenon in the IGT is cross-cultural.

Individual and Cultural Issues in the IGT

A prior critical review article (Dunn et al., 2006) reiterated Bechara and Damasio's (2002) finding that about 20% of normal participants performed poorly in the IGT. In fact, Bechara and Damasio (2002) showed that 37% of normal (control group) participants performed within the range of vmPFC patients, referring to the criterion of the net score (C + D) − (A + B) < 10. The present research showed that in more than 60% of sample studies, normal participants consistently favored the disadvantageous deck B. This PDB phenomenon is evidently different from the results obtained by Bechara and Damasio (2002).

Previous IGT-related studies have attributed participants' preference for decks with a high-frequency gain (decks B and D) to cultural issues. For example, Bakos et al. (2010) postulated that a preference for deck B only existed in certain cultures and further investigated decision-making differences between Brazilians and Americans. In their study, 17% of the Brazilian participants in an IGT were categorized as "normal decision makers," compared to the 60% of American participants who were categorized as normal, according to the measure (C + D) − (A + B) > 18, a criterion proposed by Denburg et al. (2005). These results suggested that Americans perform better than Brazilians in the IGT; Bakos et al. (2010) posited that the difference might relate to capitalism in the United States making the daily lives of Americans much more reliant on their ability to manage financial issues compared to Brazilians. However, the study did not clarify whether a preference for decks with a high-frequency gain existed in both Americans and Brazilians.

Similar to our study, Ekhtiari et al. (2009) performed an analysis of individual decks and found that Iranian participants favored the high-frequency gain decks B and D. The researchers attributed the phenomenon to two possible causes: (1) the limitations on gambling under Islamic law meant that Iranian participants were unclear about or lacking gambling concepts, which further affected their decision-making performance in the IGT according to frequency-based valuations; and (2) the late development of a bourgeois class in Iran, and therefore of concepts such as land ownership and work ownership, meant that the country's workers lacked long-term decision-making experience (Ekhtiari et al., 2009). In contrast to the cultural difference perspective, we suggested a cross-cultural preference for high-frequency gain decks B and D in the IGT. This is supported by our confirmation that the phenomenon exists in 16 areas across North America, South America, Europe, Asia, and Oceania.

However, although our sample of studies showed that the PDB phenomenon existed cross-culturally, the finding was limited by the lack of analysis regarding cultural factors. Future studies could further analyze the performance of normal participants under different cultural factors (e.g., Western or Eastern cultural contexts) and examine whether the PDB phenomenon exists universally.

Methodological Issue in Iowa Gambling Task-Related Studies

Furthermore, of the 951 IGT-related studies originally sourced through the MEDLINE database, only 140 showed individual deck data, and most of the remaining 811 studies used the calculation (C + D) − (A + B) to differentiate the performances of clinical versus control participants. It is possible that the scoring method may have obscured the existence of the PDB phenomenon in control participants (Chiu and Lin, 2007; Lin et al., 2007, 2013; Steingroever et al., 2013) and further neglect differences between the preferences of clinical versus control participants for individual decks. Consequently, researchers may be missing opportunities to observe differences regarding more specific decision-making patterns.

In the present research, we further analyzed the 86 studies that featured individual deck data according to the criterion (C + D) − (A + B) < 10, as used by Bechara and Damasio (2002). According to this analysis, 45.35% (39 out of 86) of the studies showed that normal participants performed within the range of vmPFC patients (see **Supplementary Table 1**). Additionally, even more studies (67.44%, 58 out of 86) demonstrated that the normal participants consistently preferred the disadvantageous deck B. These findings significantly challenge the basic assumption of the IGT and suggest that evidence of PDB phenomenon is obscured by the use of the measure (C + D) − (A + B). We therefore recommend that future studies should investigate and compare the individual deck selections of clinical participants based on the consistent performance of the control participants.

A New Raising Perspective: Gain–Loss Frequency

The preference for bad deck B shown by normal participants in the IGT was first demonstrated by Wilder et al. (1998), and the phenomenon has since been documented by other researchers (Toplak et al., 2005; Fernie and Tunney, 2006; Lin et al., 2007, 2013; Takano et al., 2010; Steingroever et al., 2013). Prior studies have defined participants' preferences for bad deck B and good deck D in the IGT as the "gain-loss frequency effect" (Lin et al., 2007; Chiu et al., 2008), as the preference is associated with the high-frequency gain structure (i.e., nine gains, one loss) of both bad deck B and good deck D. The observed preference also implies that, under uncertainty conditions, control participants

will use a "gain-stay loss-randomize" strategy, meaning that the probability of choosing the same deck will increase when participants face continuous gains, whereas the choice will be randomized when they face loss (Chiu et al., 2008; Worthy et al., 2013b; Lin et al., 2016). This strategy has been employed in recent IGT-related model studies (Worthy et al., 2013b; Lin et al., 2016).

Notably, the findings of our research depart from the original IGT study by Bechara et al. (1994) who proposed that normal (control group) participants would form a "somatic marker" (Damasio, 1994) when experiencing the gains and losses in the IGT and gradually develop a sensitivity to the long-term outcome—that is, preferring advantageous decks C and D and avoiding disadvantageous decks A and B. However, other studies (Wilder et al., 1998; Toplak et al., 2005; Fernie and Tunney, 2006; Lin et al., 2007, 2013; Takano et al., 2010; Steingroever et al., 2013) and the current findings have failed to replicate their results obtained in relation to normal participants. The present study also supports the argument that the PDB phenomenon should be evaluated in contemporary IGT-related studies given the apparent inconsistency with respect to the original IGT hypothesis (Chiu et al., 2018). In other words, the hypothesis proposed in the original IGT study should be carefully reconsidered and revised.

CONCLUSION

The present review found that in over 60% of IGT studies, most normal (control group) participants favored the disadvantageous deck B and consistently applied a gain–loss frequency strategy. These findings are incongruent with the original inference made by Bechara and Damasio (2002), Ekhtiari et al. (2009), and Bakos et al. (2010) that the poor performance of normal participants was due to individual and cultural differences. The PDB phenomenon and the influence of gain–loss frequency in the IGT might be obscured by the analysis and presentation methodology being principally based on the net score measure $(C + D) - (A + B)$. Considering the present integrative review and analysis of 958 studies, we conclude that gain–loss frequency could be a cross-cultural factor during decision making under dynamic-uncertain conditions.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

Y-CC initiated this research topic and C-HL focused on refining the issue. Y-CC and C-HL constructed the research strategy and developed its main structure. Y-CC, C-HL, and W-KL undertook the literature review and defined the research database. Y-CC, C-HL, and W-KL developed the idea of mapping the geographical distribution of IGT-related studies for this manuscript, and W-KL created the corresponding artwork. W-KL completed the first round of the literature data collection, defined the categorization criteria and data administration, and drafted the preliminary manuscript. C-JL completed the second round of literature data collection, redefined the categorization criteria, and finalized the data re-categorization, as well as providing some interpretation. L-HL created the initial preliminary uncompleted draft in Chinese. W-KL, C-JL, C-HL, and Y-CC undertook several rounds of discussion, and all authors finalized and approved the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.537219/full#supplementary-material

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Evaluation of Risk Behavior in Gambling Addicted and Opioid Addicted Individuals

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Evidence suggests that both opioid addicted and gambling addicted individuals are characterized by higher levels of risky behavior in comparison to healthy people. It has been shown that the administration of substitution drugs can reduce cravings for opioids and the risky decisions made by individuals addicted to opioids. Although it is suggested that the neurobiological foundations of addiction are similar, it is possible that risk behaviors in opioid addicts may differ in detail from those addicted to gambling. The aim of this work was to compare the level of risk behavior in individuals addicted to opioid, with that of individuals addicted to gambling, using the Iowa Gambling Task (IGT). The score and response time during the task were measured. It was also observed, in the basis of the whole IGT test, that individuals addicted to gambling make riskier decisions in comparison to healthy individuals from the control group but less riskier decisions in comparison to individuals addicted to opioids, before administration of methadone and without any statistically significant difference after administration of methadone—as there has been growing evidence that methadone administration is strongly associated with a significant decrease in risky behavior.

Keywords: addiction, methadone therapy, gambling, opioids, Iowa gamble task, cortico-subcortical loops, philosophy of mind

1. INTRODUCTION

The evidence, collected by inter alia authors of this paper, suggests that both opioid addicted and gambling addicted individuals can be characterized with higher levels of risk behavior in comparison to healthy people (Brevers et al., 2013; Gorzelańczyk et al., 2014). It has been shown that the administration of substitution drugs can reduce cravings for opioids and also decrease risky decision making among individuals addicted to opioids (Gorzelańczyk et al., 2014; Hu et al., 2019; Kriegler et al., 2019; Kelty et al., 2020). Although it is suggested that the neurobiological basis of addiction is similar, it is possible to assume that the risk behavior in individuals addicted to opioids can differ from gambling addicted individuals (Zeng et al., 2016; Chen et al., 2017; Coppola et al., 2017; Majuri et al., 2017; Schwaninger et al., 2017; Victorri-Vigneau et al., 2018; Kim et al., 2019).

Therefore, the main aim of this study was to compare the level and dynamics of risk behavior in opioid addicts with those addicted to gambling while performing the Iowa Gambling Task (IGT). The score and response time were measured during the IGT performance. The authors introduced for the first time the response time measurement in the IGT test as a new parameter. Response time is assessed for correct and incorrect choices and can be useful in the differential diagnosis of addicts Gorzelańczyk et al. (2014).

A large number of similarities between drug addiction and gambling addiction were found recently. It was noticed that those addictions share some common mechanism (American Psychiatric Association, 2013; Brevers et al., 2013). Addicted individuals are more prone to show risky behavior in comparison to healthy people (Leeman and Potenza, 2012; Ahmadi et al., 2017; Chamberlain and Grant, 2019).

It was also observed that impairments in decision-making reflect drifts into risky behaviors and may be at first manifested with some psychiatric symptoms or cognitive dysfunctions (Chamberlain and Grant, 2019; Vegni et al., 2019). Misuse and addiction to opioids have become a major civil challenge in the world (Volkow et al., 2018).

Gambling is an activity, where something valuable is risked on behalf of a chance for winning something even more valuable (Yau and Potenza, 2015). The chances are however less than certain (Nautiyal et al., 2017). At first it may seem like a recreational activity, as between 50 and 80% of the general population gamble at least once a year. Individuals who are addicted to gambling tend to increase their risky behavior, which can result in serious financial problems (Leeman and Potenza, 2012; Brevers et al., 2013).

From the neuropsychiatric and neurobiological perspectives, risky behavior is connected to malfunctioning of mesolimbic and executive control circuits (American Psychiatric Association, 2013; Engel and Caceda, 2015). It is known that the use of psychoactive substances can change structures and functions of circuits involved in risk decision making (Gilman et al., 2015). The structural and functional changes of the elements of the cortico-subcortical loops have been observed among addicted people (Gorzelańczyk et al., 2014, 2016; Tarnowska et al., 2018).

It has also been observed that poker gamblers exhibited higher ventral-striatal but lower dorsolateral prefrontal and orbitofrontal activation during Iowa Gambling Task performance as well as higher ventral-striatal connectivity and connectivity in posterior cingulate cortex, occipital gyrus, and temporal gyrus (Leeman and Potenza, 2012). In addition, the severity of gambling is associated with the activation of ventral striatum, occipital fusiform gyrus and middle temporal gyrus (Brevers et al., 2016). The data from experiments on pathological gamblers show increased activation in response to visual gambling cues in such brain structures as the right dorsolateral prefrontal cortex, the right parahippocampal gyrus, and the left occipital cortex (Leeman and Potenza, 2012; Epstein and Silbersweig, 2016; Chamberlain and Grant, 2019).

In this paper the authors compared various IGT parameters of risky behaviors between addicted (to gambling or opioids) and healthy individuals using the most popular Iowa Gambling Task, which is still regarded as the classical measurement tool for decision making in this clinical population (Brevers et al., 2013). The IGT test is used to assess risky behavior also in addicted individuals (Ahn et al., 2016b; Mallorquí-Bagué et al., 2016; Kovács et al., 2017; Brière et al., 2019; Khoury et al., 2019; Lin et al., 2019; Trotzke et al., 2019).

1.1. IOWA Gambling Task

The Iowa Gambling Task (IGT) is a psychological test with a continuous task performed on a computer, which simulates various situations for decisions making (Bechara et al., 1994).

Disease categories associated with risky behaviors include inter alia: compulsive stealing (kleptomania), compulsive shopping, and compulsive sexual behavior as well as addictions to opioids and other chemical substances (Chamberlain and Grant, 2019).

The Iowa Gambling Task (IGT) is the most popular test for assessment of an appropriate decision-making process (Bechara et al., 1994; Tanabe et al., 2007; Brevers et al., 2013). It deals with uncertainty in a context of penalty and reward, with some choices being advantageous in the short-term (high reward), but disadvantageous in the long run (higher penalty), there are also other choices, which are less attractive in the short-term (low reward), but advantageous in the long run (lower penalty) (Brevers et al., 2013; Vasconcelos et al., 2015; Smith et al., 2016). It shows preferences of the tested participants for choosing short-term gains at the risk of larger loses (Tanabe et al., 2007). The choice between long- and short-term benefits enables distinction between gambling and opioid addicts and description of particular decision-making mechanisms. Also, IGT can be a very good measure of impaired decision-making in people suffering various psychiatric or neurological conditions (Bechara et al., 1994; Upton et al., 2012; Brevers et al., 2013). The IGT is the most popular decision-making task applied in numerous clinical studies (Upton et al., 2012; Ahn et al., 2016a).

1.2. Background to the Study

Studies on decision making in addicted participants have a very long history and have resulted in the common knowledge that substance addicted individuals (SDI) usually prefer choices bringing immediate benefits, even if there are negative consequences, such as inter alia loss of job, home or family. For such study purposes the IGT simulating real life decision making is frequently carried out. It is also the most popular decision-making task that has been applied in numerous clinical studies (as it was mentioned above) (Upton et al., 2012).

Based on a thorough literature background—both drug addicts and healthy study participants tend to choose decks with net losses at the beginning of the test, but only the healthy individuals are able to shift their choices to the decks with net gains, learning from their experience, while the addicted individual fail to do so (Bechara and Damasio, 2002; Bechara et al., 2002; Upton et al., 2012).

2. METHODS

For the study purposes 132 subjects ($n = 132$) were recruited for this study from opioid substitution clinics in various towns

in Poland (Bydgoszcz, Gdańsk, Kraków). Summary of study-participants was illustrated with **Figure 1**.

The participants were recruited among clinics' patients, prisoners, and healthy people. The participants were diagnosed in accordance with the *ICD* − 10 criteria.

The participants' selection criteria included:

- Meeting the diagnostic and statistical manual criteria of opioid dependence;
- Age range 21–60 years old;
- Absence of illicit drugs or alcohol withdrawal or intoxication at time of the study visits;
- Absence of history of psychotic mental illnesses or history of traumatic brain injuries;
- Absence of history of cognitive or memory problems;
- Subjects are stable on methadone maintenance for at least 2 weeks.

GROUPS	n – number Σ	AGE	SEX (male : female) ♂ ♀	PLACE OF TESTING
GAMBLING	*n=33*	35.23±8.76	21:12	1
OPIOID_0	*n=30*	33.52±10.53	17:13	2
OPIOID_1	*n=30*	32.94±9.73	18:12	2
CONTROL	*n=39*	28.63±12.53	17:22	1, 3, 4

GROUPS:
GAMBLING - gambling addicted individuals
OPIOID_0 - opioid addicts before methadone administration
OPIOID_1 - opioid addicts after methadone administration
CONTROL - healthy individuals
n - number of randomly selected participants
AGE - mean ± standard deviation
PLACE OF TESTING:

1. Bydgoszcz-Fordon Prison in Bydgoszcz, Poland
2. NZOZ "Medseven" - Addiction Treatment Clinic, Bydgoszcz and Gdańsk
3. Ludwik Rydygier Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń
4. Jagiellonian University Medical College, Kraków

FIGURE 1 | Study participants—summary.

The recruitment of gambling addicts was carried out mainly in prisons. The male/female ratio among gambling addicts is higher among males, as female prisoners constitute only 4.4% of all prisoners in Poland (2020). Gender gambling addiction research requires additional logistical efforts due to the significant disproportion in the frequency of this disorder between males and females. One-sex comparative studies are advisable.

The Mini-Mental State Examination (MMSE) was used as a screening device for cognitive impairment. The individuals with a minimum of 27 points in MMSE were included in the study. The educational structure of the particular group is presented in **Table 1**.

The gambling addicts were included in the study after a psychiatric interview examination. Nicotine addiction did not exclude individuals from the study. Individuals with comorbid psychiatric disorders other than gambling were however excluded.

The dose of this substitution was selected individually in order to prevent the occurrence of withdrawal symptoms. The average dose of methadone in the study group was 70 mg per day, administered orally in a single dose.

The limitation concerning the level of education of the study participants results from sources of acquired material. However, the behavioral strategy in performing the IGT test is quite specific for gambling addicts. Further research is necessary in terms of gender and education.

All participants (opioids addict, gambling addicts, healthy individuals) had to provide written informed consent in order to take part in this study. To conduct the study, the consent of the Bioethics Commission at Medical College in Bydgoszcz, Nicolaus Copernicus University in Torun, Poland was obtained (Consent no. *KB*/416/2008).

After being appropriately classified for the project-participation—each subject was scheduled for the IGT session testing. The opioid addicted individuals were divided into two groups. Individuals from the first group were tested before the methadone administration and individuals from the second group performed the IGT test about one and a half hours after the methadone administration.

After consenting to participate in the study, each subject was scheduled for the sessions of IGT testing. The IGT is a psychological task thought to simulate real-life decision making (Bechara et al., 1994). The authors of this work used the IGT, which is a part of the PEBL Test Battery (Mueller and Piper, 2014).

The construction of the IGT test consists of simulation games and gambling. In the task there are four decks of cards which contain the winner's and loser's cards. The winner's and loser's cards contain different monetary values. It means that for each deck of cards a certain amount of reward and penalty is attributed. An individual has to choose a deck containing the cards of the highest profit (Bechara et al., 1994; Fineberg et al., 2010). There are the four decks of cards marked as *A*, *B*, *C*, and *D*. The first two decks (*A* and *B*) are disadvantageous since, although immediate gains are large, the gain is followed by large losses at unpredictable intervals. In contrast, the other two decks (*C* and *D*) are advantageous.

In this case the immediate gains are smaller but there are also unpredictable losses, which are also small so that in the longer term the player gains more.

During the IGT test performance, the study subjects sit in front of a computer screen. The study is carried out in a way that, while using the computer's mouse, the study participant clicks on a card from any of the four decks. A standard administration of 100 trials (i.e., selection of 100 cards) was done once in individuals from all groups (opioid addicted, behaviorally addicted and healthy individuals). In this study the response time was given in milliseconds (ms) and for every subject was recorded in every trial. The response time is defined as time from the appearance of the cards on the screen till the time of card selection (by clicking a computer mouse button). The main dependent measure used for the calculation of the IGT performance was the net score. It was calculated by subtracting the number of cards selected from the disadvantageous decks from the numbers of cards selected from the advantageous decks $(C+D)-(A+B)$. Lower scores reflected a more disadvantageous than advantageous decision-making performance.

In **Figure 2**, a general scheme of the conducted experiment is presented. Individuals from each group were tested once. This procedure excludes the learning effect Pasion et al. (2017); Almy et al. (2018).

TABLE 1 | Structure of education among investigated individuals.

	Gambling	Opioid_0	Opioid_1	Control
Level of education	$n = 33$	$n = 30$	$n = 30$	$n = 39$
Primary	18	20	19	17
Secondary	10	8	8	15
Tertiary	5	2	3	7

3. RESULTS

In this work the number of risky decisions (decks A + B) and safe decisions (decks C + D) was compared in opioid addicts (before and after methadone administration) with those addicted to gambling and with the healthy individuals.

It was found (One-way ANOVA. $F = 4.529, p = 0.00472$) that the participants from the control group 34.85 ± 11.52 take less risky decisions compared to the gambling addicts 41.85 ± 11.05 (mean and standard deviation) and to the opioid addicted individuals (before the administration of methadone) 46.07 ± 15.09 and to the opioid addicted individuals after the methadone administration 42 ± 14.46.

It was also found (One-way ANOVA $F = 6.666, p = 0.00032$) that the gambling addicted individuals are less likely to make safe decisions (58.152 ± 11.0542) compared to the subjects from the control group (65.359 ± 11.5656), but take less safe decisions compared to the opioid addicted individuals prior the methadone administration (51.767 ± 14.0263) and that there is no significant statistical difference compared to the opioid addicted individuals after the methadone administration (57.6 ± 14.2577). In **Table 2** (for Risky Decisions) and **Table 3**

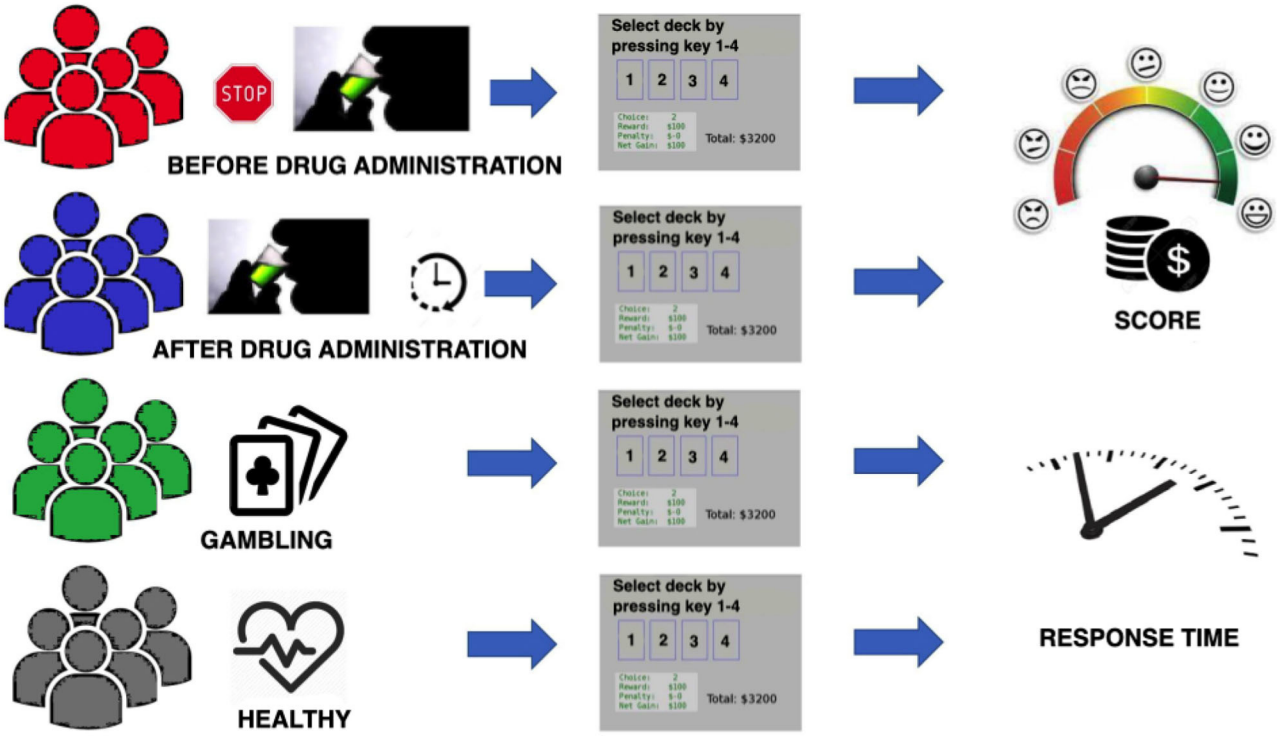

FIGURE 2 | General scheme of the conducted experiment.

TABLE 2 | Values for probabilities after *post-hoc* tests—risky decisions.

		Turkey HSD test; variable risky decisions. Approximate probabilities for *post-hoc* tests; Error: between MS = 168.84, *df* = 128.00			
		(1)	(2)	(3)	(4)
Cell no.	Groups	41.848	34.846	46.067	42.000
1	Gambling		**0.046465**	0.457858	0.999948
2	Control	**0.046465**		**0.000300**	**0.048094**
3	Opioid_0	0.457858	**0.000300**		0.511049
4	Opioid_1	0.999948	**0.048094**	0.511049	

Bold values are significantly important statistical values ($p < 0.05$).

TABLE 3 | Values for probabilities after *post-hoc* tests—safe decisions.

		Tukey HSD test; Variable Safe Decisions. Approximate Probabilities for *post-hoc* Tests; Error: Between MS = 160.89, *df* = 128.00			
		(1)	(2)	(3)	(4)
Cell no.	Groups	58.152	65.154	51.767	57.600
1	Gambling		**0.049168**	0.140795	0.997764
2	Control	**0.049168**		**0.000020**	**0.034958**
3	Opioid_0	0.140795	**0.000020**		0.223987
4	Opioid_1	0.997764	**0.034958**	0.223987	

Bold values are significantly important statistical values ($p < 0.05$).

(for Safe Decisions) the obtained results using Turkey HSD test are presented.

It was found (ANOVA $F = 14.164, p = 0.00000$) that the average response time (milliseconds) of gambling addicts (1516.748 ± 930.15) was statistically significantly longer than the mean response time of the individuals from the control group (646.6121 ± 284.23) and had a similar mean response time without a significant statistical difference when compared to the opioid addicted individuals prior to methadone administration (1418.943 ± 823.46) and the opioid addicts after the administration of methadone (1654.676 ± 757.99).

It was also found that the mean response time of the individuals from the control group after reward 636.641 ± 273.872 and after penalty 682.8462 ± 351.07 (Wilks lambda $F = 8.856, p = 0.000$) is statistically significantly shorter than the mean response time of gambling addicts after reward (1580.636 ± 965.5572) and penalty (1296.030 ± 910.7465), opioid addicts before the methadone administration (reward 1680.567 ± 840.7316; penalty 1530.933 ± 845.7030) and opioid addicts after taking methadone (reward 1432.9 ± 760.0489; penalty 1357.167 ± 794.7040).

In **Table 4**, the response time (expressed in [ms]) after reward, as a result of *post-hoc* tests is presented, while **Table 5** presents the response time after penalty.

Figure 3 illustrates the percentage of made risky decisions. **Figure 4** shows comparison of all groups in regards of time after reward and after penalty.

Table 6 presents values for the response time—mean of the entire test.

4. DISCUSSION

Various cognitive models have been applied and developed for the past 20 years in order to understand decision making deficits in drug-addicted, brain-damaged individuals (Ahn et al., 2016a).

Decision making triggers simultaneous motor, emotional, and cognitive functions (Dixon et al., 2017; Weinstein et al., 2017; Hilber et al., 2019). Therefore, the authors of this work are looking for answers on to what extent behavioral and chemical addictions have common features and to what extent they differ from each other. The results of many studies indicate that alcohol, cocaine, heroin, cannabinoids, nicotine, and glucose as well as gambling increase risky behavior and cause activation

TABLE 4 | Values for the response time (in [ms]) after *post-hoc* tests—after reward.

	Tukey HSD test; Variable response time [ms] after reward. Approximate probabilities for *post-hoc* tests; Error: between MS = 5464*E*2, *df* = 128.00				
		(1)	(2)	(3)	(4)
Cell no.	**Groups**	**1580.6**	**636.64**	**1680.6**	**1432.9**
1	Gambling		**0.000008**	0.950305	0.857985
2	Control	**0.000008**		**0.000008**	**0.000060**
3	Opioid_0	0.950305	**0.000008**		0.564378
4	Opioid_1	0.857985	**0.000060**	0.564378	

Bold values are significantly important statistical values ($p < 0.05$).

TABLE 5 | Values for the response time (in [ms]) after *post-hoc* tests—after penalty.

	Tukey HSD test; variable response time [ms] after penalty. Approximate probabilities for *post-hoc* tests; Error: between MS = 5491*E*2, *df* = 128.00				
		(1)	(2)	(3)	(4)
Cell no.	**Groups**	**1296.0**	**682.85**	**1530.9**	**1357.2**
1	Gambling		**0.002647**	0.590658	0.987930
2	Control	**0.002647**		**0.000021**	**0.001044**
3	Opioid_0	0.590658	**0.000021**		0.800470
4	Opioid_1	0.987930	**0.001044**	0.800470	

Bold values are significantly important statistical values ($p < 0.05$).

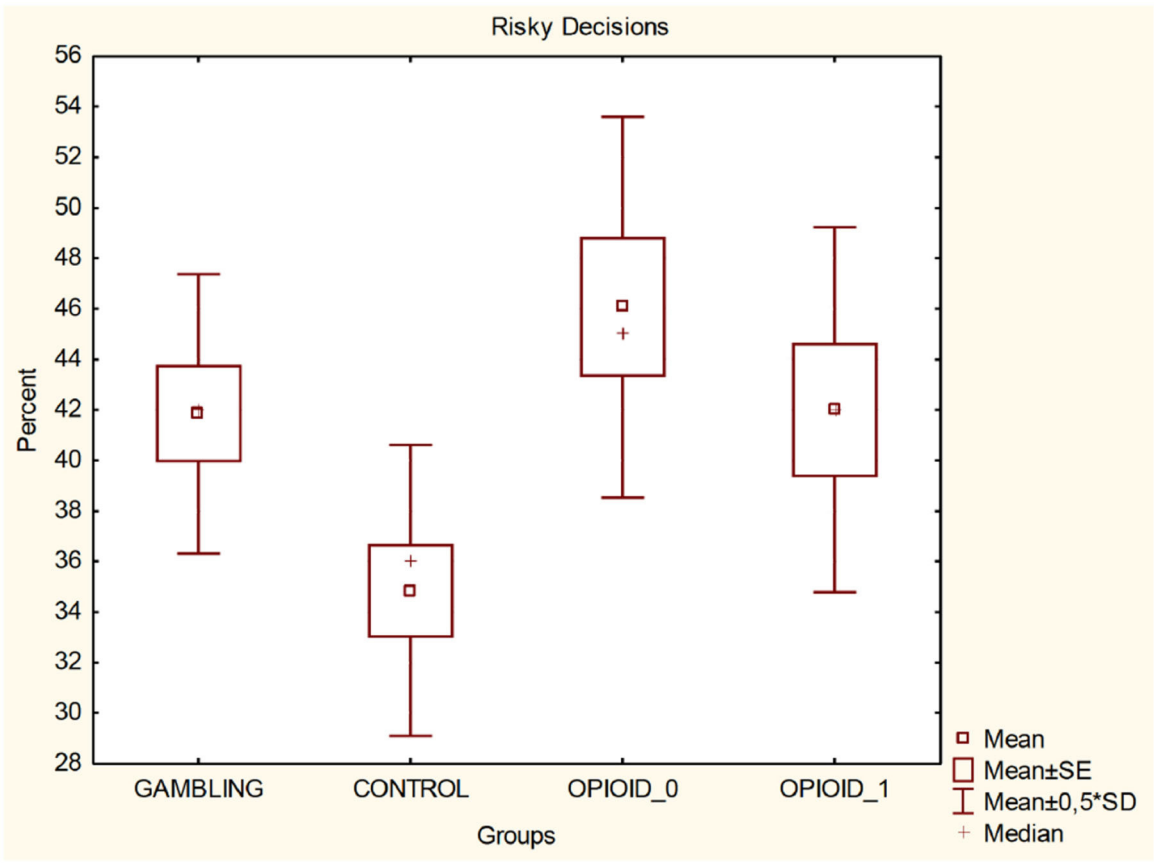

FIGURE 3 | Risky decisions—percentage.

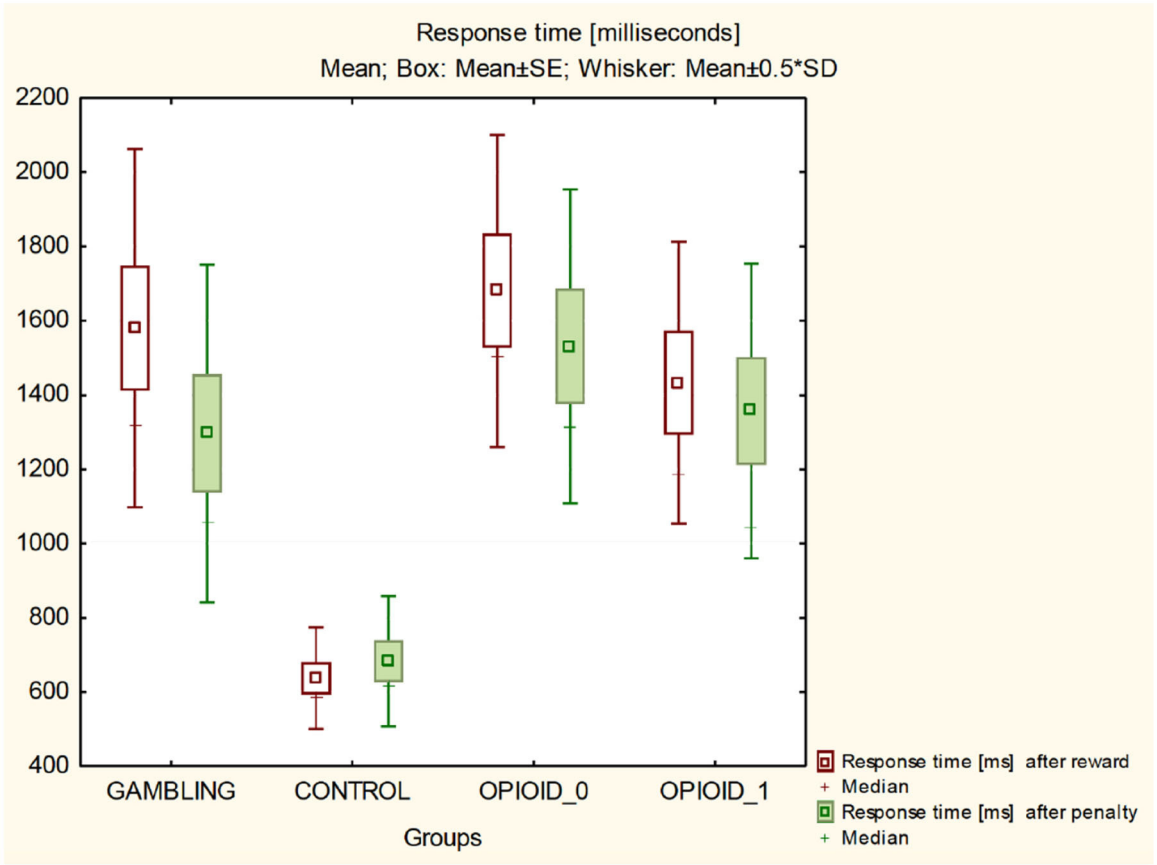

FIGURE 4 | Response time after reward and penalty—comparison of all groups.

TABLE 6 | Values for the response time [ms] mean of the entire test.

	Tukey HSD test; variable response time [ms] after penalty. Approximate probabilities for *post-hoc* tests; Error: between MS = 5241*E*2, *df* = 128.00				
		(1)	(2)	(3)	(4)
Cell no.	**Groups**	**1516.7**	**646.61**	**1654.7**	**1418.9**
1	Gambling		**0.000010**	0.874445	0.950398
2	Control	**0.000010**		**0.000008**	**0.000072**
3	Opioid_0	0.874445	**0.000008**		0.587783
4	Opioid_1	0.950398	**0.000072**	0.587783	

Bold values are significantly important statistical values ($p < 0.05$).

and neuronal release of the brain dopaminergic system, which could heal the abnormal cravings (Blum et al., 2000; Anselme and Robinson, 2013).

These results indicate the importance of cortico-subcortical loops in decision making when performing an IGT test. Mesolimbic dopamine is the main transmitter in striatum that is released to a larger extent in pathological gamblers than in healthy individuals (Linnet et al., 2011, 2012; Potenza, 2018). The impulsive, addictive, and compulsive behaviors have common characteristics (Brevers et al., 2014; Lorains et al., 2014).

Individuals with Reward Deficiency Syndrome (RDS) differ with their reactions in comparison with healthy people. It has been assumed that there is a relationship between psycho-motor ability and decision making. The working hypothesis is that people who suffer from RDS process decisions differently than healthy people. The postulated reason for this difference is based on the observation that the activity of the limbic loop (which is responsible for the processing of emotions) in individuals with the impaired RDS (Fotros et al., 2013).

In contrast, it is interesting that people addicted to gambling make less risky decisions compared to opioid-dependent individuals before the administration of methadone.

Four independent groups were compared in these studies:

- Gambling addicts,
- Opioid addicts treated with methadone substitution before administration of this drug,
- Opioid addict treated with substitution after administration of methadone,
- Healthy individuals.

The Iowa Gambling Test was performed only once. This procedure excludes the learning effect (Pasion et al., 2017; Almy et al., 2018). Previous results of our own research indicate that administration of a

substitution drug in opioid dependent individuals improves decision making.

It has been observed that the substitution drug (methadone) reduces the level of risky behavior in opioid addicts (Gorzelańczyk et al., 2014). It is interesting to see whether the decision-making strategy before administration of the substitution drug is similar in opioid addicts to the strategy in those who are addicted to gambling and whether the decision-making strategy after administration of the drug is similar to healthy individuals, which has been stated in inter alia: (King et al., 2015; Gallimberti et al., 2016).

To summarize the overall discussion, it is important to mention that a common neurobiological mechanism for chemical and behavioral addictions is still postulated, however, clinical observations and research results show some differences between different types of addiction (Jiang et al., 2020).

The IGT performance strategy is for gamblers and opioid dependent individuals without a similar substitution drug administration. But it is important to mention that gamblers' strategy leads to an endpoint similar to that of opioid addicts without administration of the drug (opioid).

The gamblers have the potential to learn from mistakes, but for some reason, during the IGT processing time, they stop learning. The explanation may be the strong activation of the striatum in gamblers at the beginning of the test, which results in the control of subcortical structures and the lack of effective inhibition of the striatum by the cerebral cortex.

Perhaps playing is much more important than winning for gamblers, as for them the game is a trigger, and it is difficult to stop the process. This is perhaps a similar mechanism to the one in alcoholics, thus gaming for gamblers is the same as an alcoholic going on a drinking binge (Cavicchioli et al., 2018).

The above mentioned mechanisms observed in gamblers are similar to the pattern followed by alcohol or drug addicted individuals.

Presumably, just joining the game temporarily increases the cognitive performance of gamblers. The IGT cues are consistent with gambling addiction and they easily fall into a binge. This is why gamblers quickly deplete cognitive resources due to the type of stimuli—although their absolute resources are greater compared to those addicted to opioids.

In opioid addicts, decision making also depends on the type of substitution drug used for substitution treatment (Pirastu et al., 2006). It was found that methadone administration is associated with impairment in the decision making ability but during dosage increase the decision making appears to improve (Barahmand et al., 2016).

These results indicate that stimulation of the reward system in both gambling addicts and opioid addicts is similarly difficult, and administration of substitution medication does not significantly reduce the response time of the opioid addicts.

It is possible to observe a significant decrease of scores and response times after penalty during the fourth deck in gambling individuals during the IGT task performance. This is assumed to be the consequence of control taking by subcortical structures and clear evidence of a reward system deficit, which results in particular decisions being taken by the addicted participants of this study and is impossible to observe in healthy, non-addicted individuals.

According to the authors' knowledge, no data are available in the literature characteristics for addicted individuals to drop at the fourth trial of the IGT. This result requires confirmation and further research.

Original results can also indicate that stimulation of the reward system in both gambling addicts and opioid addicts is similarly difficult, and administration of substitution medication does not significantly reduce the response time of opioid addicts. It is possible that the reward system is more difficult to stimulate in addicts in comparison to healthy people.

There are some limitations regarding gender ratio among the participants between the groups tested. In our original research it was found that gambling addiction is much more common among male compared to female among prisoners. However, the behavioral strategy in performing the IGT test is quite specific for gambling addicts. Further research is necessary in terms of gender and education. Also, the female prisoner ratio is significantly lower than male poland (2020).

Interestingly, the administration of opioid substitution drugs—methadone improves the performance of the IGT test (reduces the level of risky behavior) in opioid addicted individuals. Even though an improvement is observed during the IGT test performance in opioid addicted individuals after methadone administration, compared to the level of performance reached by gamblers, this improvement did not reach the level of performance observed in healthy, non-addicted individuals.

It is interesting that the average response time from noticing the reward to pressing the button is greater in gamblers in comparison to the response time of healthy individuals. This result may indicate that the activation of the reward system in gamblers is more difficult in comparison with the participants from the control group.

The results of the presented studies show that, in opioid addicts treated with methadone in the substitution treatment program, a single dose of methadone affects the number of risk behaviors measured by the IGT test.

The results of the presented studies indicate that, in opioid addict individuals treated with methadone in the substitution treatment program, a single dose of methadone affects the level of risk behaviors measured by the IGT test. It is possible that the risk behavior in individuals addicted to opioids can differ from gambling addicted individuals, despite some assumptions regarding similarity of both. The level of risky behavior in both addictions was compared during this study, including time-response during tasks. It was observed on the basis of the whole IGT test that gambling addicted individuals take more risky decisions in comparison to healthy individuals from the control group but less risky decisions in comparison to opioid addicted individuals before administration of methadone and without any statistically significant difference after administration of methadone. Various research and clinical observations postulate that there are both some similarities and some differences between drug addiction and behavioral addiction symptoms (Kluwe-Schiavon et al.,

2019). Finding objective differences in behavior strategies can help to distinguish between substance—and gambling-addicts (Kriegler et al., 2019).

Addicted people more frequently display risky behavior. The analysis of respondents after the administration of methadone showed a statistically significantly decrease of the tendency to display risky behaviors. Results of studies (based on authors' experience and literature study) show that addicted people tend to display risky behaviors in subsequent attempts of the IGT test.

It is also important to consider individual differences in risk-tolerance, as these are crucial factors in taking risky decisions. Some dependency between obesity and various addictions (Yi et al., 2007; Rasmussen et al., 2010; Petry, 2012; Castren et al., 2015) was also found. Another meaningful factor is gender-based, as some studies show that men are more prone to addiction than women. Further studies in this area would be an advantage (Carneiro et al., 2019). Appropriate stimuli can affect decisions made for choosing the correct reward (Blanchard et al., 2015; Smith et al., 2016, 2017; Zentall, 2016).

The authors of this paper would like in the near future to investigate other pharmacological agents, such as inter alia: including serotonin reuptake inhibitors (SRIs), opioid antagonists, glutamatergic agents, and the anti-dopaminergic medication olanzapine, which gave (based on a literature study) promising results, as described in Chamberlain and Grant (2019).

It is also planned to differentiate the obtained results based on the gender of the tested individuals (Carneiro et al., 2019). There is a limitation regarding the level of education, resulting from the source of the acquired material. However, the behavioral strategy in performing the IGT test is quite specific for gambling addicts. Further research is necessary in terms of gender and education and should be expanded in further research plans.

DATA AVAILABILITY STATEMENT

The datasets used and analyzed during the current study will be made available by the corresponding author upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Bioethics Commission at Medical College in Bydgoszcz, Nicolaus Copernicus University in Torun, Poland was obtained (Consent no. KB/416/2008). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EG: designed the study protocol, recruited participants, carried out research, and prepared the draft version of the paper. PW: carried out research and analyzed the results. MB: performed deep literature study, partially wrote the Future Works section and the Discussion. AK-S: prepared the final version of the manuscript, expanded the draft version, performed a very thorough literature study, proof-read the article, prepared the template, and partially wrote the Discussion and Future Works sections. EL: helped with the patients recruitment and carried out the study. All authors contributed to the article and approved the submitted version.

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Mood and Risk-Taking as Momentum for Creativity

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This study examined the effects of mood and risk-taking on divergent and convergent thinking using a Q-learning computation model. The results revealed that while mood was not significantly related to divergent or convergent thinking (as creative thinking types), risk-taking exerted positive effects on divergent thinking in the face of negative rewards. The results were consistent with the representational change theory in insight problem solving. Although this theory accounts directly for insight, the underlying idea of going beyond current contexts and implicit constrains could be applied to creative thinking as well. The results indeed accounted for the relevance of this theory to divergent thinking. The current study is one of the first empirical studies simultaneously examining the role of mood and risk-taking in creativity. In particular, no related studies exist that took a computational approach to estimate the relevant parameters in the framework of dynamic optimization. Our Q learning model enables to distinguish and identify the different roles of mood and risk-taking in updating *Q* values and making decisions.

Keywords: mood, risk-taking, divergent and convergent thinking, representational change theory, Q learning model

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INTRODUCTION

Creativity inevitably requires learning. Although learning can proceed in a logical and consistent manner, as suggested by reinforcement learning (RL) models, it also relies on mood. According to decision affect theory, mood is affected by unexpected outcomes or reward prediction errors (RPE), which represent the difference between the actual reward and the expected reward in the RL framework (Mellers et al., 1997; Shepperd and McNulty, 2002). As a result, subsequent learning performance is either promoted or obstructed (Eldar and Niv, 2015).

Mood has been extensively studied as a predictor of creativity (Isen and Baron, 1991; Mumford, 2003). This is because mood often serves as "an intermediary state between a host of situational and personality predictors, on the one hand, and creative performance, on the other" (Baas et al., 2008). In the mood-creativity literature, while a number of studies have emphasized the importance of positive mood in creative thinking (for example, Ashby et al., 1999; Lyubomirsky et al., 2005), several exceptions exist that showed that a positive mood sometimes leads to less creativity (Kaufmann and Vosburg, 1997; Anderson and Pratarelli, 1999). Moreover, some studies showed that a negative mood improves creative performance.

Given these contradictory findings, Baas et al. (2008) conducted a meta-analysis and reported that "positive moods produce more creativity than mood-neutral controls (r = 0.15), but no significant differences between negative moods and mood-neutral controls (r = 0.03) or between

positive and negative moods ($r = 0.04$) were observed." According to their analysis, creativity seems to be facilitated by "positive mood states that are activating in nature and associated with an approach motivation and promotion focus (e.g., happiness), rather than those that are deactivating and associated with an avoidance motivation and prevention focus (e.g., relaxed)" (Baas et al., 2008).

As another candidate for the determinant of creativity, risk-taking attitudes have been extensively studied because creative persons are more likely to be motivated by challenging and risky situations (Albert, 1990; Perkins, 1990), suggesting that risk-taking is closed related to creativity. While the theoretical significance of the relationship between risk-taking and creativity has been recognized (Eisenman, 1987; Sternberg and Lubart, 1992; Feist et al., 1998; Dewett, 2007), only a few empirical studies have examined the relationship. Most of these empirical studies reported that creativity and risk-taking were positively correlated (Eisenman, 1987; El-Murad and West, 2003; Dewett, 2007; Simmons and Ren, 2009; Tyagi et al., 2017; Harada, 2020a). However, Shen et al. (2018) found that low risk-taking was associated with convergent thinking, but risk-taking was not significantly correlated with divergent thinking. Probably, diversity in the research measures, definitions of risk-taking, and cultural backgrounds of the participants in the different studies accounted for these differences in results (Strum, 1971).

Despite these inconclusive results, both positive mood and risk-taking serve to relax and break implicit constraints that hinder problem solving and creative thinking. According to representational change theory (Ohlsson, 1992; Knöblich et al., 1999), insight problem solving initially involves the construction of an erroneous problem space. Representational change takes place through the relaxation of constraints such as the abandonment of unnecessarily constraining assumptions. Positive mood and risk-taking attitudes provide a strong impetus for challenging the existing rules of the game to remove unnecessary constraints and create more appropriate problem spaces. Taken together, we hypothesize that divergent thinking is facilitated by positive mood and risk-taking because new insights, as critical ingredients of divergent thinking, are considered to be a function of cognitive flexibility, which is enabled by the removal of underlying constraints.

To examine this hypothesis, we took a computation approach to estimate mood and risk-taking attitudes. In the current study, we measured mood using a model proposed by Eldar and Niv (2015), and examined its effect on creativity. Creativity is defined as a combined manifestation of novelty and usefulness (Sternberg and Lubart, 1999; Jung et al., 2010) and has often been identified with divergent thinking. Divergent thinking is defined as the ability to generate multiple solutions to an open-ended problem (Guilford, 1967). Thus, divergent thinking reflects the notion that creativity is more likely to proceed in an unpredictable and abrupt manner. In addition to divergent thinking, convergent thinking has also been highlighted as a factor accounting for creativity (Abraham, 2018). Convergent thinking, which is the ability to apply conventional decision-making strategies to produce an already known answer (Cropley, 2006), is sometimes instrumental in generating insight problem solving (Bowden et al., 2005). Accordingly, related studies seem to support that creativity research should take into account both divergent and convergent thinking (Gabora, 2010). Thus, we examined the effects of mood and emotional state on divergent and convergent thinking, in addition to exploitation and exploration.

With mood and risk being the determinants of creativity, the mood literature (Isen and Baron, 1991; Mumford, 2003) primarily examined the effects of risk attitudes, whereas the risk literature (Eisenman, 1987; El-Murad and West, 2003; Dewett, 2007; Simmons and Ren, 2009; Tyagi et al., 2017; Shen et al., 2018; Harada, 2020a) evaluated the influences of mood without reference to mood effects. None of the literature considered the simultaneous effects of risk attitudes and mood on creativity. This study could be differentiated from related prior studies in that we tested the effects of both positive mood and risk-taking on creativity using a rigorous computational approach.

Thus, our empirical analysis made explicit the underlying computational model of mood and risk-taking, upon which relevant parameter estimates were derived. We sought to test the effects of mood and risk-taking on divergent and convergent thinking.

MATERIALS AND METHODS

This study used the data analyzed in Harada (2020a,b) with permission, but the model and estimation adopted in this study differed from the latter in that the effects of mood were incorporated.

Participants

Our experiments were announced in one of the undergraduate courses the author taught at Kobe University, and some undergraduate students applied voluntarily. A total of 127 participants took part in the experiments, but 14 of them were excluded from the final sample because they did not attend one of the two sessions. As a result, the sample of this study consisted of data collected from 113 healthy undergraduate students of Kobe University (49 females, age range = 18–20 years, SD = 0.66). All participants were native Japanese-speakers with normal or corrected-to-normal vision. The local Ethics Committee approved this study. All participants signed an informed consent form before taking part in the experiment, and were paid JPY 3000 (approximately USD 28).

Procedure

The participants completed the S-A creativity test, Remote Associates Test (RAT), reading span, operation span, and matrix span tests (Conway et al., 2005), the Iowa Gambling Task (IGT), and the Big Five Scales (BFS) for personality traits. The experiments were arranged into two independent sessions: An S-A session (including S-A creativity test and RAT) and an IGT session (including reading span, operation span, matrix span tests, the IGT, and the BFS). To remove the order effects on test scores, approximately half of the participants performed the S-A session first and then the IGT session while the remaining

participants performed the sessions in the opposite order. There was at least a 7-day interval between the two successive sessions.

During the S-A session, participants completed both the S-A test and the RAT, each of which took approximately 30 min. During this session, the tests were completed in accordance with the instructor's manuals. A break of at least 5 min was taken between the two tests. To remove order effects, the order of the tests was randomly assigned.

The IGT session was arranged in groups with a maximum of 20 participants who completed the tests in the presence of an instructor. The tests were performed on a 17" CRT monitor with PsyToolkit (Stoet, 2010, 2017). A break of at least 1 min was given between every two tests. The order of the tests was randomly assigned in PsyToolkit across the participants to exclude the order effects on test scores. In the IGT, the participants were instructed to maximize the total sum of rewards. Additionally, they were informed that some of the decks might generate higher expected rewards. No other information was provided regarding the IGT and the test took approximately 30 min to be completed. Each of the reading span, operation span, and matrix span tests took approximately 5 min, and the BFS took 15 min. Thus, it took approximately 60 min to complete all of the tests in the IGT session.

Q Learning Model

This study adopted a RL framework to account for behavior in evaluating options for decision-making in the IGT. The RL framework has been applied to the study of multi-armed bandit problems and is supported by a number of empirical evidences including neural signals in various cortical and subcortical structures that behaved as predicted (Schultz et al., 1997; Glimcher and Rustichini, 2004; Hikosaka et al., 2006; Rangel et al., 2008). The framework has also been applied to studies on decision making and learning in various social contexts (Delgado et al., 2005; Montague et al., 2006; Behrens et al., 2008; Hampton et al., 2008; Coricelli and Nagel, 2009; Bhatt et al., 2010; Yoshida et al., 2010). However, little attention has been paid to the creative aspects of decision making.

To measure mood and risk-taking attitude observed in decision making in the IGT, we used a variant of the Q learning model in the RL framework (Sutton and Barto, 2018). The participants make a series of 100 choices from 4 decks of cards. Two of the decks are advantageous and the other two are disadvantageous. The two disadvantageous decks always yield relatively high gains ($100), but also occasional large losses ($150) with a 50% chance, resulting in an average loss of $25 per trial. The two advantageous decks always generate lower gains ($50) but produce no losses ($0) with a 50% chance, resulting in an average gain of $25 per trial. The goal is to maximize net scores across trials.

At each trial t, the action value $Q_i(t)$ of the chosen option (deck) i is updated via the following rule:

$$\mathrm{Q}_i(t+1) = \begin{cases} \mathrm{Q}_i(t) + \alpha^{+}\delta(t) + \phi & if\ \delta(t) \geq 0, \\ \mathrm{Q}_i(t) + \alpha^{-}\delta(t) + \phi & if\ \delta(t) < 0, \end{cases} \tag{1}$$

with,

$$\delta(t) = U(R_i(t)) f^m - \mathrm{Q}_i(t), \tag{2}$$

$$U(R_i(t)) = \begin{cases} R_i(t)^{\mu} \\ -\lambda(-R_i(t))^{\nu}, \end{cases} \tag{3}$$

where $R_i(t)$ is the reward associated with option i at trial t, and $\alpha^{\pm}$ indicates the learning rate. ϕ is added as the choice trace to account for autocorrelation of choice, which can affect learning biases (Katahira, 2018). $U(R_i(t))$ takes the form of the prospect utility function proposed by Tversky and Kahneman (1986) in which μ and ν measure the degrees of risk aversion and risk seeking, respectively. We adopted this utility function because one of our research interests was to examine the effect of risk attitudes on creativity. Thus, it was assumed that participants would evaluate the reward in terms of their own risk attitudes, which resulted in the utility function specified in (3). $\delta(t)$ represents the RPE. The RPE is computed by subtracting the current value estimate from the obtained reward R. Participants thus update the action value estimate by scaling the prediction error with the learning rate, then adding this to the estimated value in the previous trial. Learning rates close to 1 indicate that a person performs fast adaptation based on prediction errors, and learning rates closer to 0 indicate slow adaptation. In the default setting, the initial action values were set to zero so that $Q_i(1) = 0$ $\mathrm{i} = 1, \ldots, 4$.

As described in Eldar and Niv (2015), f is a positive constant that represents the mood bias and m is the participants' mood. If $\mathrm{f} = 1$, mood is neutral without biasing the perception of rewards. If $\mathrm{f} > 1$, positive feedback exists such that positive and negative mood are magnified, while $\mathrm{f} < 1$ indicates negative feedback, stabilizing the effect of mood over time. Mood (m) is specified to reflect the prediction error history (h) as:

$$\mathrm{h}(t+1) = \mathrm{h}(t) + \zeta_h\left(\delta(t) - \mathrm{h}(t)\right), \tag{4}$$

Given this prediction history, mood is defined as a sigmoid function of h:

$$m(t) = \tanh\left(h(t)\right), \tag{5}$$

This implies that m takes values between $[-1,\ 1]$. Thus, m indicates good ($0 < \mathrm{m} < 1$) or bad ($-1 < \mathrm{m} < 0$) mood. Good and bad moods, respectively, increase and decrease Q values of current choices. According to Eldar and Niv (2015), the mood inferred from this model accords with participants' self-reported feeling throughout their experiment. Thus, we assumed m and f captured the mood and its biases in our experiment as well.

For the unselected option j ($\mathrm{i} \neq \mathrm{j}$), the action value is updated as:

$$Q_j(t+1) = Q_j(t) \tag{6}$$

We assume that the chosen action at trial t is denoted by $a(t) \in \{1,\ 2,\ 3,\ 4\}$. The action value estimates of these four options are used to determine the probability of choosing either option. This probability is computed via the following softmax decision rule:

$$P(a(t) = i) = \frac{exp\left(\beta Q_i(t)\right)}{\sum_{j=1}^{4} exp\left(\beta Q_j(t)\right)} \tag{7}$$

where $P(a(t) = i)$ is the probability of choosing the action $a(t) = i$ at trial t. The parameter β is the inverse temperature, a parameter that indicates the sensitivity of a participant's choice to the difference in action value estimates.

The parameters of $\alpha_t^{\pm}$ and β in this model were estimated by optimizing the maximum a posteriori (MAP) objective function, to find the posterior mode:

$$\hat{\theta} = argmax\ p(D_s|\theta_s)\, p(\theta_s) \quad (8)$$

where $p(D_s|\theta_s)$ is the likelihood of data D_s for subject s conditional on parameters $\theta_s = \left\{\alpha^{\pm S}, \mu^S, \nu^S, \lambda^S, \phi^S, f^S, \zeta^S, \beta^S\right\}$, and $p(\theta_s)$ is the prior probability of θ_s. We assumed that each parameter is bounded and used constrained optimization to find the MAP estimates. Specifically, since $\alpha^{\pm}$ is bounded between 0 and 1, and μ, ν, λ, β and f take non-negative values, their priors were assumed to follow beta distributions for $\alpha^{\pm}$, and gamma distributions for μ, ν, λ, β and f. Given these parameter estimates, we calculated the average m values over 100 trials in the IGT for each participant.

Measures

In the current study, divergent and convergent thinking were used as dependent variables. We focused on examining the effects of mood (m) and risk-taking measures (μ and ν) on divergent and convergent thinking scores. Working memory capacity and personality characteristics, which might affect the dependent variables, were used as control variables.

Divergent Thinking

Divergent thinking is defined as the ability to produce new approaches and original ideas by forming unexpected combinations from available information, and by applying such abilities as semantic flexibility, and fluency of association, ideation, and transformation (Guilford, 1967). In the current study, divergent thinking ability was measured with the S-A creativity test (Society for Creative Minds, 1969), a timed laboratory test corresponding to the measures used in the Torrance Tests of Creative Thinking. The test involves three types of tasks. In the first task, the participants are instructed to generate unique ways of using two objects specified in the test. The second task requires the participants to imagine desirable functions of two specified ordinary objects. In the third task, the participants are instructed to imagine the consequences of "unimaginable things" happening. Each task requires the participants to generate as many answers as possible (up to 10).

The S-A creativity test measures divergent thinking in terms of (a) fluency, (b) flexibility, (c) originality, and (d) elaboration. Fluency is measured by the number of relevant responses to the questions, and is related to the ability to produce and consider many alternatives. Flexibility is the ability to produce responses from a broad perspective, and is measured by the sum of the total number of category types to which answers are assigned based on a criteria table or an almost equivalent judgment. Originality is the ability to produce ideas that differ from others and is scored as the sum of idea categories that are weighted based on a criteria table or an almost equivalent judgment. Elaboration is the ability to produce ideas in detail and is measured by the sum of answers that are weighted based on a criteria table or an almost equivalent judgment. This test also provides a total score for divergent thinking, which was mainly used in this study. For more details about the S-A creativity test, see Takeuchi et al. (2010).

Convergent Thinking

Convergent thinking is defined as the ability to apply conventional and logical search, recognition, and decision-making strategies to stored information to produce an already known answer (Cropley, 2006). Thus, convergent thinking requires prior knowledge and is typically correlated with measures of crystallized intelligence. However, most creativity researchers have described convergent thinking as a process entailing the evaluation of initial ideas and/or a sudden insight in arriving at the correct solution for problems with task constraints (Cropley, 2006; Smith and Ward, 2012; Lee and Therriault, 2013). As a result, in the insight problem-solving literature, convergent thinking has typically been measured using the RAT; Mednick, 1962) which entails the task constraint that the correct solution must fit with each of the three words in the presented triad (e.g., "cheese" as the correct response for the triad "cottage, cream, and blue"). As all the participants in this study were native Japanese-speakers, we adopted the Japanese version of the RAT developed by Terai et al. (2013), and used the 40 problems selected by Orita et al. (2018) in our experiment. RAT (convergent thinking) scores were measured by the number of correct solutions for the 40 problems.

Mood

In this model, mood can be measured by the magnitude of m in (3). Positive mood is reflected as higher values in m as the exponent of f because it magnifies the utility of choosing the current deck. This means that positive mood tends to reinforce the current choices in the future as well, which implies that an increase in the corresponding utility should be reflected. On the other hand, negative mood discourages repeatedly selecting the current choice in the future, which turns out to be a decrease in the corresponding utility of the current choice. Thus, lower values of m indicate negative mood. As the base of m, f measures the stability of mood.

Risk Attitudes

Risk attitudes can be measured by the parameters μ and ν in (3), which incorporate part of the prospect utility function in which an asymmetric form of risk aversion is specified. Risk aversion in cases with positive rewards and risk-taking in cases with negative rewards are, respectively, measured by μ and ν, indicating that the participants have different risk attitudes toward gains and losses. We were interested in examining these effects on creativity performance.

Inverse Temperature

We used the inverse temperature β to represent levels of exploitation and exploration. Exploitation refers to the optimization of current tasks under existing information and memory conditions, while exploration implies wider and

sometimes random search and trials that do not coincide with the optimal solutions provided by exploitation (see Sutton and Barto, 2018, for the trade-off between exploitation and exploration in the RL framework), for the trade-off between exploitation and exploration in the RL framework). A higher β value implies that the participants selected the decks based on the action value Q calculated in (1)∼(3), leading to exploitation. Conversely, as β approaches zero, the choice is more likely to have been made randomly because the weight of the *Q* value in the soft max decision rule in (3) significantly declines. This implies that participants undertake exploration. Thus, the inverse temperature β measures the relative importance of exploitation and exploration.

Working Memory Capacity (WMC)

Working memory capacity was measured using reading span, operation span, and matrix span tests, which are representative working memory tests (Conway et al., 2005). Reading span and operation span tests evaluate the capacity of verbal WMC and logical WMC, respectively, which in turn correspond to the phonological loop, according to Baddeley (2000). The matrix span test measures spatial WMC, corresponding to the visuo-spatial sketchpad in Baddeley's model.

Big Five Scales of Personality

The BFS of personality traits is widely used to describe personality differences, consisting of five factors: openness to experience (inventive/curious vs. consistent/cautious), conscientiousness (efficient/organized vs. easy-going/careless), extraversion (outgoing/energetic vs. solitary/reserved), agreeableness (friendly/compassionate vs. challenging/detached), and neuroticism (sensitive/nervous vs. secure/confident) (Barrick and Mount, 1991; Miller, 1991; Piedmont et al., 1991). In the current study, these scales were administered using 60 questions in Japanese, developed by Wada (1996). Higher scores on a trait implied that the participant was low on that particular trait. For example, a high score on openness to experience implied lower openness to experience.

The descriptive statistics for all the variables used in the empirical analyses in this study are reported in **Table 1**.

RESULTS

Effects of Mood

To examine the effects of mood on divergent and convergent thinking, we regressed mood (m) on divergent and convergent thinking scores with WMC and personality as control variables. The results are shown in **Table 2**.

The dependent variables in the left and right columns are divergent and convergent thinking scores, respectively. As shown in the table, both mood and mood biases exhibited no significant effect on divergent and convergent thinking. Instead, inverse temperature had a positive effect on divergent thinking. This suggests that exploitation accounts for divergent thinking.

Regarding the control variables, noting that high scores on the personality scales meant low trait presence, we found that agreeableness exerted a negative effect on divergent thinking, whereas openness to experience and spatial WMC exerted positive effects on divergent thinking. Agreeableness is amenable to conservative behavior, implying that highly divergent thinkers tend to break conservative behavior with its negative effects. Moreover, openness to experience indicates curiosity about new experiences, which is also expected to promote divergent thinking. These results are consistent with the representational change theory, that is, highly divergent thinkers are more likely to challenge and change implicit constraints and problem spaces in problem solving.

In convergent thinking, conscientiousness and spatial and logical WMC exhibited positive effects. Conscientiousness reflects efficient, organized, and thus more careful attitudes, which are instrumental for generating attentive actions. Its negative effects on convergent thinking imply that in the

TABLE 1 | Descriptive statistics.

	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Divergent thinking	39.87	10.07	–												
2. Convergent thinking	14.49	3.94	−0.08	–											
3. Exploitation	40.01	14.31	0.22***	0.09	–										
4. Exploration	19.04	7.56	−0.08	−0.13	−0.72***	–									
5. Mood	0.01	0	0.04	−0.21**	−0.06	0.01	–								
6. Mood bias	0.51	0.3	−0.07	0.05	−0.03	0.11	−0.14	–							
7. Extraversion	3.61	0.95	−0.05	0.12	−0.01	0.10	−0.21**	−0.06	–						
8. Neuroticism	3.29	0.97	0.08	0.02	−0.05	0.00	0.09	0.04	−0.40***	–					
9. Openness	3.89	0.83	−0.16*	0.00	−0.07	0.07	−0.21**	−0.14	0.23***	−0.21**	–				
10. Conscientiousness	4.19	0.69	0.00	0.20**	−0.03	−0.12	−0.01	−0.16**	0.08	0.10	0.04	–			
11. Agreeableness	3.4	0.89	0.12	−0.08	−0.11	0.14	0.02	−0.01	0.37***	−0.24***	0.14	0.29***	–		
12. Spatial WMC	23.81	13.38	0.13	0.16*	0.10	0.09	0.16*	−0.02	0.04	0.00	−0.10	0.01	0.02	–	
13. Verbal WMC	25.73	12.75	0.00	0.07	0.03	0.16*	0.02	0.00	0.05	−0.07	−0.02	0.01	−0.08	0.37***	–
14. Logical WMC	28.18	11.65	0.05	−0.12	0.04	0.08	0.11	0.03	−0.02	0.01	0.07	−0.01	−0.02	0.22***	0.24***

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

TABLE 2 | Effects of mood (SE in parentheses).

Variables	DT (1)	CT (2)
constant terms	40.14***	8.33**
	(6.41)	(3.86)
Exploitation/Exploration	0.65***	0.14
	(0.18)	(0.11)
Mood	0.69	−1.84
	(2.13)	(1.29)
Mood bias	−103.19	49.16
	(221.84)	(138.13)
Extraversion	−1.11	0.65
	(0.74)	(0.44)
Neuroticism	0.95	0.27
	(0.71)	(0.43)
Openness	−1.98***	0.06
	(0.75)	(0.46)
Conscientiousness	−1.10	1.44***
	(0.92)	(0.55)
Agreeableness	2.42***	−0.90*
	(0.77)	(0.46)
Spatial WMC	0.11**	0.06*
	(0.05)	(0.03)
Verbal WMC	−0.04	0.01
	(0.05)	(0.03)
Logical WMC	0.05	−0.06*
	(0.05)	(0.03)
AIC	899.95	632.84

DT and CT refer to divergent and convergent thinking, respectively.
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

TABLE 3 | Effects of risk-taking (SE in parentheses).

Variables	DT (1)	CT (2)
Constant terms	37.51***	8.10**
	(6.02)	(3.59)
Exploitation/Exploration	0.66***	0.13
	(0.18)	(0.11)
H (risk aversion in gains)	3.55	1.18
	(2.17)	(1.31)
v (risk-seeking in losses)	4.03**	0.60
	(2.04)	(1.23)
Extraversion	−1.40*	0.62
	(0.75)	(0.45)
Neuroticism	0.94	0.18
	(0.70)	(0.43)
Openness	−2.17***	0.02
	(0.76)	(0.46)
Conscientiousness	−1.10	1.26**
	(0.92)	(0.55)
Agreeableness	2.47***	−0.92**
	(0.77)	(0.46)
Spatial WMC	0.14***	0.07**
	(0.05)	(0.03)
Verbal WMC	−0.06	0.00
	(0.05)	(0.03)
Logical WMC	0.04	−0.06*
	(0.05)	(0.03)
AIC	894.20	634.18

$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

RAT experiment, more exploratory search is required in order to hit upon candidates for correct solutions. Probably, after gaining these candidates, more careful attitudes are required. This phase of convergent thinking might be reflected in the positive effect of agreeableness on convergent thinking, leading to more conservative behavior. Moreover, since our RAT experiment used hieroglyphic Chinese characters, it seems reasonable that spatial and logical WMC had positive effects on convergent thinking.

Effects of Risk-Taking

Next, we examined the effects of risk-taking on creativity. The results are shown in **Table 3**.

As in **Table 2**, dependent variables in the left and right columns are divergent and convergent thinking, respectively. In this regression analysis, risk parameters, μ and ν were added, instead of the mood parameters. According to the table, the risk-taking index ν was positively associated with divergent thinking. Thus, participants behaved in a risk-taking manner in the face of losses. In contrast, in convergent thinking, risk parameters exhibited no effect, indicating that risk attitudes did not account for performance in convergent thinking. Other parameters showed the same results as shown in **Table 2**.

Simultaneous Effects of Mood and Risk-Taking

Finally, we simultaneously regressed mood and risk parameters on divergent and convergent thinking (**Table 4**). The results regarding the effects of mood, risk attitudes, and control variables remained the same as those in the individual regression analyses (**Tables 2**, **3**), indicating that the results were statistically robust with respect to the regressors. Therefore, our empirical analyses revealed that risk-taking behavior in the face of losses accounted for high divergent thinking, while mood parameters, regardless of positive or negative, exerted no effects on divergent, and convergent thinking.

DISCUSSION

In this study, we tested the effects of positive mood and risk-taking on creativity using a rigorous computational approach. We found that risk-taking behavior in the face of losses exhibited positive effects on divergent thinking, whereas mood did not play a role in both divergent and convergent thinking. While most of the mood and risk literatures, respectively, emphasized the importance of positive mood and risk attitude as the determinants of creativity, the simultaneous evaluation revealed the contrasting effects between the two variables.

TABLE 4 | Simultaneous effects of mood and risk-taking (SE in parentheses).

Variables	DT (1)	CT (2)
Constant terms	38.71***	8.27**
	(6.45)	(3.88)
Exploitation/Exploration	0.64***	0.13
	(0.18)	(0.11)
Mood	0.43	−1.87
	(2.14)	(1.29)
Mood bias	−133.40	42.91
	(222.80)	(138.79)
μ (risk aversion in gains)	3.59	1.21
	(2.18)	(1.31)
ν (risk-seeking in losses)	4.04**	0.54
	(2.04)	(1.23)
Extraversion	−1.39*	0.58
	(0.75)	(0.45)
Neuroticism	0.89	0.26
	(0.71)	(0.43)
Openness	−2.20***	−0.01
	(0.76)	(0.46)
Conscientiousness	−1.17	1.37**
	(0.93)	(0.55)
Agreeableness	2.47***	−0.87*
	(0.77)	(0.46)
Spatial WMC	0.14***	0.06**
	(0.05)	(0.03)
Verbal WMC	−0.06	0.01
	(0.05)	(0.03)
Logical WMC	0.05	−0.07**
	(0.05)	(0.03)
AIC	897.77	635.83

DT and CT refer to divergent and convergent thinking, respectively.
**p < 0.10, **p < 0.05, ***p < 0.01.*

One of the unique contributions of this study lies in the use of measures for risk attitudes and mood. While the related literature primarily adopted the measures evaluated in relevant psychological tests, this study estimated these measures through behavioral characteristics observed in the IGT. Risk attitude was evaluated by the estimates of risk parameters in the underlying utility function (3) and mood was calculated in the model specified in (5). However, this approach has a limitation because alternative measures for risk and mood were excluded in this specification. In particular, the results regarding mood must be interpreted with caution. Mood in this study refers to the fact that participants reinforce the *Q* value of current choices, which is assumed to be caused by their mood. Although this measure was found to be significantly associated with self-reported mood in Eldar and Niv (2015), positive mood under this measure exhibited magnifying effects on *Q* values of current choices. These effects encourage the status quo, and discourage shifting to different choices. Positive mood in this study refers to self-reinforcing forces to increase the *Q* values of current choices. This implies that positive mood impedes challenging and changing current contexts and implicit assumptions. In contrast, positive mood in the related literature encourages challenging and changing current situations and implicit constraints, which corresponded to negative mood in this study. Although our results did not show negative effects of mood, this suggests that positive mood in our model did not at least facilitate divergent thinking.

In addition, although this study was conducted with a relatively large sample, different results could be found in different samples, in particular, in different cultural contexts. For example, Shen et al. (2018) examined the effects of risk-taking on convergent thinking in China. Their results were in contrast to our findings, showing that risk-taking was negatively associated with convergent thinking, but it had no effect on divergent thinking. On the other hand, our results are in line with Harada (2020a), indicating the positive association between risk-taking and divergent thinking and no relationship between risk-taking and convergent thinking. The different results might be caused by cultural differences. As Shen et al. (2018) noted, on the one hand, a positive correlation between divergent and convergent thinking was identified in their study. On the other hand, the study conducted in the Netherlands revealed that these correlations were close to zero or negative (e.g., Chermahini and Hommel, 2010). In this study, the correlation was not statistically significant (see **Table 1**). Thus, the different results with respect to risk-taking might be attributed to cultural differences between China and Japan.

Despite these limitations, our findings deserve some attention because previous literature examined the effect of either mood or risk-taking on creative thinking, but did not evaluate both at the same time. First, the result that risk-taking attitudes accounted for high scores in divergent thinking is consistent with prior findings and the underlying representational change theory. Divergent thinking requires challenging and changing current contexts and constraints. In particular, in the case of IGT, facing losses several times implies that participants choose high risk, high return decks. In order to maximize the rewards, they have to shift to low risk, low return decks, which seems to be enabled by risk-taking behavior in the face of losses. The results suggest that participants with these risk attitudes tend to obtain high scores in divergent thinking. This is because these participants are more likely to challenge and change their current contexts and constraints in divergent thinking, leading to high scores.

Second, while the current study explicitly defined and measured the magnitude of mood, related studies did not necessarily measure the mood in a parametrically clear manner. Typically, positive mood was induced in participants by giving a small gift such as a package of candy (see, for example, Estrada et al., 1994). However, it remains ambiguous whether the mood variables measured by these methods correspond to self-reinforcing or self-destructive forces with respect to current contexts and implicit assumptions. The positive moods induced by some gifts are too broad to apply to the specific decision-making situations such as the IGT. Since our measure for mood derived from actual behaviors in the IGT, it seems more relevant to account for learning behaviors of participants.

Third, the positive effects of inverse temperature on divergent thinking deserve to be mentioned here. As described above, inverse temperature measures the relative levels of exploitation and exploration. Noting that exploitation measures the optimization under existing information, its positive effect on divergent thinking may seem to contradict the representational change theory. This is because exploitation seems to reinforce current choices, rather than shifting to different choices. However, the inverse temperature in this model incorporated risk-taking forces because Q values in (1) include the risk attitudes specified in (3). Consequently, the positive effect of the inverse temperature on divergent thinking facilitates, rather than impedes, risk-taking attitude reflected in ν. Thus, this result is indeed consistent with the positive effect of risk-taking on divergent thinking.

Forth, the results revealed that neither risk-taking nor inverse temperature accounted for convergent thinking performance. However, caution should be exercised when interpreting this result because the RAT required both divergent and convergent thinking to yield correct solutions. Moreover, the correct solution was sometimes obtained through insight. A combination of problem solving with and without insight makes it difficult to identify the relative contributions of risk-taking and exploitation/exploration ratio. As described above, insight is caused by the representational change, which requires some explorative activities. Problem solving without insight, however, proceeds in an incremental manner. Consequently, it is possible that the mixing of problem solving with and without insight in the RAT caused ambiguity regarding the effects of risk-taking and exploitation/exploration ratio.

By and large, the results of this study are consistent with the representational change theory. According to this theory, problem solving initially involves the construction of an erroneous problem space, making it infeasible to come up with correct solutions. Representational change can then occur through constraint relaxation. This relaxation is enabled by automatic and unconscious processes. Smith and Kounios (1996) and Topolinski and Reber (2010) emphasized the interplay between conscious and unconscious mechanisms in problem solving, and provided a framework for interpreting insight as the conscious correlate of processing fluency caused by a sudden appearance of the solution. Although there exists a debate regarding whether insight occurs through a sudden or gradual process, most researchers share the view that insight, as one of the most important ingredients of creative thinking, is enabled by representational change. This change is facilitated by risk-taking and self-destructive mood. The finding that risk-taking is positively related to divergent thinking, but self-reinforcing mood does not account for either divergent or convergent thinking is consistent with the representational change theory.

However, our study differs from the typical representational theory in that the underlying decision-making process is explicitly modeled. The representational change in our model is caused by shifting to seemingly non-optimal choices. This shift is enabled by increasing the Q value of such choices. Thus, any parameters that induce this increase lead to the representational choice. In our model, they correspond to risk-taking parameters. The inverse temperature, as a proxy for exploitation/exploration ratio, could also account for explorative behavior. However, as noted above, since risk-taking behavior was reflected in the Q values, exploitation, rather than exploration, played a significant role in divergent thinking. One of the advantages of this computational approach to the representational change is that we could interpret and discuss precisely how each parameter effect is related to the representational change in terms of increasing non-optimal choices. Related studies in the representational change theory, without exception, hinge on verbal and conceptual, instead of mathematically rigorous, models. The main disadvantage of verbal and conceptual models is the difficulty of interpreting complex interplays across many relevant variables. As the computational model explicitly models these interactions, this interplay is easily interpreted. Admittedly, model misspecification is a disadvantage of the mathematical model. However, this potential problem should be overcome by proposing more realistic mathematical models, instead of abandoning the computational approach.

On the whole, the results in this study are consistent with the representational change theory, and thus, seem to be generalizable in different cultural contexts. Indeed, Quartiroli et al. (2018) demonstrated the cross-cultural generalizability of the mood profiles (combinations) between English-speaking and Italian-speaking participants. Since this study also examined the effects of mood, their findings support the generalizability of our results. It should be noted, however, that similar mood profiles do not necessarily lead to similar effects on behavior and performance. For example, Ozer (2015) and Giorgi et al. (2020) studied cross-cultural adjustment of expatriate employees and international university students, respectively, attesting its importance in improving performance and the positive role of social support in facilitating adjustment. This implies that cross-cultural adjustment matters in behavioral patterns and performance. Therefore, while the results of this study seem generalizable, it would be difficult to deny the possibility that the relations between mood, risk-taking, and creativity, to some extent, depend on underlying cultural contexts, as demonstrated by Shen et al. (2018). The study of cultural effects on creativity constitutes one of the important future research challenges.

CONCLUSION

The current results revealed that risk-taking played a role in providing momentum for exploratory behavior, which in turn facilitated divergent thinking. In contrast, mood as a self-reinforcing force specified in this study was related to neither divergent nor convergent thinking. These results were consistent with the representational change theory in insight problem solving. Although this theory accounts directly for insight, and not necessarily for creative thinking, the underlying idea of going beyond current contexts and implicit constrains could be applied to creative thinking as well. The results indeed account for the relevance of this theory to divergent thinking.

To the best of our knowledge, the current study is one of the first empirical studies simultaneously examining the role of mood and risk-taking in creativity. In particular, no related studies exist that took a computational approach to estimate the relevant parameters in the framework of dynamic optimization. Although mathematical models inevitably entail the risk of misspecification, they have the capacity to clarify interactions across relevant parameters. This allows for estimating the interdependence of relevant parameters in a statistically consistent manner. For example, concepts of exploration, risk-taking, and positive mood are closely related and overlapping so that their mutual effects are usually difficult to evaluate without model specifications. Our Q learning models enable distinguishing and identifying their different roles in updating Q values and making decisions. We strongly believe that this computational approach should be applied not only to creativity research but also to other psychological research fields to elucidate underlying cognitive and psychological mechanisms.

Further research is required to explore the role of risk-taking and mood in facilitating or impeding creativity in more detail. In particular, more direct measurements of mood that facilitate exploratory behavior will be required to examine the effects of positive mood on creativity. This constitutes one of our future research challenges.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee, Graduate School of Business Administration, Kobe University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Stress Makes the Difference: Social Stress and Social Anxiety in Decision-Making Under Uncertainty

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Stress and anxiety can both influence risk-taking in decision-making. While stress typically increases risk-taking, anxiety often leads to risk-averse choices. Few studies have examined both stress and anxiety in a single paradigm to assess risk-averse choices. We therefore set out to examine emotional decision-making under stress in socially anxious participants. In our study, individuals ($N = 87$) high or low in social anxiety completed an expanded variation of the *Balloon Analogue Risk Task* (*BART*). While inflating a balloon to a larger degree is rewarded, a possible explosion leads to (a) a loss of money and (b) it is followed by an emotional picture (i.e., a calm vs. an angry face). To induce stress before this task, participants were told that they would have to deliver a speech. We operationalized risk-taking by the number of pumps during inflation and its functionality by the amount of monetary gain. In addition, response times were recorded as an index of decisional conflict. Without the stressor, high socially anxious compared to low socially anxious participants did not differ in any of the dependent variables. However, under stress, the low socially anxious group took more risk and earned more money, while high socially anxious individuals remained more cautious and did not change their risk-taking under social stress. Overall, high socially anxious individuals made their decisions more hesitantly compared to low socially anxious individuals. Unexpectedly, there were no main effects or interactions with the valence of the emotional faces. This data shows that stress affects socially anxious individuals differently: in low socially anxious individuals stress fosters risk-taking, whereas high socially anxious individuals did not alter their behavior and remained risk-averse. The novel *eBART* is a promising research tool to examine the specific factors that influence decision-making.

Keywords: anxiety, stress, decision-making, avoidance, social anxiety

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INTRODUCTION

There is convincing evidence that stress and anxiety change how we evaluate the risk and benefit of an option and that they strongly influence our decisions (Kudielka et al., 2009; Pittig et al., 2015). They both occupy cognitive resources during information processing (Botvinick et al., 2001) and may hinder adaptive processing of emotional as well as cognitive conflicts which might, for example, result in longer response times (e.g., Etkin and Schatzberg, 2011; Larson et al., 2013). Although they share a similar pattern of physiological reactions (Dickerson and Kemeny, 2004),

they differ in the interpretation of the situation (Sarason, 1984). While stress emerges when an organism is confronted with overstraining demands (Koolhaas et al., 2011), anxiety is an emotional consequence of perceived threat (see Rosen and Schulkin, 1998).

Despite their documented relevance, little is known about the specific and mutual effects of stress and anxiety on risk-taking behavior, especially in decisions where approach-avoidance motivations compete against each other. Because anxiety is the most important motivation for avoidance behavior (Hofmann et al., 2008) and stress is common in many situations in daily life (McEwen, 2008), it is of special interest to investigate both states in the context of an approach-avoidance conflict.

Several researchers examined the impact of stress on risk-taking (e.g., Starcke et al., 2008; Kassam et al., 2009). A recent meta-analysis concludes that stress leads to riskier decisions, especially when risk-taking is dysfunctional (Starcke and Brand, 2016). On this basis, we sought to investigate the effects of stress and anxiety on risky decision-making in an ecologically valid paradigm in high and low socially anxious individuals.

To experimentally induce stress in the laboratory, the so-called *public speaking task* is frequently used and has been shown to be an effective stressor is (e.g., Steele and Josephs, 1988). In this task, participants are told that they are to give a speech on a controversial topic without time for preparation. They are also told that they will be videotaped and later evaluated by experts after the experiment. This task is a reliable method to evoke emotionally triggered self-reported and physiological arousal (e.g., Mühlberger et al., 2008; Schulz et al., 2008). Especially in social anxiety, where a classificatory feature is the fear of being embarrassed in front of an audience, this method effectively induces anxiety.

In addition to the stress induction, the selection of the appropriate decision-making paradigm is most relevant. Potential paradigms differ with respect to the (un)certainty of the risk involved in each decision. Many laboratory tasks measure decision-making under uncertainty, where the probability of an outcome and the outcome itself are unknown. For example, being stressed participants learned reward contingencies under uncertainty in the *Iowa Gambling Task (IGT)* more slowly than non-stressed individuals (Preston et al., 2007). Similarly, in the *Game of Dice Task* (*GDT*; Brand et al., 2005), stress interfered with task performance and consequently lead to more disadvantageous decisions (Starcke et al., 2008). Common to these paradigms is that they require participants to learn reward and loss contingencies through feedback during the task. However, reward contingencies in these tasks are not obviously clear and participants are less likely to learn them through feedback. In addition, induced stress may interfere with cognitive resources during information processing and may further deteriorate emotional feedback processing (Starcke et al., 2011). Furthermore, these tasks also encourage participants to focus more on the potential losses because riskier decisions are classified as disadvantageous.

Thus, we made use of a well-established paradigm to assess the shift from decisions under uncertainty to decisions under risk by feedback learning. In the *Balloon Analogue Risk Task* (*BART*; Lejuez et al., 2002), participants inflate a computer-simulated balloon and earn a certain amount of money with each pump. Simultaneously, with each pump, the risk of the balloon exploding increases. If the balloon explodes, the money earned so far is lost. As decision-making in everyday life includes the potential of reward and loss at the same time (Leigh, 1999), this task is an ecologically valid paradigm to model risk-taking under experimental conditions. It transfers well to real-life risk behavior (Lejuez et al., 2003), as taking a risk often includes several sequential decisions and seldom all-or-nothing decisions, as implemented in other decision-making tasks. Indeed, the number of pumps in the *BART* correlates with risk behavior in real life, such as smoking or heavy drinking (Lejuez et al., 2003). It also fosters individuals to focus more on the immediate incentives and it rewards riskier decisions. Many studies illustrate heightened risk-taking and, consequently, more advantageous decisions under stressful than under non-stressful conditions (e.g., Reynolds et al., 2013).

In this line, anxiety is often manipulated as an emotional state for risk-taking behavior in the laboratory. In addition, when perceived in a decision-making situation, anxiety exhibits a powerful influence on our decision-making behavior (Finucane et al., 2000; Pittig et al., 2015; Buelow and Barnhart, 2017). Anxiety in particular leads to biased risk estimations of negative events, especially of negative outcomes (Hengen and Alpers, 2019). From a clinical perspective it is evident that this can lead to maladaptive avoidance behavior, which is a classificatory feature of anxiety disorders (Hofmann et al., 2008). Some researchers argue that this biased risk evaluation is a mediating factor between heightened risk perception and higher risk avoidance (Maner and Schmidt, 2006; Lorian and Grisham, 2010). A systematic study on these fear-driven estimated risks showed heightened risk estimates for negative outcomes of fear-relevant encounters and not of the encounter itself (Hengen and Alpers, 2019). Furthermore, less is clear about the distinct and interacting effects of anxiety and stress on the distinct components of risk perception.

In turn, avoidance behavior is an important factor in the etiology and maintenance of anxiety disorders (Hofmann et al., 2008; Craske et al., 2009) and the reason for a maladaptive decision-making strategy. For example, high socially anxious individuals report they avoid social opportunities (Antony and Stein, 2008) even if they are aware of the incurred costs of their decision (Kashdan et al., 2008). Few laboratory paradigms have replicated this finding, and fewer still that were aimed at modeling this approach-avoidance conflict. We previously used a modified version of the *IGT* (Bechara et al., 1994) and added fear-related stimuli as indicators for advantageous or disadvantageous choices (Pittig et al., 2014a,b,c; Bublatzky et al., 2017). In a study with high socially anxious individuals, they avoided pictures of angry faces at the expense of monetary losses (Pittig et al., 2015). Thus, this modified version of the *IGT* is one of the few

paradigms that validly assesses the approach-avoidance conflict in anxiety.

In the previously developed emotional *BART* (*eBART*; Hengen and Alpers, accepted pending revision), we added a fear-relevant event as a second consequence in addition to the risk of losing the money earned after an explosion to create an approach-avoidance conflict. Thus, when participants inflate the virtual balloon, they run the risk a) of losing the money earned with each pump – as in the established BART – and b) being confronted with task-irrelevant but fear-relevant stimuli. We maintained the loss of money from the original version to ensure that non-fearful individuals would not inflate all balloons to the very last pump, which would otherwise be the normative response.

This modified *eBART* proved to be an ecologically valid method in modeling the fear-driven approach-avoidance conflict in spider-fearful individuals. For the present study, we replaced the fear-relevant stimuli spiders with angry (and neutral) faces as fear-relevant outcomes for our socially anxious group. Angry facial expressions were effective in eliciting social threat and rejection in high socially anxious individuals in previous research (e.g., Mogg et al., 2004; Wieser et al., 2009; Pittig et al., 2015). As detailed above, to evoke stress in low socially anxious and anxiety in high socially anxious individuals, we made use of the *public speaking task*.

When we are confronted with such a difficult situation, namely the approach-avoidance conflict in the *eBART*, we are challenged to allocate cognitive resources toward the task's demands (Botvinick et al., 2001). Anxiety and stress may modulate our capacity to allocate these resources to solve the conflict situation. Whereas anxiety leads to more conflict adaptation and consequently to longer response times (e.g., Clayson and Larson, 2011; van Steenbergen et al., 2015; Hengen and Alpers, accepted pending revision), little is known about the specific effects of stress and the mutual effects of anxiety and stress on response times. Therefore, just as in our recently modified *eBART*, we set out to measure response times.

As it is also unclear if effects found in studies with spider-fearful individuals can be generalized to social anxiety (see Berdica et al., 2018), we sought to replicate our earlier findings of spider-fearful and spider non-fearful individuals (Hengen and Alpers, accepted pending revision) in social anxiety. We expected that social anxiety would lead to an overall risk avoidance behavior; this being most pronounced in the context of fear-relevant stimuli. As the *eBART* rewards risk-taking behavior, anxious individuals compared to non-anxious ones should not learn to adapt their behavior to a more risk-taking and functional strategy. Furthermore, we expected that stress would provoke more risk-taking in non-anxious but not in anxious individuals. To add to previous research and findings on risk perception, we argue that anxiety and stress should result in heightened risk estimates of negative outcomes of fear-relevant encounters, but not in heightened risk estimates of fear-relevant encounters themselves. Furthermore, as stress and anxiety are affective states that limit cognitive resources and impede conflict processing, we expected longer response times for both anxious and non-anxious individuals under stress.

MATERIALS AND METHODS

Participants

A large sample ($N = 87$)[1] of individuals with an age range of 18–32 ($M = 22.37$, $SD = 3.32$) from the local community and from students at the University of Mannheim were first screened for high and low levels of social anxiety with the mini-*Social Phobia Inventory* (mini-SPIN; Connor et al., 2001). This questionnaire consists of three items that must be rated on a 0 (*not at all*) − 5 (*absolutely*) Likert scale. They capture the key features of social anxiety, namely anxiety of feeling ashamed and the avoidance of social activities [American Psychiatric Association (APA), 2013]. Participants with values ≤ 2 were classified as low socially anxious and participants with values ≥ 6 as high socially anxious (Connor et al., 2001; Seeley-Wait et al., 2009). Participants who met the criteria for high and low social anxiety were invited to the laboratory. Participants with neurological or other severe medical conditions, traumatic brain injuries, current or past psychiatric hospitalization, a current use of psychoactive medication as well as pregnant women and persons under 18 years of age were excluded from the study.

Subsequently, 46 individuals were classified as low ($n = 34$, 73.9% females; age: $M = 23.50$, $SD = 3.40$) and 41 as high socially anxious ($n = 27$, 65.9% females; age: $M = 21.10$, $SD = 2.76$)[2]. To verify the assignment to the high and low socially anxious groups at the time of the laboratory study, we used the German version of the *Social Phobia Inventory* (SPIN; Consbruch et al., 2016) with 17 items to be rated (0 = *not at all* to 4 = *absolutely*). The SPIN is a reliable and valid method to differentiate efficiently between people with and without social phobia (Connor et al., 2000). In our sample SPIN, mean scores of the low ($M = 16.24$, $SD = 9.26$) and high socially anxious group ($M = 33.54$, $SD = 17.84$) are similar to the mean scores of a healthy sample and one with diagnosed social phobia, respectively (Connor et al., 2000).

For pragmatic reasons, most importantly, the availability of 87 participants, we collected our data for the study in two waves. To avoid word of mouth among the students, in the first wave we assessed 40 high and low anxious participants without a social stressor. In the second wave, we invited a further 47 participants into our laboratory and induced stress. Only 25 of the low socially anxious and 22 of the high socially anxious individuals underwent a stress induction procedure whereas the remaining 41 participants did not. Due to the staggered recruitment, we conducted analyses on control variables and found no differences between the stress and no-stress condition (see **Table 1**). To account for gender differences, we counterbalanced males and females in the high and low anxious groups as well as in the

[1]Referring to previous results of the *eBART* (Hengen and Alpers, accepted pending revision) and to similar approach-avoidance paradigms (e.g., Pittig et al., 2018), effect sizes for the influence of anxiety as well as induced stress were transformed into Cohen's f and set as a large effect of $f = 0.40$. We conducted post-hoc power analyses (GPower; Faul et al., 2009) with a given $\alpha = 0.05$ and a given sample size of 87 participants. The statistical power for all main effects and interactions was ≥ 0.96 and thus interpreted as sufficiently for our analyses.

[2]Additional analyses for the effects of gender on risk avoidance are described in more detail in the **Supplementary Material**.

TABLE 1 | Demographics and questionnaire data.

	No stress ($N = 40$)				Stress ($N = 47$)			
	High socially anxious	Low socially anxious	t/χ^2	p	High socially anxious	Low socially anxious	t/χ^2	p
N	19	21			22	25		
Age	21.95 (*1.39*)	23.43 (*3.28*)	−1.89[a]	=0.069	20.36 (*3.40*)	23.56 (*3.57*)	−3.13[a]	=0.003
	22.73 (*2.64*)				22.06 (*3.81*)		−0.95[a]	=0.345
Gender (female)	10 (*52.6%*)	18 (*85.7%*)	5.20[b]	=0.023[4]	17 (77.3%)	16 (*64%*)	0.99[b]	=0.321
	28 (*70.0%*)				33 (*70.2%*)		<0.01[b]	=0.983
BDI-II	10.37 (*8.26*)	4.52 (*3.87*)	2.82[a]	=0.009	10.50 (*6.94*)	3.64 (*3.26*)	4.24[a]	<0.001
	7.30 (*6.92*)				6.85 (*6.29*)		−0.32[a]	=0.752
STAI-T	42.63 (*9.62*)	34.05 (*5.70*)	3.39[a]	=0.002	46.55 (*10.48*)	31.92 (*7.46*)	5.56[a]	<0.001
	38.13 (*8.84*)				38.77 (*11.56*)		0.29[a]	=0.775
SPIN	28.84 (*11.01*)	9.48 (*5.76*)	6.87[a]	<0.001	27.95 (*11.14*)	6.21 (*4.34*)	3.23[a]	=0.003
	18.68 (*12.99*)				15.81 (*13.52*)		−0.98[a]	=0.329
SSS-V	18.63 (*3.99*)	18.67 (*6.34*)	−0.021[a]	=0.983	16.70 (*5.43*)	24.04 (*5.47*)	−3.05[a]	=0.006
	18.65 (*5.28*)				20.78 (*6.53*)		1.64[a]	=0.105
QMI	2.43 (*0.65*)	2.25 (*0.50*)	0.97[a]	=0.336	2.76 (*0.94*)	2.56 (*1.17*)	0.64[a]	=0.524
	2.33 (*0.58*)				2.65 (*1.06*)		1.71[a]	=0.091

Means and standard deviations displayed separately for high and low socially anxious individuals. n = Number of participants; BDI = Beck Depression Inventory (Hautzinger et al., 2006); STAI-T = State and trait version of the State-Trait Anxiety Inventory (Laux et al., 1981); SPIN = Social Phobia Inventory (Consbruch et al., 2016); SSS-V = Sensations-Seeking-Scale (Beauducel et al., 2003); QMI = Questionnaire Upon Mental Imagery (Sack et al., 2005).

[a] *t score for group comparison.*

[b] χ^2 *score for gender ratio comparison.*

stress and non-stress conditions. See further demographic and questionnaire data in **Table 1**.

The ethics committee approved the procedure. None of the screened participants met our exclusion criteria, they were consequently all invited to the laboratory. After providing informed consent, all participants filled in a questionnaire battery.

Questionnaires

To ascertain whether our stress induction worked and to account for high levels of dispositional anxiety, we measured state and trait anxiety with the *State-Trait Anxiety Inventory* (STAI; German version: Laux et al., 1981). Depressive symptoms were assessed with the *Beck's Depression Inventory* (BDI-II; Hautzinger et al., 2006) due to their effects on reward and punishment processing (e.g., Eshel and Roiser, 2010). We administered the *Impulsive Behavior Scale* (UPPS; German version: Schmidt et al., 2008) and *Sensations-Seeking-Scale* (SSS-V; German version: Beauducel et al., 2003) because both values are related to behavior in the *BART* (e.g., Bornovalova et al., 2009). Due to the issue of statistical power, we did not consider the UPPS in our analyses because sensation-seeking and impulsivity have overlapping features and show high correlations with each other (Zuckerman, 1994; Steinberg et al., 2008; Meule et al., 2011).

To examine differences in specific risk estimations between low and high socially anxious individuals, we adapted items of two previously established risk estimation questionnaires, the *Risk of Encounter Questionnaire* and the *Risk of Negative Outcomes Questionnaire* (RNOQ; Hengen and Alpers, 2019). We created items specific to social anxiety for the *Encounter Domain* (e.g., to give a talk) and for the *Outcome Domain* of such encounters (e.g., being laughed at when one gives a talk).

Stimuli

For the fear-relevant stimuli in the *eBART*, we selected 12 pictures of angry (6 female) and 8 pictures of calm (4 female) facial expressions from the well-validated *NimStim* set (Tottenham et al., 2009). We selected only the most validated facial expressions (Adolph and Alpers, 2010). Calm facial expressions are faces which are perceptually similar to neutral, however, actors are instructed to leave their face more relaxed (Tottenham et al., 2009). We chose these facial expressions as our neutral stimuli because research on face perception has shown that neutral faces are not always perceived as neutral (Donegan et al., 2003; Iidaka et al., 2005). Socially anxious individuals in particular tend to interpret neutral or ambiguous stimuli as negative (Winton et al., 1995; Amin et al., 1998; Amir et al., 2005). To control for head size and form of the facial expressions, we cropped the pictures to an oval form. To standardize the color intensity, we removed the color from the faces and replaced them with shades of gray.

Immediately before and after the *eBART*, participants rated the pictures on a 10-point Likert scale on the dimensions valence ("1 = very unpleasant" to "10 = very pleasant"), arousal ("1 = not at all arousing" to "10 = very arousing"), and, in addition, intensity ("1 = not at all intense" to "10 = very intense"). We added the intensity dimension because anxiety is known to modulate the perception of the intensity and, consequently, the recognition of facial expressions (Kavcioglu et al., 2019).

Experimental Procedure

At the beginning, in order to comply with standards of informed consent, all participants received a short and unspecific information that they may possibly be asked to give a speech which would be video-taped after the experiment and following rated by professional raters. However, only the 47 participants in the stress condition received the detailed instructions for the *public speaking task* after filling in the questionnaires (Steele and Josephs, 1988; Wieser et al., 2010). They were told that they would need to give a speech at the end of the experiment and that it would be videotaped and later evaluated by experts of the department. They were also informed that the talk would be on a controversial topic and that they would have no time to prepare. Afterwards, they again reported their arousal on the STAI-State. The no-stress condition group did not receive such instructions but also filled in the STAI-State a second time.

Participants then rated the fear-relevant angry and neutral/slightly positive facial expressions used in the *eBART*. Following this, they performed the *eBART* and rated the facial expressions again. They were also asked to rank their motivation to win money and to avoid the fear-relevant stimuli ("0% = not motivated" to "100% = highly motivated") in the *eBART*. After that, they rated their situational anxiety on the STAI-State and answered questions about their explicit knowledge of the contingencies in the computer task. Finally, they were asked about the plausibility of the stress induction. They were then debriefed and received either a certain amount of money which they won during the task or course credit for their participation[3].

Balloon Task With Social Stimuli

The *eBART* is a modified version of the original *BART* (Lejuez et al., 2002) which we previously introduced with spider and butterfly pictures as emotional stimuli (Hengen and Alpers, accepted pending revision). As in the original *BART*, participants were asked to inflate a computer-simulated balloon by pressing a key on the keyboard. With each pump, the balloon grows larger and participants earn a certain amount of virtual money (5 cents). After each pump, participants are free to choose if they want to collect the money earned in this trial (i.e., per balloon) or if they want to continue inflating the balloon. Simultaneously, with each successive pump the risk increases that the balloon explodes. Such explosions concurred with the loss of money earned during this trial.

We set the explosion probability to 1/128 for the first pump. In case the balloon did not explode this probability was increased on the successive pumps to $1/(128 - n)$. This algorithm resulted in an average explosion point after 64 pumps. Thus, a normative and most adaptive point to stop inflating and collect the money earned so far would have been 63 pumps.

Three differently colors of the balloons predicted the contingency of a fear-relevant stimulus after an explosion. The first color indicated a 100% contingency of an angry facial expression, the second a 50% contingency of an angry or a calm facial expression, and the third a 0% probability of an angry facial expression (but a 100% contingency of a calm facial expression). Thus, on successive pumps participants increased the risk of losing the money earned so far. In addition, in the 100 and 50% condition (indicated by balloon color) the risk of an angry facial expression appearing increased. There were 15 balloons of each color/contingency. Thus, the total number of balloons to inflate during the task was 45. For each color, the maximum break point was set to 128. Across all colors, the probability of a balloon exploding was held constant [i.e., $1/(128 - n)$]. After 6 s, a small square appeared in the middle of the picture and participants had to perform a mouse-click to continue with the next balloon. This procedure ensured that high socially anxious individuals could not visually avoid the aversive stimuli.

At the beginning, participants were explicitly told which color indicated which contingency, but they had to learn the explosion probability by experience. This procedure increases ecological validity and creates a continuous shift from decisions under uncertainty (probability is yet unknown) to decisions under risk (probabilities become transparent with experience). To avoid confounding effects, the color assigned to each contingency was counterbalanced across participants. Further, contingency blocks were assigned in a randomized manner across the *eBART*. **Figure 1** shows an example trial in the 100% contingency condition.

Statistical Analyses

As a manipulation check for the classification as high and low socially anxious, we compared mean scores of the SPIN between the high and low socially anxious groups with a *t*-test for independent samples. As a manipulation check for the stress induction method, we compared self-reported arousal with the STAI-state scores. Therefore, we conducted a 2 × 2 × 2 mixed ANOVA with the between-subject factors *Social Anxiety* groups (high vs. low) and *Stress* condition (yes vs. no) as well as the within-subject factors *Time* (before stress induction vs. after stress induction).

To check for the emotional relevance of the stimulus material, we ran several 2 × 2 mixed ANOVAs with the between subject factor *Social Anxiety* and the within subject factor *Expression* (angry vs. calm) for each rating dimension (valence, arousal and intensity).

We used three dependent variables as indicators of risk avoidance tendencies. We operationalized risk avoidance behavior by following the recommended procedures for the original BART and computed the average adjusted number of pumps. This is a measure for the number of pumps on trials in which the balloons did not explode. It is more reliable than the total number of average pumps across all balloons and accounts for more between-group variability (Lejuez et al., 2002). As an index for dysfunctional risk avoidance, we used the amount of money earned in the task. In addition, we recorded

[3]31 participants (48.4% high socially anxious and 25.8% under stress) received a performance-based monetary incentive, the other 56 participants (46.4% high socially anxious and 69.6% under stress) were rewarded with course credits. Although performance-based rewarded and credit rewarded participants were not equally distributed across groups, they did not differ in any of the dependent variables, all $ts \leq 1.60$, all $ps \geq 0.114$. Thus, the following observed effects were not influenced by the type of compensation.

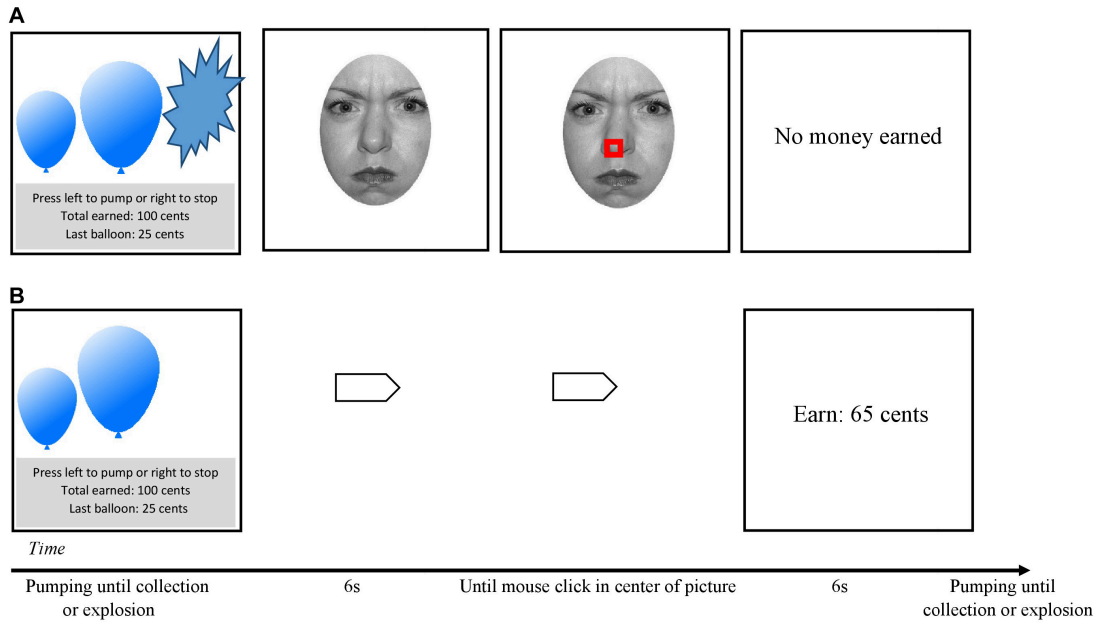

FIGURE 1 | Example of a sequence of the social *eBART* in the 100% contingency condition (all losses accompanied with angry facial expressions). **(A)** Depicts a trial with an explosion: a screen with a balloon was presented. The participants were asked to inflate it. The sequence ends when the participants decided to collect the earned money or the balloon explodes. After an explosion a picture of an angry facial expression was presented. To proceed, participants had to click in the middle of the facial expression (indicated by a little square; Feedback presentation followed and the next trail began. **(B)** Depicts a trial without an explosion. When participants decided to stop inflating before the explosion, the participant only received feedback on their earned money in this trial and the next trial started. The right to publish the actor's photograph was granted by the authors of the NimStim inventory (Tottenham et al., 2009).

response times for the decisions to inflate the balloon across all balloon trials as a measure of the cognitive resources invested in the approach-avodiance situation. We calculated the average response time per pump for each participant.

For avoidance behavior across the *eBART*, we grouped the task in three sequential blocks [Block 1 (balloons 1–15), Block 2 (balloons 16–30), Block 3 (balloons 31–45)]. For each block, we calculated the average number of adjusted pumps, the money earned as well as the response times. We then conducted $2 \times 2 \times 3$ mixed ANOVAs with the between subject factor *Social Anxiety* and *Stress* and the within subject factor *Block*.

Furthermore, we used the 100, 50, and 0% contingency trials to manipulate fear-driven avoidance tendencies. For the average adjusted number of pumps, the money earned and the response times, we also ran several $2 \times 2 \times 3$ ANOVAs with the same between subject factors *Social Anxiety* and *Stress* and the within subject factor *Contingency* (100% vs. 50% vs. 0% probability of a fear-relevant stimulus after an explosion).

In order to test our *a priori* hypotheses on the effects of stress, we split the overall $2 \times 2 \times 3$ ANOVA into two separate analyses for each, the stress and the no-stress condition. This resulted in two 2×3 ANOVAs with the between subject factor *Stress* and *Social Anxiety* and the relevant within subject factors (*Contingency* and *Block*). We followed this hypothesis-driven rationale even when there was no significant three-way interaction involving *Stress* in the overall test. However, in every instance when the overall test did not support it, we marked *a priori* contrasts as exploratory.

In addition, we examined the distinct components of risk estimates by using two 2×2 ANOVAs with *Stress* and *Social Anxiety* as between subject factors and either risk estimates of fear-relevant encounters or risk estimates of negative outcomes of such encounters as dependent variables. In case of significant main effects and interactions, these were further specified with post-hoc comparisons. In case of violated sphericity, Greenhouse-Geisser's we adjusted degrees of freedom appropriately.

RESULTS

Manipulation Check for the Stress Induction

We tested the effectiveness of our stress induction by assessing situational arousal with the STAI- state before and after the stress induction; see **Figure 2**. Overall, participants experienced more arousal after the stress induction, indicated by a significant main effect of *Time*, $F(1, 83) = 9.44$, $p = 0.003$, $\eta_p^2 = 0.10$; $t(86) = 3.04$, $p = 0.003$. Furthermore, high socially anxious individuals were more aroused at both times than low socially anxious individuals; main effect of *Social Anxiety*, $F(1, 83) = 14.02$, $p < 0.001$, $\eta_p^2 = 0.15$; Pre: $t(65.76) = 3.65$, $p = 0.001$, Post: $t(80.42) = 3.12$, $p = 0.003$. In addition, the effectiveness of our stress induction varied with the level of social anxiety; interaction *Stress* × *Social Anxiety*, $F(1, 83) = 7.07$, $p = 0.009$,

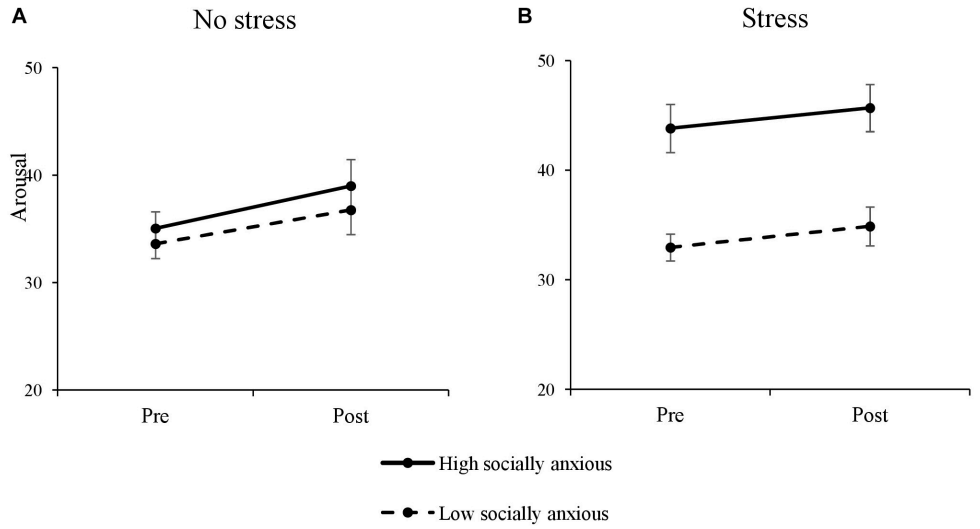

FIGURE 2 | Means of the sums scores of the STAI-S before and after the stress induction. **(A)** The group with no stress. **(B)** The group with the social stress induction. Error bars reflect the standard error of the mean.

$\eta_p^2 = 0.08$. Thus, we conducted separate 2 × 3 ANOVAs for each stress condition.

Without the stress induction, there were no differences between the anxiety groups, $F(1, 38) = 0.61$, $p = 0.439$, $\eta_p^2 = 0.02$; Pre: $t(38) = 0.70$, $p = 0.491$, Post: $t(38) = 0.67$, $p = 0.508$. However, under stress, high socially anxious individuals generally reported more arousal than low socially anxious individuals on both time points, indicated by a significant main effect of *Social anxiety*, $F(1, 45) = 20.45$, $p \leq 0.001$, $\eta_p^2 = 0.3$, Pre: $t(33.42) = 4.30$, $p < 0.001$, and Post: $t(45) = 3.91$, $p < 0.001$. None of the other main effects and interactions were significant, all Fs ≤ 3.64, all ps ≥ 0.060, all η_p^2 s ≤ 0.04.

To further check, if only high socially anxious individuals were assigned to the stress condition we conducted an univariate ANOVA with the between-subject factors *Stress* and *Social Anxiety* and the dependent variable STAI-S. Our results showed a significant main effect of both, *Stress*, $F(1, 83) = 6.17$, $p = 0.015$, $\eta_p^2 = 0.07$, and *Social Anxiety*, $F(1, 83) = 14.19$, $p < 0.001$, $\eta_p^2 = 0.15$, as well. In addition, there was also a significant interaction of both factors, $F(1, 83) = 8.34$, $p = 0.005$, $\eta_p^2 = 0.09$, that might indicated that especially high socially anxious with elevated baseline levels of state anxiety, were assigned to stress condition.

To sum up, high socially anxious individuals in the stress condition showed already elevated stress levels at the very beginning of the task.

Manipulation Check for the Stimulus Material

To determine the emotional relevance of the stimulus material, we conducted separate ANOVAs for each rating dimension. For valence, all participants rated angry facial expressions as more negative than calm expressions, indicated by a significant main effect of *Expression*, $F(1, 85) = 260.47$, $p < 0.001$, $\eta_p^2 = 0.75$. There was no main effect of *Social Anxiety*, $F(1, 85) = 2.61$, $p = 0.110$, $\eta_p^2 = 0.03$, and no significant interaction, $F(1, 85) = 0.49$, $p = 0.486$, $\eta_p^2 = 0.01$.

For arousal, all participants perceived angry facial expressions as more arousing than calm ones, main effects of *Expression*, $F(1, 85) = 201.10$, $p < 0.001$, $\eta_p^2 = 0.04$. In addition, high compared to low socially anxious individuals rated angry faces as more arousing, indicated by the significant main effect of *Social Anxiety*, $F(1, 85) = 5.78$, $p = 0.018$, $\eta_p^2 = 0.06$, $t(86) = 2.44$, $p = 0.017$, but there were no differences for calm faces, $t(86) = 1.86$, $p = 0.066$. There was no significant interaction, $F(1, 85) = 2.09$, $p = 0.152$, $\eta_p^2 = 0.02$.

For intensity, angry faces were perceived as more intense than calm faces by all individuals; main effect of *Expression*, $F(1, 85) = 610.53$; $p < 0.001$, $\eta_p^2 = 0.88$. However, high compared to low socially anxious individuals perceived angry faces, $t(85) = 1.36$, $p = 0.177$, and calm faces, $t(85) = 1.84$, $p = 0.070$, as more intense, which was indicated by the significant main effect of *Social Anxiety*, $F(1, 85) = 4.01$, $p = 0.048$, $\eta_p^2 = 0.05$. There was no significant interaction, $F(1, 85) = 0.22$, $p = 0.638$, $\eta_p^2 = 0.00$. Figures to illustrate the ratings are provided in the **Supplementary Material**.

To conclude, our stimulus material proved to be emotionally relevant and, especially for high socially anxious individuals, arousing.

Effects of Social Anxiety and Stress on Decision-Making

Risk Avoidance of Emotionally Relevant Stimuli

The results of the dependent variables for the different contingencies (0% vs. 50% vs. 100%) are presented in **Figure 3**. To test the assumption that stress affects high and low socially anxious individuals differently, we conducted a 2 × 2 × 3

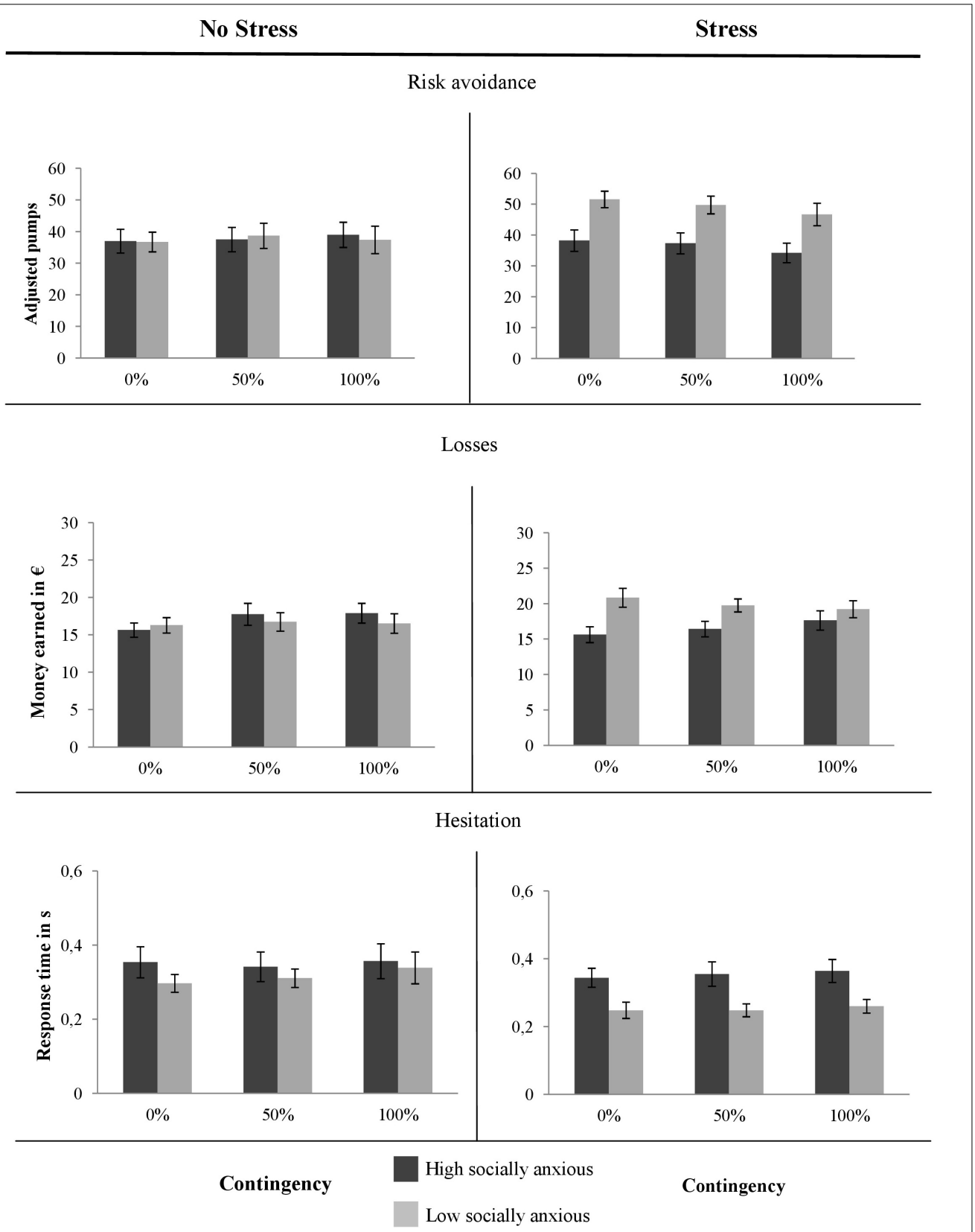

FIGURE 3 | Means of the adjusted number of pumps, of the earned money and the time per pump depending on the contingency of a fear-relevant stimulus. Error bars reflect the standard error of means.

ANOVA for the averaged adjusted pumps. There was a significant interaction between *Social Anxiety* and *Stress*, $F(1, 83) = 3.94$, $p = 0.050$, $\eta_p^2 = 0.05$, and between *Contingency* and *Stress*, $F(2, 83) = 3.17$, $p = 0.045$, $\eta_p^2 = 0.04$. No main effects and three-way interactions were observed, all Fs ≤ 3.68, all ps ≥ 0.058, all η_p^2 s ≤ 0.04.

Exploratory analysis of emotional risk avoidance

Without stress, there were no effects for *Social Anxiety*, $F(1, 38) = 0.00$, $p = 0.967$, $\eta_p^2 = 0.00$, nor for *Contingency*, $F(2, 76) = 0.46$, $p = 0.631$, $\eta_p^2 = 0.01$, nor an interaction between the two factors, $F(2, 76) = 0.41$, $p = 0.655$, $\eta_p^2 = 0.01$. Thus, without stress, high socially anxious individuals behaved in the same way as low socially anxious individuals.

Under stress, however, we observed a significant main effect of *Contingency*, $F(2, 90) = 3.17$, $p = 0.045$, $\eta_p^2 = 0.04$, but no significant interaction with *Social Anxiety*, $F(2, 90) = 0.50$, $p = 0.951$, $\eta_p^2 = 0.00$. On an individual level, all participants more frequently avoided trials with a 100% contingency than trials with a 50% contingency, $t(46) = -2.03$, $p = 0.049$, and trials with a 100% contingency of fear-relevant stimuli compared to ones with 0% contingency, $t(46) = -2.47$, $p = 0.017$. However, there were no differences in the number of pumps between the 50 and 0% contingency trials, $t(46) = 0.87$, $p = 0.3.88$.

The significant main effect of *Social Anxiety*, $F(1, 45) = 9.57$, $p = 0.003$, $\eta_p^2 = 0.18$, indicated that high socially anxious individuals had an overall risk avoidance tendency, regardless of the contingency between the decision and fear-relevant outcomes. We conducted further post-hoc tests to account for differences within high and low socially individuals between the stress and no-stress conditions. In all contingency conditions, high socially anxious individuals under stress were equally averse to risk as high socially anxious individuals without stress, all ts ≤ 0.95, all ps ≥ 0.351. Interestingly, low socially anxious individuals under stress increased their risk-taking in the stress compared to the no-stress condition, 0% contingency: $t(44) = 3.64$, $p \leq 0.001$, 50% contingency: $t(44) = 2.30$, $p = 0.026$. However, low socially anxious individuals did not differ in the 100% contingency between the stress and no-stress condition, $t(44) = 1.65$, $p = 0.105$.

To sum up, stress affected high and low socially anxious individuals differently: whereas high socially anxious individuals remained risk-averse independently of the stress conditions, low socially anxious individuals became more willing to take risks, especially when the risk of an emotional stimulus was rather low.

Monetary Losses Due to Risk Avoidance

To account for dysfunctional avoidance behavior operationalized by the money earned, we again conducted the overall $2 \times 2 \times 3$ ANOVA and found a significant interaction between *Social Anxiety* and *Stress*, $F(1, 83) = 5.49$, $p = 0.021$, $\eta_p^2 = 0.06$, but no other significant effects, all Fs ≤ 2.92, all ps ≥ 0.091, all η_p^2 s ≤ 0.03.

Exploratory analysis of monetary losses

Without stress, high and low socially anxious individuals did not differ, all Fs ≤ 3.68, all ps ≥ 0.058, all η_p^2s ≤ 0.04. In contrast, under stress, high socially anxious individuals earned less money, *Social Anxiety* $F(1, 45) = 10.11$, $p = 0.003$, $\eta_p^2 = 0.18$. This was not affected by the contingency of fear-relevant stimuli; all other effects did not reach significance, all Fs ≤ 3.68, all ps ≥ 0.058, all η_p^2 s ≤ 0.04.

Response Times of Decisions

To analyze if stress affects the response time of high and low socially anxious individuals differentially, we again conducted the overall $2 \times 2 \times 3$ ANOVA. There was a significant main effect of *Social Anxiety*, $F(1, 45) = 5.37$, $p = 0.023$, $\eta_p^2 = 0.06$, but no other significant differences or interactions, all Fs ≤ 1.93, all ps ≥ 0.148, all η_p^2 s ≤ 0.02.

Exploratory analysis of response times

Without a stressor, high and low socially anxious individuals did not differ in their response times, all Fs ≤ 1.21, all ps ≥ 0.298, all η_p^2 s ≤ 0.03.

However, under stress, high socially anxious individuals had slower response times, main effect of *Social Anxiety*: $F(1, 45) = 8.59$, $p = 0.005$, $\eta_p^2 = 0.16$, regardless of whether they were at risk of a fear-relevant stimulus; no main effect of *Contingency*, $F(2, 90) = 0.736$, $p = 0.482$, $\eta_p^2 = 0.02$, no significant interaction, $F(2, 90) = 0.09$, $p = 0.918$, $\eta_p^2 = 0.00$.

To conclude, high socially anxious individuals showed same response times independent of a social stressor. The social stressor reduced response times only in those with low social anxiety. This finding is in line with the other risk-related dependent variables.

Risk Avoidance Across the Task

In this section, we report the results from the $2 \times 2 \times 3$ ANOVAs with the between subject factors *Stress* and *Social Anxiety* and dependent measures as above. Instead of the within subject factor *Contingency*, we added the within subject factor *Block* to account for time effects on the risk-related variables across the task. The overall findings of the dependent variables across the *eBART* are presented in **Figure 4**.

To find out whether high and low socially anxious individuals systematically differ in their risk avoidance depending on stress, we ran the $2 \times 2 \times 3$ ANOVA for the number of adjusted pumps across the task. We had a significant main effect of *Block*, $F(2, 166) = 15.83$, $p < 0.001$, $\eta_p^2 = 0.16$, which indicated that all individuals inflated the balloons more when the task proceeded. Furthermore, high socially anxious compared to low socially anxious individuals inflated the balloons to a lesser degree across the *eBART*, $F(1, 83) = 4.50$, $p = 0.037$, $\eta_p^2 = 0.05$. A significant interaction between *Stress* and *Social Anxiety* showed that stress affected high and low socially anxious individuals differently, $F(1, 83) = 4.50$, $p = 0.037$, $\eta_p^2 = 0.08$. There were no other significant differences, all Fs ≤ 2.80, all ps ≥ 0.098, all η_p^2 s ≤ 0.03.

Exploratory analysis of risk avoidance across the task

Without stress, high and low socially anxious individuals did not differ in the average number of pumps across the task: significant

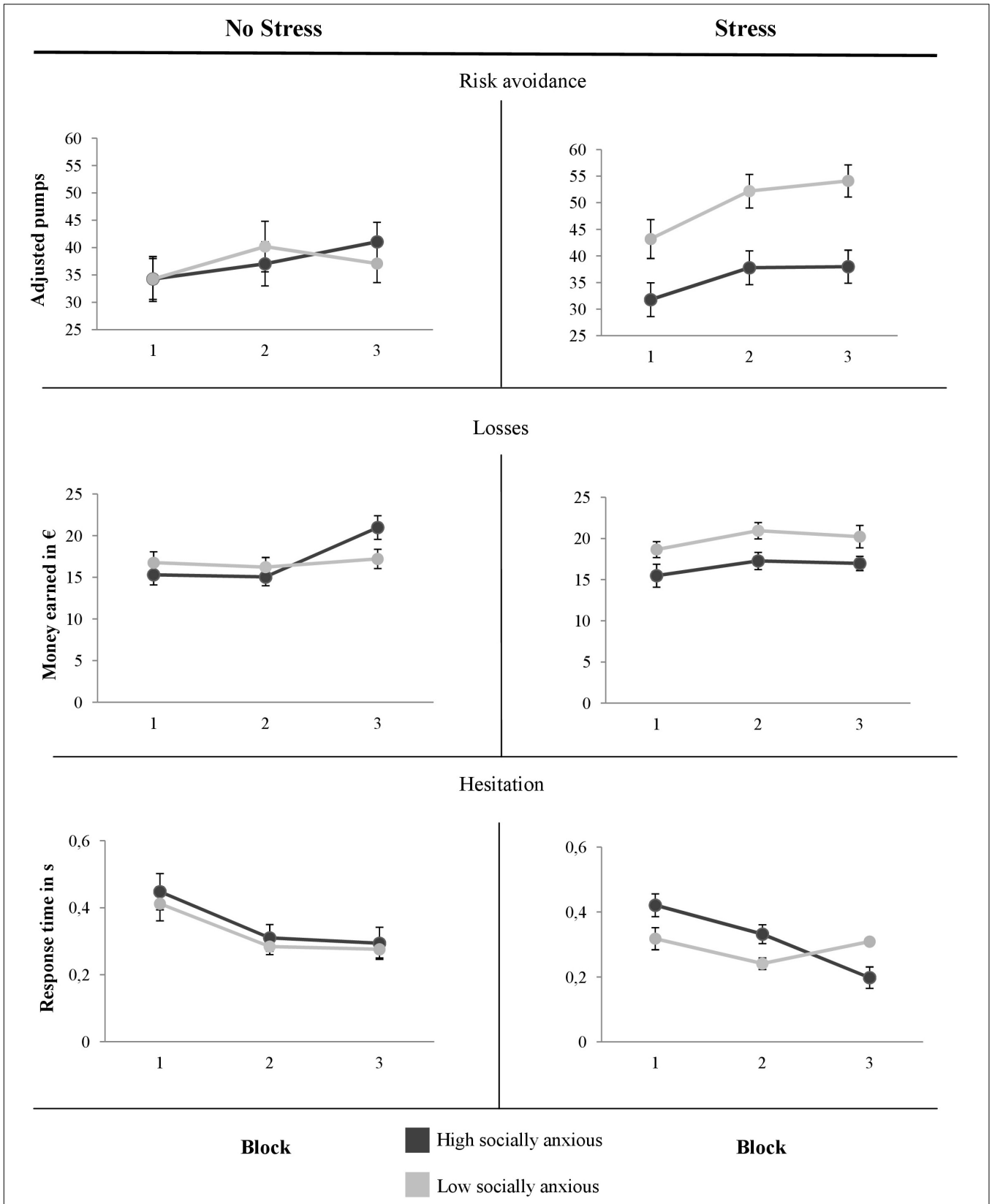

FIGURE 4 | Means of the adjusted number of pumps, of the earned money and the time per pump depending on the block (1 = balloon 1–10; 2 = balloon 11–20; 3 = 2 balloon 1–30) throughout the *eBART.* Error bars reflect the standard error of means.

main effect of *Block*, $F(1, 38) = 0.00$, $p < 0.983$, $\eta_p^2 = 0.00$. Indeed, they all had the same increase in the adjusted number of pumps, $F(2, 76) = 3.48$, $p < 0.001$, $\eta_p^2 = 0.25$. Further, all individuals inflated the balloon more in Block 2, $t(39) = 2.10$, $p = 0.043$, and Block 3, $t(39) = 2.28$, $p = 0.028$. There was no difference between Block 2 and 3, $t(39) = 0.16$, $p = 0.878$. The results indicated that the adjusted number of pumps did not differ as a function of *Social Anxiety*, $F(2, 76) = 1.79$, $p = 0.176$, $\eta_p^2 = 0.05$.

Under stress, all individuals learned to adapt their behavior and inflated the balloons more, indicated by a significant main effect of *Block*, $F(2, 90) = 14.98$, $p < 0.001$, $\eta_p^2 = 0.25$. This difference was due to a larger increment of pumps from Block 1 to Block 2, $t(46) = 4.56$, $p < 0.001$, and from Block 1 to Block 3, $t(46) = 4.60$, $p < 0.001$. However, there was no difference between Block 2 and 3, $t(46) = 0.74$, $p = 0.463$. Further, the significant main effect of *Social Anxiety* revealed that high socially anxious individuals inflated the balloon less across the entire task, $F(1, 45) = 11.38$, $p = 0.002$, $\eta_p^2 = 0.20$. In addition, there was no significant interaction between *Social Anxiety* and *Block*, $F(2, 90) = 0.98$, $p = 378$, $\eta_p^2 = 0.02$.

To summarize, learning might have taken place in the first trials of the *eBART*. Furthermore, when being stressed, low socially anxious individuals inflated the balloon more and learned to adapt their behavior over the course of the task. High socially anxious participants remained risk-averse regardless of whether they were exposed to stress or not.

Losses Due to Risk Avoidance

We analyzed differences between high and low socially anxious individuals in the amount of money that they earned across the task. The 2 × 2 × 3 ANOVA showed a significant main effect of *Block*, $F(2, 166) = 5.45$, $p = 0.005$, $\eta_p^2 = 0.06$, as well as a significant interaction between *Block* and *Stress*, $F(2, 166) = 4.10$, $p = 0.018$, $\eta_p^2 = 0.05$, and *Social Anxiety* and *Stress*, $F(1, 83) = 4.77$, $p = 0.032$, $\eta_p^2 = 0.05$. The other main effects and interactions did not reach significance, all Fs ≤ 2.35, all ps ≥ 0.099, all η_p^2 s ≤ 0.03.

Exploratory analyses of losses across the task

Without the social stressor, all individuals earned more money as the task proceeded, $F(2, 76) = 8.47$, $p < 0.001$, $\eta_p^2 = 0.18$. Furthermore, without stress, groups did not differ in how much money they earned, $F(1, 38) = 0.07$, $p = 0.792$, $\eta_p^2 = 0.00$. However, the increase in the money earned across the task varied as a function of *Social anxiety*, $F(2, 76) = 5.13$, $p = 0.009$, $\eta_p^2 = 0.12$.

To account for this interaction effect, we conducted a separate one-way ANOVA for high and low socially anxious individuals each. High socially anxious individuals learned to inflate the balloon more and increased their money earned as the task proceeded, $F(2, 36) = 12.85$, $p < 0.001$, $\eta_p^2 = 0.42$. This main effect was driven by a significant increase in money earned from Block 2 to 3, $t(18) = 4.97$, $p = 0.043$, but not from Block 1 to 2, $t(18) = 0.19$, $p = 0.850$. Interestingly, low socially anxious individuals did not earn more money across the task, $F(2, 40) = 0.31$, $p = 0.734$, $\eta_p^2 = 0.02$.

When they were stressed, high socially anxious individuals compared to low socially anxious individuals also earned less money across the task, which was indicated by the significant main effect of *Social anxiety*, $F(1, 45) = 10.11$, $p = 0.003$, $\eta_p^2 = 0.18$. There were no other significant differences, all Fs ≤ 2.12, all ps ≥ 0.127, all η_p^2 s ≤ 0.05.

To sum up, low socially anxious individuals took more risks under stress and earned more money across the *eBART*. High socially anxious individuals remained risk-averse and therefore earned less.

Decision Response Time

For the response time in individual decisions, the overall 2 × 2 × 3 ANOVA showed that all individuals regardless of their degree of social anxiety and being stressed inflated the balloon faster as the task proceeded, indicated by the significant main effect of *Block*, $F(2, 162) = 45.87$, $p < 0.001$, $\eta_p^2 = 0.36$. Furthermore, regardless of whether they were stressed, high socially anxious individuals took longer in their decisions to inflate the balloons across the entire task, $F(1, 81) = 4.57$, $p = 0.036$, $\eta_p^2 = 0.05$. There were no other significant effects, all Fs ≤ 2.12, all ps ≥ 0.127, all η_p^2 s ≤ 0.05.

Exploratory analysis of response times across the task

Without stress, all individuals reduced response times across trials in the task, $F(1.21, 43.45) = 19.89$, $p < 0.001$, $\eta_p^2 = 0.36$. This effect was due to early faster response times from Block 1 to 2, $t(37) = 4.58$, $p < 0.001$, but not from Block 2 to 3, $t(37) = 1.07$, $p = 0.292$. High and low socially anxious individuals did not differ in their response times while inflating the balloons during the *eBART*, $F(1, 36) = 0.28$, $p = 0.603$, $\eta_p^2 = 0.01$.

Under stress, all individuals inflated the balloons faster as the task proceeded, $F(1.56, 70.19) = 27.31$, $p < 0.001$, $\eta_p^2 = 0.38$. Their response time decreased from Block 1 to 2, $t(46) = 2.94$, $p = 0.005$, and from Block 2 to 3, $t(4) = 4.97$, $p < 0.001$. However, high socially anxious individuals responded more slowly across the whole task, $F(1, 45) = 8.57$, $p = 0.005$, $\eta_p^2 = 0.16$. Again, this effect was a result of faster responses in low socially anxious individuals. Furthermore, the response time did not differ as a function of social anxiety, $F(1, 45) = 8.57$, $p = 0.005$, $\eta_p^2 = 0.16$. Under stress, high socially anxious individuals responded as slowly as under no stress, whereas individuals low in social anxiety sped up their responses.

Risk Estimations: Questionnaire Scores

For the risk questionnaires, we conducted two 2 × 2 univariate ANOVAs with the factors *Stress* and *Social anxiety* and the risk estimates of socially relevant encounters and negative outcomes as dependent variables.

For risk estimates of socially relevant encounters, stress affected high and low socially anxious individuals equally: individuals in the stress condition gave lower risk estimates of socially relevant encounters than individuals in the no-stress condition, $F(1,83) = 4.79$, $p = 0.031$, $\eta_p^2 = 0.06$. Counterintuitively, high socially anxious compared to low socially anxious individuals gave lower risk estimates of such encounters, $F(1,83) = 4.94$, $p = 0.029$, $\eta_p^2 = 0.06$. There was

no significant interaction between *Stress* and *Social anxiety*, $F(1,83) = 0.33$, $p = 0.566$, $\eta_p^2 \leq 0.00$.

For risk estimates of negative outcomes of socially relevant encounters, there was only a significant main effect of *Social anxiety*, $F(1,83) = 19.26$, $p \leq 0.001$, $\eta_p^2 = 0.19$, in the way that high socially anxious rated the risk of negative outcomes of socially relevant encounters higher than low socially individuals. There were no other significant results, all Fs ≤ 3.78, all ps ≥ 0.055, all η_p^2 s ≤ 0.04.

To conclude, both stress and anxiety led to lower risk estimates of socially relevant encounters. Interestingly, the estimated risk of negative outcomes of such encounters was only affected by social anxiety in the way that high socially anxious rated the risk of negative outcomes higher than low socially anxious individuals.

DISCUSSION

Stress and anxiety can both affect human information processing (Ekman and Davidson, 1994; Lorian and Grisham, 2010; Starcke and Brand, 2016). In the present study, we systematically investigated the distinct effects of stress and anxiety on risk-taking behavior. We examined risk-taking in an adapted version of a well-established risk-taking paradigm for high and low socially anxious individuals, the social *eBART*. To induce stress, participants were led to anticipate a socially evaluative task.

The main results confirmed that stress made the difference: It induces low socially anxious individuals to take more risks – independently of socially relevant stimuli – and therefore earn more money. Without stress, there was no influence of either of the risk-taking parameters. Interestingly, stress and anxiety had opposite effects on the perceived risk of socially relevant events. On the one hand, stress resulted in higher risk estimates in socially relevant encounters. On the other hand, anxiety triggered lower risk estimates of such encounters. Whereas anxiety affected risk estimates of negative outcomes of socially relevant encounters, stress did not.

This is the second study that used the *eBART* as a measure for risk avoidance in anxiety when competing approach-avoidance tendencies are present (Hengen and Alpers, accepted pending revision). Our findings show that the type of fear might moderate the extent of avoidance in the task. In our first study with the *eBART*, spider-fearful individuals overall showed heightened risk avoidance in the *eBART,* even in the absence of fear-relevant stimuli. In the present study, this was not the case for high socially anxious individuals. When they were confronted with socially fear-relevant material in the *eBART*, they did not differ from low socially anxious participants. This is in line with previous research that shows findings with fear-relevant spider pictures cannot be generalized directly to facial expressions (Alpers et al., 2011; Diemer et al., 2015; Berdica et al., 2018). This may be due to the cognitive complexity of social anxiety compared to specific phobias. Facial expressions are of emotional relevance to all individuals and are processed preferentially in low anxious individuals as well as in high anxious ones (Alpers and Gerdes, 2007; Kavcioglu et al., 2019). Previous research highlighted the importance of the social context when using facial expressions for anxious individuals (Richards et al., 2007; Wieser and Brosch, 2012; Bublatzky and Alpers, 2017; Bublatzky et al., 2017).

In addition, our finding of more risk avoidance in high socially anxious individuals corresponds with self-reported risk aversion in other recent work (Stamatis et al., 2020). However, the same study reported a small but significant correlation between social anxiety and incentivized gambling attractiveness (especially so in a genetic risk group), which they interpret as a specific component of behavioral risk-taking (Stamatis et al., 2020). Although their task to assess gambling attractiveness addresses decision-making under risk as well, their task also differs from ours. Interestingly, Stamatis et al. (2020) found that high socially anxious individuals who were better able to estimate reward probabilities in the experiment took more risks. Because reward probabilities in the *BART* are not easily assessable (Lejuez et al., 2002; Hunt et al., 2005) this may contribute to the differences between their and our findings; only more research can resolve this issue.

In order to interpret the group differences, it is important to more closely consider characteristics of our low socially anxious control group. Because their mean scores on social anxiety were comparable to a representative German sample of healthy individuals (e.g., Sosic et al., 2008) we have no reason to assume that this group behaved differently from the norm. Importantly, their behavior is in line with previous research that indicates heightened risk-taking in non-anxious participants when being stressed (Porcelli and Delgado, 2009; Putman et al., 2010; Starcke and Brand, 2016). Thus, we consider the change in behavior that we observed in the low socially anxious group as a benchmark for the comparisons with the high socially anxious participants who clearly score higher in social anxiety than the normative sample (Sosic et al., 2008). Because we have presented theoretically supported hypotheses for highly anxious participants – that they are more avoidant than the norm – we interpret the group differences as a result of their social anxiety.

Different from other decision-making tasks (e.g., *IGT*; Bechara et al., 1994), heightened risk-taking behavior in the *eBART*, as in the original task (Lejuez et al., 2002), is adaptive and riskier decisions are rewarded (up to a certain extent). In addition, the fixed probability schedule gives participants the opportunity to learn from experience and to adapt their behavior to more risk-taking. Interestingly, as our findings indicated, learning in the *eBART* took place in the first third of the task and remained stable. However, stress only affects the learning curve of low socially anxious individuals as they adapted their behavior to the task more quickly and earned more money. This finding is in line with previous studies that show how individuals under stress might focus more on rewards than losses (Petzold et al., 2010). However, when being dispositionally anxious, the adaptive effects of stress in tasks that reward risk-taking is undermined. As in previous studies, anxiety might mitigate the reward sensitivity and consequently result in dysfunctional reward processing (Held-Poschardt et al., 2018).

As stress and anxiety are known to influence information processing, we assessed response times as an indirect measure of decisional conflict in this study. Especially when decisions

include emotionally relevant options to choose from, efficient processing of rewards and losses is necessary to adapt one's behavior to the demands of the task at hand (Botvinick et al., 2001; Larson et al., 2013). In our study, this should have been particularly the case for high socially anxious individuals when they are confronted with fear-relevant stimuli. Interestingly, only stress affected the processing of the conflict between approach and avoidance such that low socially anxious individuals responded faster to inflate the balloon than high socially anxious individuals. However, this finding must be interpreted cautiously, as response time is only an indirect measure of information processing. Contrary to conflict-driven tasks, the *eBART* does not require faster response times as an index of task performance. Thus, response times in this paradigm might not be an adequate representation of deficient conflict processing. Slowed responses also may indicate a stronger approach-avoidance conflict as high socially anxious individuals might have evaluated costs and benefits more intensively.

Previous studies have shown that both acute stress (Starcke and Brand, 2016) and anxiety as a trait (Hengen and Alpers, 2019) affect risk perception. However, the systematic investigation of the distinct aspect of fear-relevant risk estimations has indicated that stress and anxiety have opposite effects. Stress prompts heightened estimates of socially relevant encounters; high anxious individuals merely overestimated the risk of negative outcomes of such encounters. Our findings again emphasize the importance of systematically investigating the distinct components of risk perception, namely emotionally relevant encounters and the negative outcomes of such encounters, and to consider the distinct effects of stress as well as anxiety. Simultaneously, we replicated findings of a recent study (Hengen and Alpers, 2019) and showed that high anxious individuals only gave higher risk estimates of the negative outcomes.

There are some limitations to consider. First, we do not have strong evidence that our stress induction was sufficient to induce heightened arousal levels. We observed that especially high socially anxious individuals in our stress condition had elevated levels of state anxiety at the baseline. Thus, the effects in state anxiety might not have been caused by our stress induction. One reason why the stress effect did not turn out more clearly may have been that all participants in the high socially anxious group were anxious about the stress induction. This was because all individuals received an unspecific information about an upcoming public speech in the study information and informed consent at the very beginning of the study. Thus, this announcement may have diminished the effect of the actual intervention and rendered the three-way interaction between *Stress*, *Time* and *Group* non-significant. Indeed, high socially anxious individuals in our sample report higher state anxiety at both time points. In addition, and more importantly, the STAI-S may not have been most sensitive measurement to specifically assess current arousal (Balsamo et al., 2013). Thus, although the manipulation check was not unambiguous, the pattern of the main outcomes was. The experimental data clearly show differences in form of significant two-way interactions between stress conditions and anxiety groups. Because we have no reason to believe that these effects were driven by anything else but the experimental manipulation, we are convinced that our stress induction was sufficiently effective. However, we recommend more specific measures to assess the effectiveness of the manipulation in future studies.

Third, we need to look at the assignment of the participants to the stress and non-stress conditions. Due to pragmatic considerations concerning recruitment (e.g., word of mouth between participants in the stress and no- stress condition), we first assessed the non-stress condition and then the stress condition. One may thus argue that stress effects might be due to *a priori* differences in the samples. However, as we did check and control for such differences, this does not appear to be a problem. Furthermore, regarding clinical implications, we only assessed individuals with variations of social anxiety and no clinical sample. However, our high anxious sample had values in the same range as patients with a social anxiety disorder (Connor et al., 2000). Consequently, our findings may be generalized to socially phobic individuals. Last, a balloon explosion in the *eBART* resulted in a monetary loss as well as in the appearance of a fear-relevant stimulus. Therefore, more risk-averse behavior under stress might be the result of heightened sensitivity to potential losses (Hartley and Phelps, 2012). However, other findings of support the idea that risk aversion triggers avoidance behavior under uncertain conditions, not the sensitivity to potential losses (Charpentier et al., 2017).

CONCLUSION

Although stress and anxiety are important affective states that play a key role in many mental disorders (Ekman and Davidson, 1994), little is known about their distinct effects. This study systematically examined these meaningful constructs in a novel decision-making paradigm that models competing approach-avoidance conflicts. Our findings support the idea that anxiety and stress have interacting effects on behavior. We conclude that anxious individuals do not always evaluate risks in a dysfunctional way. In the context that we examined, their avoidance remained at the same level even when this incurred costs for them; in this they differed from the low anxious control participants.

DATA AVAILABILITY STATEMENT

The datasets analyzed for this study is stored on MADATA-Mannheim Research Data Repository (doi: 10.7801/340).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the University of Mannheim. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

KH and GA contributed to the design and implementation of the research, analysis of the results, and writing of the manuscript. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Role of Cortisol and Testosterone in Risky Decision-Making: Deciphering Male Decision-Making in the Iowa Gambling Task

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Despite the widely observed high risk-taking behaviors in males, studies using the Iowa gambling task (IGT) have suggested that males choose safe long-term rewards over risky short-term rewards. The role of sex and stress hormones in male decision-making is examined in the initial uncertainty and the latter risk phase of the IGT. The task was tested at peak hormone activity, with breath counting to facilitate cortisol regulation and its cognitive benefits. Results from IGT decision-making before and after counting with saliva samples from two all-male groups (breath *vs*. number counting) indicated that cortisol declined independent of counting. IGT decision-making showed phase-specific malleability: alteration in the uncertainty phase and stability in the risk phase. Working memory showed alteration, whereas inhibition task performance remained stable, potentially aligning with the phase-specific demands of working memory and inhibition. The results of hierarchical regression for the uncertainty and risk trials indicated that testosterone improved the model fit, cortisol was detrimental for decision-making in uncertainty, and decision-making in the risk trials was benefitted by testosterone. Cortisol regulation accentuated hormones' phase-specific effects on decision-making. Aligned with the dual-hormone hypothesis, sex, and stress hormones might jointly regulate male long-term decision-making in the IGT.

Keywords: Iowa gambling task, risk, male decision making, stress-cortisol, testosterone, dual hormone hypothesis

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INTRODUCTION

In general, males display higher risk-taking behaviors than do females (Byrnes et al., 1999), while females display more risk aversion than do males (Charness and Gneezy, 2012). However, in a widely used decision-making task, the Iowa gambling task (IGT; Bechara et al., 1994), males outperform females by choosing safe long-term rewards over risky short-term rewards (Bolla et al., 2004; see review in van den Bos et al., 2013). Unknown to the decision maker, the task involves 100 trials of picking one card after another (forming five blocks of 20 trials) by deciding between four decks of cards labeled A, B, C, and D. Each card pick results in a reward and, at times, is accompanied by occasional losses. Decision-making is carried out based on intertemporality; that is, more cards are drawn from the two safe/good decks, C and D, that give a small immediate reward (50 points), but result in long-term net gain, whereas fewer cards are picked from risky/bad decks, A and B, that give large immediate rewards (100 points), but result in long-term net loss. In other

words, deck cards (C and D) are safe/good in the long term because, although they give small immediate rewards of 50 points for each of the card picked, 50% of the cards drawn from deck C have a loss in the range of 25–75 points, and 10% of cards drawn from deck D have a loss of 250 points; therefore, drawing 10 cards from decks C and D results in a long-term net gain of 250 points. On the other hand, every card drawn from the risky/bad decks (A and B) is risky because they give a large immediate reward (100 points), but 50% of the cards drawn from deck A give a loss in the range of 75–100 points, and 10% of the cards drawn from deck B give a loss of 1,250 points; therefore, drawing 10 cards from the risky decks results in a long-term net loss of 250 points. Furthermore, the outcomes associated with the decks are largely unknown in the initial IGT phase (trials 1–40, blocks 1 and 2), and this phase is characterized by uncertainty, whereas, as the payoffs associated with each of the four decks become known with task progression (trials 60–100, blocks 4 and 5), the later trials are characterized as decision-making under risk (Brand et al., 2007). Long-term decision-making is prominent in the risk phase of male IGT decision-making (Stanton et al., 2011; van den Bos et al., 2013; Evans and Hampson, 2014). Male preference for long-term decision-making is observed in countries that vary in socioeconomic and gender inequality (Singh et al., 2020), pointing toward a potential biological basis of male IGT decision-making and risk-taking.

Hormones might play a critical role in male decision-making in the IGT; for instance, a prenatal male sex hormone, testosterone influences male risk-taking in the IGT (Reavis and Overman, 2001; d'Acremont and Van der Linden, 2006; van den Bos et al., 2013; Evans and Hampson, 2014), impairing decision-making in the IGT (Reavis and Overman, 2001; Stanton et al., 2011; Evans and Hampson, 2014). Although testosterone is higher in males compared to females (Southren et al., 1965), males make more long-term decisions in the IGT (van den Bos et al., 2013), and long-term decision-making is prominent when male testosterone is low (Stanton et al., 2011). Testosterone's effects on male long-term decision-making might reflect a regulatory control, and one likely factor might be the stress hormone cortisol, which might inhibit testosterone's effects on male IGT decision-making. Male risk-taking is governed by testosterone's and cortisol's combined effects (Mehta and Josephs, 2010). Since cortisol stress triggers motor impulsivity and a "fight-or-flight" response in males (Taylor et al., 2000), its regulation might play a role in testosterone's effects on risk-taking in the IGT. For instance, cortisol impairs long-term decision-making in males (Preston et al., 2007) by increasing risk-taking in IGT decision-making (Simonovic et al., 2017). Cortisol regulation might aid in testosterone regulation for keeping male risk-taking under control; that is, the dual regulation of cortisol and testosterone might contribute to male IGT decision-making.

Furthermore, the effects of cortisol and testosterone might differ in the two phases of male IGT decision-making (uncertainty and risk phases). For instance, since cortisol impairs working memory and the impairment is more detrimental to male IGT decision makers (Preston et al., 2007; van den Bos et al., 2009), cortisol's effect might be more prominent in the uncertainty phase of the IGT. Furthermore, cortisol elevation impaired male IGT decision-making, the most prominent impairment being in the uncertainty phase (Figure 2A in van den Bos et al., 2009), and the deficit was possibly due to cortisol impairment of higher working memory demands (Bagneux et al., 2013). Cortisol's effect on male IGT decision-making in the risk phase is less clear: one study indicated that cortisol stress impaired male decision-making in the risk phase (Table 3 in Preston et al., 2007), while in another study, cortisol stress improved decision-making in the risk phase (fourth block; van den Bos et al., 2009). Unlike cortisol's effect in the risk phase, testosterone's most prominent effect is more clearly observed in the IGT risk phase (Evans and Hampson, 2014). Decision-making in the uncertainty phase was least affected by high testosterone; in contrast, decision-making in the risk phase was impaired by high testosterone and was benefited by low testosterone (Figure 2 in Stanton et al., 2011), suggesting that testosterone might influence male decision-making in the risk phase of the task.

To examine the phase-specific effects of testosterone and cortisol, IGT task performance was assessed during the morning period when testosterone levels are high (Kriegsfeld et al., 2002), and post-awakening cortisol activity as a reliable biomarker (Pruessner et al., 1997) reflects the peak cortisol elevation and decline (Kalsbeek et al., 2012). Morning cortisol elevation reflects post-awakening activation response, whereas post-awakening cortisol decline reflects cortisol regulation (Adam et al., 2017). Others have employed psychosocial stress (using the Trier social stress test) for inducing cortisol elevation *via* social stress to examine its influences on IGT decision-making (e.g., van den Bos et al., 2009; Wemm and Wulfert, 2017). However, inducting social stress shows heterogeneous cortisol response attributed to the procedural variations in inducing social stress (Liu et al., 2017). Therefore, awakening cortisol provided a naturally occurring diurnal measure of cortisol response and regulation. Apart from diurnal regulation of cortisol, breath counting was used to enhance cortisol regulation (Ma et al., 2017) due to its working memory benefits (Levinson et al., 2014) and was compared with number counting that provided no cortisol-reducing or working memory benefits (Garavan, 1998). A consistent version of IGT at baseline and retest provided task repetition that benefits IGT decision-making in males (Bechara et al., 2000; Overman and Pierce, 2013). Cortisol and testosterone were expected to account for male IGT decision-making in a phase-specific manner, with cortisol regulation enhancing the hormones' phase-specific effects.

MATERIALS AND METHODS

Participants

Forty-two healthy right-handed male participants (mean age = 23.37 years, SD = 3.89) volunteered for the study. A power analysis (G power) suggested that using a sample size of 36 would be sufficient to reach the desired power (0.95) and large effect size (0.70). The participants were recruited as part of a study on mind, body, and cognition. The inclusion criteria were as follows: >18 years old, medication-free, no history of psychiatric or respiratory illness, and willing to

comply with the protocol for saliva sample analysis (i.e., early morning empty stomach collection of the saliva sample before and after the counting procedure). Participants in the two groups of counting type were matched in terms of sex (all male), age (breath counting = 22.39 years, number counting = 23.82 years), handedness (right-handed), education (undergraduate engineering program), and comfort with the English language.

Measures

Psychology Experiment Building Language

The psychology experiment building language was used to assess decision-making in the IGT. This task assesses decision-making where the participant has to choose between short-term, risky card decks (decks A and B) and long-term, safe reward decks (decks C and D). Unknown to the participant, the task consists of 100 trials (1 trial = 1 card drawn, 20 trials = 1 block). Long-term decision-making is reflected in a score that is calculated by taking the number of cards drawn from the safe decks minus those drawn from the risky decks [(C + D) − (A + B), calculated for 20 trials]. The net score of the first 40 trials reflects decision-making in the uncertainty phase because the choice outcomes are relatively unknown in the initial trials; the net score of the last 40 trials reflects decision-making in the risk phase because the choice outcomes are known in the later trials (Brand et al., 2007). A high net score reflects drawing fewer cards from the risky immediate reward decks and drawing more cards from the safe reward decks. Decision-making net scores were examined before and after counting (IGT 1 and IGT 2). Unknown to the participants, the IGT version was kept consistent for the two sessions. High variability in decision-making is observed despite increased task exposure (e.g., Buelow et al., 2013; Lin et al., 2013; Bull et al., 2015). Nearly 54% of the participants formed stable preferences within the 100 trials, whereas 28% did not develop a preference even after 200 trials (Bull et al., 2015). The complex nature of the IGT makes it suitable for maintaining a consistent IGT version in two testing sessions.

Cognitive and Impulsivity Measures

Because risk-taking in the IGT reflects cognitive and motor impulsivity (Bechara et al., 2000), two additional measures were included: (a) the digit span task (forward; Wechsler, 2008) that assesses the cognitive component, specifically working memory, by asking participants to recall digits (1–9), presented in increasing order (poor performance in the digit span task co-occurs with poor IGT decision-making; e.g., Zhou and Ni, 2017), and (b) the Simon task (Simon, 1990) that assesses motor impulsivity due to stimulus–response incongruence. A stimulus (colored circle) appears and the participant responds *via* button press (red = left side, blue = right side). It is observed that the response time is higher when the stimulus color is incongruent to the response side (i.e., red color stimulus appears on the right side). Simon task performance requires inhibiting the response that is based on the target location. Males show faster motor inhibition in the Simon task (Evans and Hampson, 2015), and motor inhibition seems to facilitate regulatory control in IGT decision-making (van den Wildenberg and Crone, 2005). The digit span task assessed the cognitive component and the Simon task assessed the motor component of impulsivity. The tasks were assessed before and after counting, maintaining consistency, and order of the tasks on the two testing occasions.

Procedure

The ethics committee of the institution approved the protocol, and all participants provided signed informed consent. Participants received payment for participation at the end of the study (500 INR). All research was carried out in accord with the principles expressed in the Declaration of Helsinki. Because cortisol rises to 50% within 30 min of awakening and starts to decline thereafter, but remains elevated for more than 60 min (Wust et al., 2000), the participants were requested to arrive within 30 min of awakening on an empty stomach (the study venue was close to the male hostel to enable timely arrival, and the participants were provided breakfast at the end of the session). The study followed regulations for saliva testing; for example, all participants were tested within 45 min of awakening to obtain peak basal hormone levels and within the duration of early morning cortisol surge (7:00–10:00 a.m.), ensuring that the tests were carried out on an empty stomach. Participants were tested in groups of 6−10 and were assigned to two groups (counting type) using an odd–even scheme. An equal number of participants were tested in the two groups in a day, and the same laboratory space was used to ensure homogeneity in the acclimatization of both groups. After obtaining demographic information, the participants performed the digit span task, followed by the Simon task and the IGT (IGT 1). After this baseline assessment of the tasks, the participants provided their first saliva sample (saliva T1) and proceeded to the counting session. They were assigned to either one of the two counting groups using an odd–even scheme (e.g., odd number participant assigned to the breath counting group and an even number participant assigned to the number counting group; see counting instructions and study design flow in Supporting Information). All participants gave saliva samples and performed the IGT and other tasks before and after counting. Task performance was examined under peak concentrations of the hormones (cortisol and testosterone) and cortisol decline. This procedure is similar to that of Stauble et al. (2013), where task assessment (T1) was followed by a saliva sample pre- and post-stress alteration (i.e., counting in the present study), followed by an assessment of task performance (T2). The participants were seated on mats and performed mental counting as per their assigned condition (i.e., breathe or number counting). Immediately after the counting session, the participants provided the second saliva sample (saliva T2) and performed the working memory task and the Simon task with the IGT (IGT 2; see **Supplementary Figure 1**). The participants completed the protocol and were remunerated for their participation at the end of the study.

Saliva Sample

Each participant provided saliva samples on an empty stomach, and the samples were collected between 7:00 and 10:00 a.m. Analyses of the first two saliva samples, before and after the counting procedure (breath *vs.* number counting), are reported.

Each sample of up to 3 ml was collected in separate sterilized vials. The vials were labeled and stored in a cold storage box. All vials in the cold storage box were transported to a pathology laboratory within 3.5 h, where saliva analysis was performed according to the guidelines set forth by Schultheiss and Stanton (2009). Samples were stored at −20°C until the assay was performed. For the analysis, all samples were removed from the freezer, allowed to thaw completely at room temperature, and then thoroughly mixed. An aliquot of each sample was placed into a centrifuge for 10 min at 2,000 × *g* in an attempt to produce a clean supernatant, which was then used for examination. The samples were centrifuged according to the guidelines for electrochemiluminescence immunoassays. According to the manufacturer, the detection range for cortisol was 0.20–75 ng/dl, while the coefficient of variation was 6.5%. The range for testosterone was 10–1,500 ng/dl (0.35–52.1 nmol/L), while the coefficient of variation was 7.6%. The cortisol concentrations (in micrograms per deciliter) displayed a non-normal distribution, so a log10 transformation was performed. Cortisol levels at T1 and T2, average cortisol level (average of T1 and T2), and cortisol decline (T1 minus T2), as cortisol measures, were used for analysis. Testosterone was analyzed from the first saliva sample and was non-normally distributed and log-transformed (log10; Stanton et al., 2011). The data of two participants were excluded based on the outlier detection method of 3 standard deviation (mean ± 3 SD; Mehta et al., 2015): one participant was excluded based on testosterone (mean = 2.1018, SD = 0.55626, 3 SD = 1.66878, range = 0.43302–3.77058, and outlier = −0.10) and another participant excluded based on the difference in cortisol (cortisol T1 minus cortisol T2; mean = 0.0730, SD = 0.12404, 3 SD = 0.37212, range = −0.29912–0.44512, and outlier = 0.53).

Statistical Analysis

All data were imported into statistical software for social sciences version 18. The threshold for significance was 0.05. A mixed model analysis of variance used within-subjects variables (e.g., pre- and post-counting cortisol and pre- and post-counting task performance) and between-subjects variables (e.g., counting type) to examine changes in cortisol and IGT decision-making and other measures (working memory and inhibition tasks). Participants gave saliva samples and performed the IGT task before and after counting. Counting type was the between-group variable (i.e., pre- and post-counting IGT performance was compared between the two groups, breath counting and number counting) and repeated saliva samples and pre–post IGT task scores were treated as repeated measures or within-subjects measures (i.e., these measures were assessed repeatedly, providing a within-subject comparison). In support of a recent call to report statistical results of hormone data that enable examining the effect of outlier exclusion (Pollet and van der Meij, 2017), the analyses are repeated with outlier exclusion. Four hierarchical regression analyses were used to understand how a change in IGT choices might be accounted for by hormones. The contributions of cortisol, testosterone, and their interaction to a change in IGT decision-making were examined. The cortisol and testosterone values were mean-centered, and two separate interaction terms were derived for cortisol and testosterone interaction: (a) average cortisol × testosterone and (b) cortisol decline × testosterone. The first analysis aimed to predict change in decision-making in the uncertainty phase: average cortisol was entered at step 1, testosterone was entered at step 2, and cortisol × testosterone interaction was entered at step 3. A similar analysis was used for decision-making in the risk phase. Next, two analyses were performed using cortisol regulation (cortisol decline) at step 1, testosterone at step 2, and cortisol × testosterone interaction at step 3 for the uncertainty and the risk phase. Bootstrapped coefficients with 95% confidence intervals (CIs) and bias-corrected values (2,000 samples) are reported (significance level reported for 0.05, and *p* values less than 0.10 were reported to indicate a trend).

RESULTS

Cortisol decline was analyzed using pre- and post-counting cortisol levels as a within-subjects variable and counting type (breath and number) as a between-subjects variable. The main effect of cortisol was significant [$F(1, 40) = 15.27$, $p < 0.0001$, partial $\eta^2 = 0.28$], suggesting cortisol decline (mean 1 = −0.49, mean 2 = −0.56). The two-way interaction of cortisol and counting type was not significant, indicating that counting type had no effect on cortisol decline [$F(1, 40) = 1.79$, $p = 0.19$].

Alteration in Decision-Making and Working Memory

Decision-making in the uncertainty trials (trials 1–40 for IGT 1 and IGT 2) was a within-subjects variable and counting type was the between-subjects variable. The results showed that the main effect of the IGT scores in the uncertainty phase was significant [$F(1, 40) = 4.37$, $p = 0.043$, partial $\eta^2 = 0.10$], indicating increased long-term decision-making (mean 1 = −0.86, mean 2 = 3.13). The non-significant two-way interaction suggested that the change was unaffected by counting type [$F(1, 40) = 0.003$, $p = 0.96$]. The results for decision-making in the risk phase (net scores for trials 60–100 for IGT 1 and IGT 2) showed that the main effect was non-significant [$F(1, 40) = 1.62$, $p = 0.211$] and decision-making in the risk phase remained unchanged (mean 1 = 8.82, mean 2 = 6.18). Two-way interaction with counting type was not significant [$F(1, 40) = 1.50$, $p = 0.23$].

The malleability of decision-making in the uncertainty trials might be due to the greater demands on working memory in the uncertainty phase. Aligned with this expectation, the results from the working memory task performance (digit span task) showed a significant main effect of task performance [$F(1, 40) = 9.42$, $p = 0.004$, partial $\eta^2 = 0.19$], suggesting improved working memory at retest (T2; mean 1 = 9.48, mean 2 = 10.97). Counting type had no effect [$F(1, 40) = 0.24$, $p = 0.62$]. Unlike working memory performance, the main effect of the Simon task scores was not significant [$F(1, 40) = 0.10$, $p = 0.76$], suggesting that inhibition did not change (mean 1 = 134.78, mean 2 = 134.98). The two-way interaction of counting type and Simon task scores was significant at the trend level [$F(1, 40) = 3.05$, $p = 0.08$, partial $\eta^2 = 0.07$]. Breath counting marginally improved inhibition

(mean 1 = 133.25, mean 2 = 134.55), and number counting lowered it (mean 1 = 136.32, mean 2 = 135.41). The results indicated post-awakening cortisol decline, and decision-making in the uncertainty phase showed improvement, potentially due to working memory.

Effects of Cortisol–Testosterone on IGT Decision-Making

Four hierarchical regressions were used to examine the effects of cortisol, testosterone, and their interaction on decision-making (IGT net scores) in the uncertainty and the risk trials. Average cortisol (average of cortisol at T1 and T2), cortisol decline (cortisol at T1 minus T2), and testosterone were mean-centered. Average cortisol was uncorrelated with cortisol decline ($p > 0.05$), cortisol decline was uncorrelated with testosterone ($p > 0.05$), like others (Mehta and Josephs, 2010), and average cortisol and testosterone were marginally correlated ($r = 0.29$, $p = 0.06$). Two interaction terms were derived from cortisol and testosterone: (a) average cortisol × testosterone and (b) cortisol decline × testosterone. Counting type had no effect on the measures of interest and was excluded. The first two regressions used cortisol (average of cortisol) at step 1, testosterone at step 2, and cortisol and testosterone interaction was entered at step 3 to predict decision-making in the uncertainty phase and the risk phase examined separately (see the results in **Table 1**). Bootstrapped CIs with bias-corrected estimates are reported (2,000 samples).

The results for the uncertainty phase (regression 1) indicated that cortisol did not account for IGT decision-making (step 1) and testosterone (step 2) improved the model at trend-level significance [$F(2, 39) = 2.74$, $p = 0.08$], explaining 11% of the variance in decision-making in uncertainty ($\Delta R^2 = 0.11$, $p = 0.04$). The beta values indicated that cortisol impaired decision-making in the uncertainty trials [$B = -13.41$, $p = 0.04$, bias-corrected and accelerated (BCa) CI = −27.46 to −2.80], and testosterone's effect was non-significant. Cortisol and testosterone interaction (step 3) did not improve the model fit ($p = 0.15$). The coefficient for cortisol indicated that it might be detrimental for decision-making in the uncertainty trials ($B = -12.83$, $p = 0.04$, BCa CI = −25.10 to −3.72). Testosterone's effect and the effect of cortisol × testosterone interaction were non-significant.

The results for decision-making in the risk phase (regression 2) indicated that average cortisol did not account for decision-making (step 1) and testosterone (step 2) improved the model fit at trend-level significance [$F(2, 39) = 2.86$, $p = 0.07$], explaining 12% of the variance in decision-making ($\Delta R^2 = 0.12$, $p = 0.03$). The coefficients indicated that cortisol was non-significant, whereas testosterone improved decision-making in the risk phase ($B = 10.76$, $p = 0.03$, BCa CI = 1.30–18.60). The interaction term (step 3) did not improve the model fit ($p = 0.15$), and the coefficients indicated that cortisol's effect was non-significant. Only testosterone improved decision-making in the risk trials ($B = 10.90$, $p = 0.03$, BCa CI = 0.02–19.34). The interaction of cortisol and testosterone was non-significant.

To examine the effect of cortisol regulation on male decision-making; cortisol decline was entered at step 1, testosterone at step 2, and the interaction of cortisol decline and testosterone was entered at step 3. Two separate regressions were carried out for decision-making in the uncertainty and risk phases (see results in **Table 2**). The results for the uncertainty phase indicated that cortisol decline (step 1) failed to account for decision-making. Adding testosterone (step 2) or the interaction of cortisol and testosterone (step 3) did not have a significant effect on the model fit (all $p > 0.10$). Beta values indicated that cortisol decline, testosterone, and their interaction did not influence decision-making in the uncertainty trials. Interestingly, cortisol's negative effect on decision-making in uncertainty was not observed. Perhaps, cortisol's impairment of decision-making in uncertainty might be eliminated with cortisol regulation.

The results for the risk phase indicated that cortisol decline (step 1) did not account for decision-making and testosterone (step 2) improved the model fit at trend-level significance [$F(2, 39) = 2.86$, $p = 0.07$], explaining 13% of the variance in decision-making ($\Delta R^2 = 0.13$, $p = 0.02$). The coefficients indicated that cortisol decline did not have an effect and testosterone significantly improved decision-making ($B = 10.81$, $p = 0.04$, BCa CI = 1.97–17.67). Adding cortisol decline and testosterone interaction (step 3) improved the model fit significantly [$F(2, 39) = 4.02$, $p = 0.01$), explaining 12% of the variance in decision-making ($\Delta R^2 = 0.12$, $p = 0.02$). The coefficients indicated that cortisol decline had no effect on decision-making ($p > 0.10$) and testosterone improved decision-making in the risk phase ($B = 7.59$, $p = 0.06$, BCa CI = 0.61–12.61). Although the coefficients for the interaction of cortisol decline and testosterone showed significant improvement in decision-making in risk ($B = 87.18$, $p = 0.03$, BCa CI = −143.57–185.72), the CIs overlapped with zero, suggesting that the interaction effect might not be robust. A joint regulation of cortisol and testosterone might have influenced male risk-taking; therefore, the interaction of cortisol decline and testosterone was further examined to determine whether testosterone's (predictor) effect on decision-making in the risk phase (dependent variable) varied with high and low levels of cortisol regulation (median-based cutoffs). The analysis indicated that testosterone improved decision-making in high cortisol decline ($\beta = 13.79$, $p = 0.017$), but testosterone's effect on decision-making in low cortisol decline was non-significant ($p > 0.10$). High cortisol regulation (decline) might contribute to testosterone regulation and benefit male long-term decision-making in the risk phase (see **Figure 1**).

Together, the results of four regressions indicate that cortisol and testosterone might account for male decision-making in the IGT. Cortisol might impair decision-making in the uncertainty trials (regression 1), whereas testosterone might improve decision-making in the risk trials (regression 2). Cortisol regulation (decline) might eliminate the detrimental effects of cortisol on decision-making in the uncertainty trials (regression 3), and high cortisol regulation might aid testosterone's effects to improve long-term decision-making in the risk trials (regression 4).

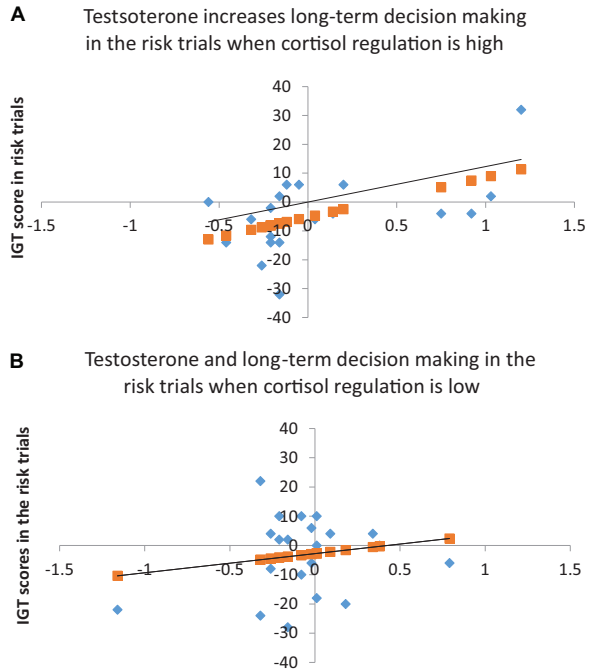

FIGURE 1 | (A) Testosterone and long-term decision-making in the risk trials when cortisol regulation is high ($R^2 = 0.29$, $p < 0.05$). **(B)** Testosterone and long-term decision-making in the risk trials for low cortisol regulation ($R^2 = 0.03$, $p > 0.05$). Linear regression line shows the predicted long-term choices in the risk trial (*Y*).

DISCUSSION

The study aimed to understand the male low-risk, long-term decision-making in the IGT by examining the potential contributions of cortisol, testosterone, and their interaction to uncertainty and risk as two phases of the IGT. Decision-making was assessed at the circadian point of peak testosterone and high cortisol regulation (i.e., post-awakening cortisol elevation and decline) using breath counting as a cortisol regulation measure with cognitive benefits. The results confirmed cortisol decline in the all-male sample of the present study. Blunted cortisol decline in healthy participants is characteristic of early life stressors (Kuras et al., 2017) and is considered particularly maladaptive in males (Carol et al., 2016). Furthermore, the results indicated that cortisol decline was independent of counting type. Others have also observed that, contrary to expectations, a breathing-based intervention failed to influence cortisol reduction (Engert et al., 2017). Cortisol regulation in male IGT decision makers might not be malleable to short-term interventions such as breath counting. Similarly, IGT decision-making in uncertainty and risk was unaffected by counting type, and the results align with an earlier observation of male IGT decision-making being non-malleable to short-term interventions (Singh and Mutreja, 2020).

Decision-making was altered in a phase-specific manner, and the results indicated that decision-making was altered in the uncertainty phase, whereas it remained stable in the risk phase. Working memory task performance showed alterations, whereas inhibition task performance remained consistent. The cognitive demands of decision-making in the uncertainty phase are different from those in the risk phase, and the results from the working memory task align with this assumption. The change in the uncertainty phase might be linked to working memory (digit span task), indicating that decision-making in uncertainty relies on working memory (Bagneux et al., 2013). Furthermore, working memory depletion influenced IGT decision-making (Hinson et al., 2002), which impaired decision-making only in healthy male controls (compared to substance dependence and conduct; Fridberg et al., 2013). Male decision-making in the uncertainty trials might be sensitive to cortisol-induced alterations in working memory (Preston et al., 2007; van den Bos et al., 2009).

Unlike the malleability in decision-making that was observed in the uncertainty phase, the results for the risk phase showed consistency in long-term decision-making. Male long-term decision-making is most prominent in the risk phase (e.g., van den Bos et al., 2009, 2013; Stanton et al., 2011; Evans and Hampson, 2014), suggesting that males tend to choose consistent long-term rewards in the risk phase rather than in the uncertainty phase. Others have also alluded to male decision-making being most resistant to change in the risk phase of the IGT (Buelow and Barnhart, 2018). Male long-term decision-making in the risk phase and motor inhibition in the Simon task performance were unaltered, indicating a possible link between inhibitory control and decision-making in the risk phase. Together, the results indicate a possible phase-specific distinction in male IGT decision-making: decision-making varied in the uncertainty trials potentially due to the link between cortisol activity and the working memory demands of the uncertainty phase, whereas decision-making remained consistent in the risk trials potentially due to the inhibitory demands of the risk phase.

Next, hierarchical regressions examined the effects of cortisol (cortisol average and cortisol decline), testosterone, and their interaction on male IGT decision-making in the uncertainty and risk phases. The results for the uncertainty trials indicated that cortisol did not account for IGT decision-making (step 1) and testosterone improved the model's explanatory power (step 2), accounting for 11% decision-making in the uncertainty phase, and only cortisol's effect was significant. The coefficients suggested that cortisol impaired decision-making in the uncertainty trials. These results align with those of other reports of cortisol impairment in male decision-making (Preston et al., 2007; van den Bos et al., 2009). Testosterone might improve our understanding of cortisol impairment in male decision-making in the uncertainty phase. The results could be attributed to the greater demand of long decision-making for cognitive resources (Lin et al., 2007; Singh and Khan, 2009), which aligns with other observations of specifically the uncertainty phase having higher demands on cognitive resources (Bagneux et al., 2013). Cortisol-impaired decision-making in the uncertainty phase suggests that IGT's uncertainty and risk phases pose distinct demands, and testosterone might potentially account for the cortisol-induced impairment of male decision-making in the uncertainty trials.

TABLE 1 | Results of hierarchical regression using average cortisol (step 1), testosterone (step 2), and average cortisol × testosterone (step 3) to explain Iowa gambling task (IGT) decision-making in the uncertainty and risk phases.

Steps and predictors		R^2	F	ΔR^2	ΔF	B	SE	BCa 95% CI
DV = Uncertainty trials								
1	CORT avg.	0.02	0.93 (1, 39)	0.02	0.91	−8.09	7.45	−23.33 to 13.27
2	CORT avg.	0.13	2.74 (2, 39)*	0.11	4.46**	−13.41**	6.85	**−27.46 to −2.80**
	Testosterone					9.30	6.46	-5.23 to 19.07
3	CORT avg.	0.14	1.88 (3, 39)	0.01	0.26	−12.83**	6.51	**−25.10 to −3.72**
	Testosterone					10.20	7.78	−4.53 to 21.95
	CORT avg. × testosterone					−10.70	33.92	−66.01 to 73.99
DV = Risk trials								
1	CORT avg.	0.01	0.46 (1, 39)	0.01	0.46	6.16	10.00	−9.46 to 37.40
2	CORT avg.	0.13	2.86 (2, 39)*	0.12	5.20**	0.00	8.52	−14.92 to 28.55
	Testosterone					10.76**	5.03	**1.30–18.60**
3	CORT avg.	0.13	1.86 (3, 39)	0.00	0.01	0.09	9.73	−16.61 to 37.81
	Testosterone					10.90**	5.43	**0.02–19.34**
	CORT avg. × testosterone					−1.66	24.93	−43.41 to 46.25

Transformed and mean-centered predictors were entered in three steps: cortisol measures (CORT avg. = average of cortisol at T1 and T2), followed by testosterone, and lastly, average cortisol × testosterone interaction. F values are presented with degrees of freedom in parentheses. BCa bootstrapped values indicate 95% CI. Durbin–Watson values were within the recommended range of 1–3, suggesting independence of errors.
*Level of significance indicated as: *p < 0.10, **p < 0.05.*
Boldface values of BCa confidence intervals highlight a non-overlapping zero.

TABLE 2 | Results of hierarchical regression using cortisol regulation (step 1), testosterone (step 2), and cortisol decline × testosterone (step 3) to explain Iowa gambling task (IGT) decision-making in the uncertainty and risk phases.

Steps and predictors		R^2	F	ΔR^2	ΔF	B	SE	BCa 95% CI
DV = Uncertainty trials								
1	CORT dif.	0.01	0.54 (1, 39)	0.01	0.54	14.49	24.06	−41.47 to 55.21
2	CORT dif.	0.08	1.51(2, 39)	0.06	2.46	9.78	21.75	−35.17 to 40.33
	Testosterone					6.87	6.49	−5.57 to 15.83
3	CORT dif.	0.11	1.44 (3, 39)	0.03	1.28	3.25	30.68	−41.37 to 17.34
	Testosterone					5.31	7.13	−6.13 to 11.82
	CORT dif. × testosterone					42.19	178.51	−314.34 to 92.46
DV = Risk trials								
1	CORT dif.	0.05	0.46 (1, 39)	0.00	0.08	5.88	32.73	−53.67 to 55.54
2	CORT dif.	0.13	2.86 (2, 39)*	0.13	5.64**	−1.53	26.38	−49.38 to 31.84
	Testosterone					10.81**	5.10	**1.97–17.67**
3	CORT dif.	0.25	4.02 (3, 39)**	0.12	5.63**	15.02	23.56	−56.44 to 12.11
	Testosterone					7.59∗	4.09	**0.61–12.61**
	CORT dif. × testosterone					87.18**	91.56	−143.57 to 185.72

Transformed and mean-centered predictors were entered in three steps: cortisol regulation (CORT dif. = cortisol decline assessed as cortisol at T1 minus that at T2) followed by testosterone, and lastly the cortisol decline x testosterone interaction. F values presented with the degrees of freedom in parentheses. BCa bootstrapped values are 95% CIs. Durbin–Watson values were within the recommended range of 1–3, suggesting independence of errors.
*Level of significance indicated as: *p < 0.10 and ** p < 0.05.*

The results of IGT decision-making in the risk phase showed that cortisol failed to explain decision-making (step 1), that adding testosterone improved the model fit at trend-level significance (step 2), and that only testosterone's effects on decision-making were significant. The beta coefficients suggested that testosterone improved male decision-making in the risk phase. The cortisol and testosterone interaction model did not improve the model fit (step 3). Testosterone's effect was prominent and testosterone improved decision-making in the risk phase. Testosterone tends to hamper long-term decision-making in the IGT risk phase (Reavis and Overman, 2001; Evans and Hampson, 2014). One possibility for testosterone improving decision-making in the present study might align with the dual-hormone hypothesis; peak cortisol activity (post-awakening response) potentially curtailed testosterone's effect on male risk-taking (Mehta and Josephs, 2010).

Cortisol regulation (i.e., cortisol decline) was expected to accentuate the link between testosterone and decision-making in the risk phase because it might have high

regulatory demand on testosterone. The results for the uncertainty phase indicated that cortisol regulation (step 1), testosterone (step 2), and cortisol regulation and testosterone interaction (step 3) failed to account for decision-making in the uncertainty phase.

The results for the risk phase indicated that cortisol regulation was not significant (step 1), that testosterone significantly improved the model fit (step 2), and the coefficient values indicated that only testosterone's effect was significant and improved decision-making in the risk phase. The interaction of cortisol regulation and testosterone improved the explanatory power of the model (step 3). The coefficients indicated that only testosterone's effect was significant such that it improved decision-making in the risk phase. A non-overlapping zero in the CIs suggested that the effect was reliable. Coefficients for the interaction of cortisol regulation and testosterone were significant; however, overlapping zero in the CIs suggests that the effect might be less reliable. A simple slope analysis was used to examine the interaction effect of cortisol regulation and testosterone. Testosterone improvement in decision-making in the risk phase was significant for high cortisol regulation. The dual-hormone hypothesis suggests that cortisol inhibits testosterone's effects on male risk-taking (Mehta and Josephs, 2010); therefore, high cortisol regulation might facilitate testosterone regulation, and the dual regulation might navigate male decision-making in the risk phase toward safe, low-risk rewards.

Overall, the results of the first two regressions indicated that testosterone improved the model's explanatory fit for decision-making in the uncertainty and risk phases, specifically the cortisol-impaired uncertainty phase decision-making, whereas testosterone benefitted the risk phase decision-making. Cortisol regulation accentuated the phase-specific effects of cortisol and testosterone, indicating that testosterone improved decision-making, and this improvement was evident only in the risk phase, where prominent effects of testosterone were expected. Combining cortisol decline and testosterone improved the model's fit. The results lend support to cortisol's and testosterone's joint effects on male risk-taking (Mehta and Josephs, 2010; Knight et al., 2019). The results align with observations where stress and sex hormones accounted for male IGT decision-making in the risk phase (Alacreu-Crespo et al., 2019). Cortisol regulation improves cognitive control (Evans et al., 2012); possibly, it might have inhibited testosterone's effect and promoted long-term decision-making in the risk phase.

LIMITATIONS AND CONCLUSION

The study explored the roles of cortisol and testosterone in male IGT decision-making. The results indicated that hormones might contribute to decision-making in a phase-specific manner; however, the results are preliminary, given the following limitations: the study utilized awakening surge in cortisol and testosterone to examine the effects of hormones at their peak levels and with immediate diurnal decline. Future studies could explore multiple points of diurnal decline in hormone concentrations across the day to examine whether cortisol's and testosterone's effects on male IGT decision-making alter through the day. Counting type failed to influence cortisol decline in male IGT decision makers. Although the study aimed to understand male decision-making, the inclusion of female participants would further our understanding of cortisol's and testosterone's effects on risk taking in IGT decision-making. The study used a within-subjects comparison of cortisol decline (pre and post); a larger sample size might enable between-subjects comparison of cortisol regulation and testosterone levels (high and low levels), and a larger sample size might benefit the marginally significant effects (trend-level significance, $p < 0.10$). There were no performance-dependent incentives in the task, potentially altering risk-taking; however, studies have documented that real monetary incentives did not alter IGT decision-making (Bowman and Turnbull, 2003). Although the participants were unaware that the task is being repeated (T1 and T2), a consistent task version might have contributed to improved task performance due to practice effect. However, as outlined earlier, due to the complex nature of the IGT, the performance did not show a uniform practice effect, instead showing phase-specific variations in decision-making (i.e., decision-making improved in the uncertainty trials and remained stable in the risk trials). Task consistency was maintained in the other tasks used in the present study (digit span and Simon task). The digit span task performance showed improvement, whereas the Simon task performance showed stability. Although the effects of hormones on IGT decision-making are explored in the present study, decision-making might have influenced the hormone levels. Future studies should examine whether improved reward learning and learning to accrue long-term rewards reduce cortisol, or whether poor learning and increased risk-taking increase testosterone. Despite the limitations, and the exploratory nature of the study, cortisol regulation and testosterone interaction explained 25% of the decision-making variation in the risk phase. Studies using hierarchical regression for IGT performance explain a modest proportion of IGT decision-making because IGT is a complex task with considerable heterogeneity (large standard deviations; Bowman and Turnbull, 2003; Newman et al., 2008; Singh and Khan, 2009; Singh, 2013a,b). For example, measures of emotional and cognitive intelligence explained 12% of IGT choices (adjusted $R^2 = 0.12$; Ramchandran et al., 2020), personality explained 10% of the IGT choices ($R^2 = 0.10$ for males and 0.05 for females; Hooper et al., 2008), and heart rate explained 19% of male IGT decision-making in the risk phase (Wemm and Wulfert, 2017).

Significance

Testosterone and cortisol hormones might contribute to male IGT decision-making in a phase-specific manner; that is, testosterone might contribute to the cortisol-induced deficit in decision-making in the uncertainty phase and cortisol regulation might aid testosterone inhibition and enable safe decision-making in the risk phase. Others have attributed males' preference for safe rewards to factors such as greater

hemispheric specialization (Bolla et al., 2004) and high cognitive control in males (van den Bos et al., 2013). In an earlier study, we speculated that prominent male advantage in the risk phase of the IGT decision-making might reflect population-level testosterone (Singh et al., 2020). Although the results are preliminary, testosterone might contribute to male long-term decision-making in the risk phase of the IGT. Cortisol regulation potentially contributes to inhibiting testosterone, promoting long-term decision-making in males. Whether lower stress levels in males (Matud, 2004; Weekes et al., 2008) enable the regulation of cortisol and testosterone remains unclear. Males are overrepresented as household decision makers, specifically in gender-inequitable, developing societies with economic stress, so understanding the effects of stress and sex hormones on male decision-making might have broader implications for attaining the goals of gender parity. In male-dominated professions where decision-making takes place under stress, uncertainty, and risk (e.g., decision-making in nighttime military combat and high-risk medical emergencies), the effects of sex and stress hormones on decision-making might have vital implications.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institute Ethics Committee, Indian Institute of Technology Delhi, New Delhi, India. The patients/participants provided their written informed consent to participate in this study. Consent to the publication of the results was taken in verbal and written form, assuring that it follows the conditions laid down by the Institute Ethics Committee (IEC).

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnins.2021.631195/full#supplementary-material

Supplementary Figure 1 | Study design.

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The Prominent Deck B Phenomenon in Schizophrenia: An Empirical Study on Iowa Gambling Task

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Background: The Iowa Gambling Task (IGT) was established to evaluate emotion-based decision-making ability under uncertain circumstances in clinical populations, including schizophrenia (Sz). However, there remains a lack of stable behavioral measures regarding discrimination for decision-making performance in IGT between schizophrenic cases and healthy participants. None of the Sz-IGT studies has specifically verified the prominent deck B (PDB) phenomenon gradually revealed in other populations. Here, we provided a global review and empirical study to verify these Sz-IGT issues.

Methods: Seeking reliable and valid behavioral measures, we reviewed 38 studies using IGT to investigate decision-making behavior in Sz groups. The IGT, the Wisconsin Card Sorting Test (WCST), and clinical symptoms evaluations were administered to 61 schizophrenia or schizoaffective cases diagnosed by psychiatrists and 62 demographically matched healthy participants.

Results: There were no valid behavioral measures in IGT that could significantly identify the decision-making dysfunction of Sz. However, Sz cases, on average, made more choices from disadvantageous deck B relative to other decks, particularly in the later learning process (block 3–5). Compared to the control group, the Sz group was more impaired on the WCST. The high-gain frequency decks B and D showed significant correlations with WCST but no correlation between clinical symptoms and IGT/WCST.

Conclusions: Gain–loss frequency (GLF) has a dominant and stable impact on the decision-making process in both Sz and control groups. PDB phenomenon is essentially challenging to be observed on the ground of the expected value (EV) viewpoint approach on the IGT in both populations. Consequently, caution should be exercised when launching the IGT to assess the decision-making ability of Sz under a clinical scenario.

Keywords: Iowa Gambling Task, prominent deck B phenomenon, gain-loss frequency, schizophrenia, expected value, decision making

INTRODUCTION

Schizophrenia (Sz) remains a chronic, severe, and complicated psychiatric disorder with positive symptoms (i.e., hallucinations, delusions, disorganized thinking, and disorganized behaviors) and negative symptoms (i.e., blunted affect, alogia, asociality, anhedonia, and avolition) (American Psychiatric Association, 2013). It is generally accepted that Sz cases have impaired learning and rewarding systems (Waltz and Gold, 2007; Saperia et al., 2019; Woodrow et al., 2019), dysfunctional emotion processing (Trémeau, 2006), and decision-making deficits in goal-directed behavior (Gold et al., 2008; Saperia et al., 2019). Patients with Sz are impaired in flexible and value-based decision-making, particularly in changing and volatile environments (Waltz and Gold, 2007). Consistent evidence supports that Sz displays disrupted reward anticipation and reinforcement learning on behavioral and neural levels (Dayan and Daw, 2008). In Sz, decision-making dysfunction has been related to both positive and negative symptoms (Sterzer et al., 2019). The "jumping-to-conclusion" (JTC) bias refers to a tendency to make hasty decisions without sufficient information, which is related to positive symptoms, particularly delusions in Sz (Evans et al., 2015). Alternations in reward processing associated with negative symptoms may lead to inappropriate evaluation and analysis of long-term rewards guiding short-term decision-making behavior (Gold et al., 2008; Maia and Frank, 2017).

Review and meta-analysis studies have provided behavioral evidence that Sz has impaired reward-based decision-making process (Brown et al., 2015; Betz et al., 2018). In terms of the evidence from neuroimaging studies, Sz cases show hypofrontality with fewer activations in the frontal cortex, including dorsolateral frontal cortex (DLPFC) assessed with the Wisconsin Card Sorting Test (WCST) (Riehemann et al., 2001). Sz cases typically present a higher number of perseverative errors in WCST that is negatively correlated with DLPFC in Magnetic Resonance Imaging (MRI) and is related to reduced DLPFC activation in Functional Magnetic Resonance Imaging (fMRI), suggesting a deficit in switching and inhibitory functions (Seidman et al., 1994; Riehemann et al., 2001). The orbitofrontal cortex (OFC)/ ventromedial prefrontal cortex (VMPFC) associated with decision-making performance, reversal learning, and devaluation ability is also suggested to be impaired in Sz cases (Kringelbach, 2005; Nakamura et al., 2007). Previous studies using the Iowa gambling task (IGT), involving the interaction of "hot" affective signals and "cold" rational processing, highlighted that emotion plays a critical role in the decision-making process related to VMPFC (Bechara et al., 1997, 2005; Chiu et al., 2018). This laboratory task was developed to mimic daily life context and assess individual emotion-based decision-making behavior under ambiguity. It has been used with diverse clinical populations [i.e., Sz, substance addiction, pathological gambling, anorexia nervosa, obesity, chronic pain, aggression disorders, affective disorders, Huntington's disease, obsessive–compulsive disorder (OCD), attention-deficit/hyperactivity disorder (ADHD)] (Bechara, 2007, 2016).

Iowa Gambling Task

Initially, Bechara et al. developed the IGT in 1994, aiming to verify the somatic marker hypothesis (SMH). SMH assumed that people had intact somatic marker systems that could assist them in making decisions beneficial to long-term outcomes under uncertain situations. Given the support of neural circuits of healthy somatic markers, participants could achieve a final win (total amount of money > 0) in IGT. Conversely, if this system was impaired (e.g., in VMPFC-impaired patients), individuals could not generate behavior that could avoid losses and tended to ignore long-term profits. This suggested that participants were easily affected by immediate losses and gains and neglected long-term benefits, which ultimately ended with a final loss in the IGT (Bechara et al., 1994, 1997, 1999).

The original IGT consisted of four decks (see **Supplementary Figure 1**). Participants had 100 trials for selection and they were free to choose from four decks. At the initiation of the experiment, participants had a loan of $2,000 from the bank and were informed instantly about the amount of money gained or lost after each choice. Participants were informed to try their best to determine the winning strategy and to maximize the money they gained. Of the four decks, decks A and B were regarded as disadvantageous decks because of the negative expected value (EV) ($-250) based on every 10 cards. By contrast, decks C and D were advantageous decks because of the positive EV ($+250). In terms of gain–loss frequency (GLF) of IGT, decks A and C had similar gain–loss structure: 10 gains and 5 losses per 10 cards; decks B and D shared a similar high winning frequency of 10 gains and 1 loss per 10 cards (see **Supplementary Table 2**).

Expected Value Viewpoint: IGT and Net Score

Bechara et al. (1994) believed that typical VMPFC-impaired patients had intact intellect and problem-solving abilities, but they could not learn the concept of EV lacking intact somatic marker systems and chose more cards from decks A and B with negative EV in IGT. In contrast, with the guidance of somatic marker systems, healthy subjects who could gradually learn the concept of EV and were sensitive to future outcomes could make more selections from deck C and deck D with positive EV in IGT (Bechara and Damasio, 2002). In 1994, Bechara et al. compared 44 controls and six VMPFC-impaired patients and showed that the healthy participants picked more cards from advantageous decks, whereas the VMPFC-impaired patients selected more cards from the disadvantageous decks.

Bechara et al. developed the net score, which took the difference between choices from advantageous decks and disadvantageous decks [(C+D) - (A+B)] as a behavioral measure of whether participants were sensitive to future outcomes (Bechara et al., 1994). Most subsequent studies used this behavioral measure to probe decision-making patterns in Sz and control groups from the viewpoint of EV (Shurman et al., 2005; Kester et al., 2006; Sevy et al., 2007; Premkumar et al., 2008; Lee et al., 2009; Shirayama et al., 2010; Nestor et al., 2014;

Matsuzawa et al., 2015; Stratta et al., 2015; Kim et al., 2016; Pedersen et al., 2017; Glick et al., 2021). However, interestingly, the evidence from Sz-IGT literature was somewhat inconclusive in relation to EV. Some studies revealed that Sz cases preferred disadvantageous decks relative to advantageous decks (Beninger et al., 2003; Ritter et al., 2004; Shurman et al., 2005; Kester et al., 2006; Lee et al., 2007; Nakamura et al., 2007; Premkumar et al., 2008; Yip et al., 2009; Wasserman et al., 2012; Brown et al., 2013; Nestor et al., 2014; Matsuzawa et al., 2015; Kim et al., 2016). Other studies suggested that Sz cases and healthy subjects performed equally on the net score in IGT (Wilder et al., 1998; Bark et al., 2005; Evans et al., 2005; Rodríguez-Sánchez et al., 2005; Turnbull et al., 2006; Martino et al., 2007; Sevy et al., 2007; González-Blanch et al., 2008; Shirayama et al., 2010; Choi et al., 2011; Carvalho et al., 2012; Ayesa-Arriola et al., 2013; Premkumar et al., 2015; Pedersen et al., 2017; Glick et al., 2021) (See **Supplementary Table 1**).

The contrasting results in Sz-IGT studies were likely due to the heterogeneity of characteristics of participants and methodological approaches (e.g., disparate outcome measures of IGT). Types of antipsychotic treatments (Beninger et al., 2003), doses of medication (Betz et al., 2018), diagnoses (Betz et al., 2018), clinical symptoms (Betz et al., 2018), intelligence level (Betz et al., 2018), age (Carvalho et al., 2012), gender (Singh et al., 2020), and education (Evans et al., 2004) affect decision-making performance in Sz cases. However, no conclusions based on the above factors could be made to reach a consensus. Among all the potential factors, the scoring approach is a key factor. Across 38 Sz-IGT studies, there were 15 types of outcome measures (**Supplementary Figure 1**): most studies (84.2%) used net score [(C+D) - (A+B)]; the four-deck format (47.4%) was also preferred by Sz-IGT studies; an equal number of studies employed advantageous decks (C+D) (15.8%) and disadvantageous decks (A+B) (15.8%); three studies used GLF measures [(B+D) - (A+C), B+D, or A+C]; and other scoring approaches accounted for fewer than 10 studies. Various outcome measures were developed, even where the net score was taken as the primary outcome measure.

IGT reviews have suggested that the four-deck format (scoring the number of selections from deck A, B, C, and D, respectively) could comprehensively observe effects of all variables (Buelow and Suhr, 2009; Steingroever et al., 2013; Betz et al., 2018; Chiu et al., 2018). Some Sz-IGT studies have analyzed the four-deck format to compare the performance between both groups (Wilder et al., 1998; Ritter et al., 2004; Bark et al., 2005; Rodríguez-Sánchez et al., 2005; Shurman et al., 2005; Kester et al., 2006; Lee et al., 2007; Martino et al., 2007; Sevy et al., 2007; Kim et al., 2009, 2012, 2016; Wasserman et al., 2012; Hori et al., 2014; Brown et al., 2015; Matsuzawa et al., 2015; Zhang et al., 2015; Pedersen et al., 2017), but most have continued to adopt the EV viewpoint approach, ignoring the role of GLF in the decision-making process. Some studies have found that high winning frequency decks (B or D) are preferred by healthy control groups (Wilder et al., 1998; Dunn et al., 2006; Fernie, 2007; Chiu et al., 2012; Brown et al., 2015; Kim et al., 2016) when observing the four-deck pattern.

Gain–Loss Frequency Viewpoint: IGT and "Prominent Deck B" Phenomenon

Observation of the four-deck format suggests that decision-making behavior on the IGT is affected not only by EV but also by GLF (Wilder et al., 1998; Chiu et al., 2012, 2018; Steingroever et al., 2013). Wilder et al. discovered that Sz cases favored decks B and D with high winning frequency (Wilder et al., 1998). Subsequently, Lin et al. reported that subjects preferred deck B with high winning frequency but negative EV and termed this as a "prominent deck B (PDB)" phenomenon (Lin et al., 2007), which contradicted the primary assumptions of the original IGT (Bechara et al., 1994).

The following IGT studies have suggested that GLF, rather than EV, was a critical factor influencing the decision-making behavior of the participants in IGT, which conflicts with primary IGT statements. Moreover, a series of relevant IGT studies have found that controls also preferred the disadvantageous deck B (Bark et al., 2005; Rodríguez-Sánchez et al., 2005; Fernie, 2007; Takano et al., 2010; Chiu et al., 2012; Steingroever et al., 2013). The PDB phenomenon of controls has gradually made an impact on the evaluation and development of IGT (Zhang et al., 2017; Chiu et al., 2018), including verifying IGT validity (Buelow and Suhr, 2009; Lin et al., 2013), constructing IGT decision-making models (Ahn et al., 2008; Lin et al., 2016), examining markers for sleep deprivation (Seeley et al., 2014, 2016), and examining the clinical application of IGT (Upton et al., 2012). Therefore, researchers have increasingly emphasized the association between the PDB phenomenon and IGT, suggesting that GLF plays an essential role in decision-making in healthy and neuropsychiatric individuals.

Gain–Loss Frequency in Sz-IGT Studies

In Sz-IGT studies, the impact of GLF was initially discussed by Wilder et al. (1998). This study compared the number of four-deck choices between 12 Sz and 30 controls and found that both Sz and control picked more cards from decks B and D with high reward but low punishment frequency than decks A and C with low winning but high losing frequency. Wilder et al. (1998) considered that GLF might influence the decision-making behavior of Sz and control in IGT. Some subsequent Sz-IGT studies used (B+D) - (A+C), (B+D), and (A+C) as GLF measures to examine the difference between Sz and control groups (Rodríguez-Sánchez et al., 2005; Shurman et al., 2005; Kester et al., 2006; Brown et al., 2015), but no Sz-IGT study thoroughly discussed how GLF and PDB guide decision-making behavior in Sz cases. For instance, Sevy et al. conducted a review and experiment and found no significant difference across the net scores, deck A, deck B, deck C, and deck D between groups, but the selections of deck B were more than other decks within Sz and control groups (Sevy et al., 2007). Brown and colleagues conducted a brief meta-analysis on IGT and showed that Sz cases preferred deck B and control clearly preferred decks B and D. In the empirical phase, both Sz and control demonstrated more selections from deck B and deck D (Brown et al., 2015). A meta-analysis study investigated the decision-making performance of Sz cases across all IGT indices and showed that Sz preferred high

winning frequency decks B and D (Betz et al., 2018). Based on this evidence, it is necessary to investigate the effect of GLF on the decision-making process in Sz cases.

Taken together, most Sz-IGT studies typically adopted a net score to represent individual decision-making abilities to detect schizophrenic behavior pattern from the EV viewpoint (Bechara et al., 1994; Ritter et al., 2004; Evans et al., 2005; Rodríguez-Sánchez et al., 2005; Shurman et al., 2005; Kester et al., 2006; Turnbull et al., 2006; Lee et al., 2007, 2009; Martino et al., 2007; Nakamura et al., 2007; Sevy et al., 2007; González-Blanch et al., 2008; Premkumar et al., 2008, 2015; Kim et al., 2009, 2012, 2016; Yip et al., 2009; Shirayama et al., 2010; Choi et al., 2011; Raffard et al., 2011; Struglia et al., 2011; Cella et al., 2012; Ayesa-Arriola et al., 2013; Brambilla et al., 2013; Fond et al., 2013; Hori et al., 2014; Nestor et al., 2014; Matsuzawa et al., 2015; Stratta et al., 2015; Zhang et al., 2015; Pedersen et al., 2017). The net score as a derivative measure drawing on the four decks A, B, C, and D might gloss over selections of each deck. This combination might not properly reveal that participants preferred the negative EV deck B (Horstmann et al., 2012). GLF as a potentially critical factor in decision-making behavior has not been investigated its role in Sz-IGT studies. Furthermore, most Sz-IGT studies also used WCST to examine the potential association between IGT and WCST. It was common to investigate the correlation between the net score (EV measure) and WCST; however, other IGT measures, such as decks B and D (GLF measures), were not frequently examined.

Accordingly, this study aimed to clarify the issues of inconsistency in Sz-IGT research based on EV and GLF viewpoints by using IGT, WCST, and clinical ratings and analyzing net score, four-deck format, and serial deck measures and their correlation with WCST. In order to assess whether Sz cases showed the PDB phenomenon, we compared the number of selections of decks under four-deck format, as well as D-A, D-B, D-C, C-B, C-A, and B-A. We predict that Sz cases will show the PDB phenomenon, namely, the number of deck B selection will be significantly higher than the other three decks. We argue that the disparity between decks A and B, which have exactly the same EV, supports the GLF viewpoint and violates the EV assumption.

MATERIALS AND METHODS

Participants

Initially, 68 Sz or schizoaffective (SA) cases were recruited from Kaohsiung Municipal Siaogang Hospital and community mental health rehabilitation institutions. However, seven patients were unable to complete the whole procedure due to severe psychotic symptoms and eventually 61 chronic cases [mean age: 40.44 ± 11.23 (SD); 47.54% males] between the ages of 21 and 62 with Sz or SA disorder diagnosed by psychiatrists were included. From the community, 72 healthy adults, contacted via email, networking, and advertisements, were invited to participate. After the exclusion of 10 people who had a history of psychiatric or neurologic issues, this group consisted of 62 healthy subjects (mean age: 35.50 ± 15.10 (SD); 45.16% males) between the ages of 20 and 69, matched in age and gender. Exclusion criteria included the following: acute psychiatric instability, comorbid medical issues, brain injury, and meeting criteria for substance abuse or dependence. Healthy volunteers had no history of psychosis or neurological condition that would interfere with task performance. All participants received detailed information about the study procedures and provided their written informed consent. This study received ethical approval [No. KMUHIRB-SV(I)-20150075] from the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital.

General Procedure

All participants were provided with detailed information about procedures and voluntarily consented to receive assessments, including the IGT and WCST (Heaton et al., 1993) to evaluate affective decision-making and working memory, and problem-solving skills. By correlating these two measures, we sought to determine the relationship between decision-making behavior and the shifting flexibility in Sz cases. In Sz cases, the severity of overall psychiatric symptoms and the ability to self-care were assessed with the Positive and Negative Syndrome Scale (PANSS) and the Personal and Social Performance Scale (PSP). Healthy participants received a brief interview and were assessed with the exclusion criteria.

Experimental Tasks

Iowa Gambling Task

The IGT version used in this study was corresponded closely to the structure of the original IGT (Bechara et al., 1994) (see **Supplementary Table 2**, **Supplementary Figure 1**). In our version, participants had a loan of NT$ 5,000 from the bank and were instantly informed of gained or lost money amount after each choice. They had 100 trials, which were not informed, to randomly choose from four decks and had to try their best to determine the winning strategy and maximize the money they gained. With regard to the IGT structure, each deck included 40 cards circulating with every 10 cards. Indeed, deck A and deck B were disadvantageous decks because of the negative expected value (EV) (NT$-250) based on every ten cards. If participants selected a card from deck A or B, they might receive a payoff of NT$100 or punishments ranging from NT$-150 to NT$-1250. Penalties of deck A were frequent and varied from NT$-150 to NT$-350, while punishments of deck B were infrequent, costing the participants NT$ 1250. In contrast, deck C and deck D were advantageous decks because of positive EV (NT$ +250). After selecting a card from deck C or D, participants might receive a reward of NT$ 50, or the penalties varied from NT$-25 to NT$-75. Penalties of deck C were frequent, and the amount ranged from NT$-25 to NT$-75, whereas punishments of deck D were infrequent and cost the participants NT $250. In terms of GLF of IGT, deck A and deck C had a similar gain–loss structure, which was 10 gains and 5 losses per 10 cards; for decks B and D, the structure was 10 gains and 1 loss per 10 cards (see **Supplementary Table 2**).

Wisconsin Card Sorting Test

The Wisconsin Card Sorting Test (WCST) was initially developed to assess the reasoning skills and the ability to

shift cognitive strategies under environmental changes. What we administered was the computerized modification version from PEBL Version 0.14 (The PEBL Project, 2014). This test measures different cognitive functions involving executive functions, strategic planning, organized searching, set-shifting based on feedback information, goal-oriented behaviors, and modulation of impulsive responses (Heerey et al., 2008). WCST includes 4 stimulus cards and 128 response cards that differ in shape (cross, circle, triangle, or star), color (red, blue, yellow, or green), and number (one, two, three, or four). Participants were informed to correctly match response cards to one of the stimulus cards and were provided feedback after each selection. The matching rule will automatically switch to the next rule without informing subjects after 10 consecutive matchings. There is no time limit for this test, but the computer will automatically terminate when participants have completed 6 categories or when 128 cards have been all sorted. The primary outcome measure is perseverative errors (PE), and secondary outcome measures are total errors (TE), perseverative response (PR), non-perseverative errors (NPE), categories completed (CC), conceptual level (CL), and trials to complete the first category (TFC).

Positive and Negative Syndrome Scale

The Positive and Negative Syndrome Scale (PANSS) was used to assess the severity of psychiatric symptoms and social functions in Sz cases (Kay et al., 1987; Morosini et al., 2000). This study used the traditional Chinese version of PANSS and received authorization from Dr. Hwu and Dr. Huang, who standardized the traditional Chinese version in the National Taiwan University Hospital (Hwu et al., 1995). The scale covers positive symptoms (7 items), negative symptoms (7 items), general psychopathology scales (16 items), and supplementary items for the aggression risk profile (3 items), which accounts for a total of 33 items, for example, P1. Delusions: beliefs that are unfounded, unrealistic, and idiosyncratic (Kay et al., 1987). The severity of symptoms for each item is rated according to a 7-point scale (1 = absent; 7 = extreme). The reliability of the Chinese version of PANSS is within an acceptable range (0.76–0.78) (Hwu et al., 1995).

Personal and Social Performance Scale

Morosini et al. developed the Personal and Social Performance Scale (PSP) based on Social and Occupational Functioning Assessment (SOFAS) consisting of four main areas: (1) socially useful activities (e.g., housework and voluntary work), including work and study; (2) personal and social relationships (i.e., partner, family relationships, and friends); (3) self-care (i.e., personal hygiene and care for the appearance of an individual); and (4) disturbing and aggressive behavior (Morosini et al., 2000). Each area is rated on a 6-point scale from absent (no problems on this dimension) through mild, manifest, marked, and severe to very severe difficulties. PSP is highly correlated with SOFAS ($r = 0.91$) (Morosini et al., 2000). We used the traditional Chinese version of PSP that measures four dimensions: general function, interpersonal and social relations, ability to self-care, and interference and aggressive behavior (22 items in total) (Bai et al., 2014).

Statistical Analysis

Regarding the demographic and clinical characteristics data, independent samples *t*-tests and chi-square tests were utilized to compare the matching level of gender, age, and education between two groups. The *t*-test was also used to examine the performance of WCST between Sz and control groups. For analyses of data from the IGT, independent samples *t*-tests and three separate ANOVAs were performed. Mauchly's test of sphericity was used to examine normality and homogeneity. If the results did not pass this test, we followed the Greenhouse–Geisser corrections. First, *t*-tests were performed to assess the group difference under a wide range of behavioral measures in IGT. Secondly, a two-way ANOVA using deck (four levels: A, B, C, and D) and group (Sz and control) as factors was performed to demonstrate the main effect of group and deck. After confirming the absence of a main effect of group, one-way ANOVAs were carried out to check for deck effects, respectively, in Sz and control. Scheffe *post-hoc* analyses were used to ascertain where differences in decks were present, verifying the PDB phenomenon. Third, we performed a three-way ANOVA with factors block (five levels: 20 trials per block), deck (four levels: A, B, C, and D), and group (Sz and control) to assess the group differences in learning performance on the four-deck format and all the behavioral outcome measures. Two-way ANOVAs, using block and deck as factors, and Scheffe *post-hoc* analyses were then carried out further to check block and deck effects separately in Sz and control groups. Finally, Pearson's correlation analyses were performed to explore possible relationships between IGT and measures of severity of symptom in the Sz group and between IGT and WCST within both groups. All statistical analyses were conducted using SPSS 19.0 software (IBM Corp, 2010).

RESULTS

Demographic and Clinical Characteristics

A summary of demographic and clinical variables is shown in **Table 1**. Groups were well matched in gender and age; however, education level was significantly lower in the Sz group relative to the control group. The performance of the Sz group was significantly impaired in the WCST compared to the control group. Sz cases showed mild to moderate psychiatric dysfunction, personal and social dysfunction.

IGT Results: Behavioral Measures

The data comparing a wide range of IGT behavioral measures between Sz and control groups under *t*-test in **Table 2** illustrated that there was no significant difference between the two groups. Namely, the Sz group demonstrated a similar decision-making level relative to the control group. Two-way ANOVA on all measures across five blocks (20 trials as one block) also revealed no main effects of group and no interaction effect of group and block but the main effect of block on (C+D) - (A+B) [$F_{(3, 292)} = 2.62$, $p = 0.46$, $\eta_p^2 = 0.02$], (B+D)-(A+C) [$F_{(3, 404)} = 3.23$, $p = 0.02$, $\eta_p^2 = 0.03$], D-A [$F_{(3, 362)} = 2.99$, $p = 0.04$, $\eta_p^2 = 0.04$], C-A [$F_{(3, 413)} = 4.83$, $p = 0.002$, $\eta_p^2 = 0.04$], B-A [$F_{(3, 377)} = 2.89$, $p = 0.03$, $\eta_p^2 = 0.02$]. Indeed, the Sz group showed a comparable level of decision-making performance relative to

TABLE 1 | Demographic and clinical characteristics of participants.

	Sz (*N* = 61)	Control (*N* = 62)	Test statistic	*p*	*d*
Gender (male: female)	29:32	28:34	$\chi^2 = 0.70$	0.86	
Age	40.44 (11.23)	35.50 (15.10)	$t = 2.06$	0.42	−0.37
Education	12.41 (2.32)	15.34 (2.22)	$t = -7.16^{**}$	$< 0.001^{***}$	1.29
WCST-TC	50.92 (18.36)	63.15 (16.42)	$t = -3.89^{***}$	$< 0.001^{***}$	0.70
WCST-TE	72.49 (26.20)	45.03 (31.42)	$t = 5.27^{***}$	$< 0.001^{***}$	0.90
WCST-PR	48.23 (35.20)	26.21 (27.96)	$t = 3.84^{***}$	$< 0.001^{***}$	0.65
WCST-PE	39.72 (25.87)	22.66 (21.36)	$t = 3.99^{***}$	$< 0.001^{***}$	0.66
WCST-NE	32.77 (23.56)	22.37 (20.64)	$t = 2.61^{*}$	0.02^{*}	0.43
WCST-CL	31.00 (25.20)	51.37 (23.38)	$t = -4.65^{***}$	$< 0.001^{***}$	0.84
WCST-CC	1.90 (2.17)	4.05 (2.35)	$t = -5.26^{***}$	$< 0.001^{***}$	0.95
WCST-TFC	66.46 (54.39)	38.21 (43.70)	$t = 3.17^{**}$	0.002^{**}	−0.57
PANSS-T	67.49 (14.91)	–	–		
PANSS-P	15.62 (5.30)	–	–		
PANSS-N	16.82 (4.74)	–	–		
PANSS-G	29.95 (6.54)	–	–		
PSP	69.70 (8.99)	–	–		

*Sz, Schizophrenia; WCST, Wisconsin Cards Sorting Test; PANSS, The Positive and Negative Syndrome Scale; TC, Total corrects; TE, Total errors; PR, Perseverative response; PE, Perseverative errors; NE, Non-perseverative errors; CC, Categories completed; CL, Conceptual level; TFC, Trials to first category; T, Total score of PANSS; P, Positive symptoms; N, Negative symptoms; G, general psychopathology scales; PSP, Personal and Social Performance Scale. *p < 0.05, **p < 0.01, and ***p < 0.001.*

TABLE 2 | IGT performance of Sz and control.

	Sz	Control	*t*	*p*	*d*
Total earned money	4631.15 (596.77)	4425.81 (621.13)	1.87	0.06	−0.34
(C+D)-(A+B)	−2.89 (16.51)	−5.00 (18.54)	0.67	0.51	−0.12
C+D	48.56 (8.26)	47.50 (9.27)	0.67	0.51	−0.12
A+B	51.44 (8.26)	52.50 (9.27)	−0.67	0.51	0.12
(B+D)-(A+C)	9.90 (15.67)	6.26 (14.55)	1.34	0.18	−0.24
B+D	54.95 (7.84)	53.13 (7.28)	1.34	0.18	−0.24
A+C	45.05 (7.84)	46.87 (7.28)	−1.34	0.18	0.24
D-A	3.51 (10.60)	0.63 (11.07)	1.47	0.14	−0.27
D-B	−6.66 (13.56)	−8.00 (13.63)	0.55	0.59	−0.10
D-C	−0.26 (11.20)	−2.37 (10.26)	1.09	0.28	−0.20
C-A	3.77 (8.18)	3.00 (10.84)	0.44	0.66	−0.08
C-B	−6.39 (12.18)	−5.63 (12.46)	−0.35	0.73	0.08
B-A	10.16 (10.58)	8.63 (11.49)	0.77	0.44	−0.18

Sz, Schizophrenia.

the control group, but a differentiation across five blocks within groups was observed, suggesting that the two groups might have distinct reward learning processes.

IGT Results: Prominent Deck B Phenomenon

The two-way ANOVA using the four-deck format in **Figure 1** revealed no significant main effect of group and interaction of group and deck, while the main effect of deck [$F_{(3, 326)} = 30.72$, $p < 0.001$, $\eta_p{}^2 = 0.20$] was statistically significant with a small effect size. As there was no group difference in four-deck selective patterns, one-way ANOVAs were conducted to elucidate the factors in IGT, respectively, for Sz and control groups as shown in **Table 3**, indicating the main effect of the deck in both groups with small effect size [Sz: $F_{(3, 154)} = 17.56$, $p < 0.001$, $\eta_p{}^2 = 0.23$; control: $F_{(3, 167)} = 14.03$, $p < 0.001$, $\eta_p{}^2 = 0.19$]. From Scheffe *post-hoc* analysis of four decks in **Figures 2**, **3**, it appears that both the Sz and control groups both preferred high-gain frequency deck B (Sz: B>A***, B>C***, and B>D***; control: B>A***, B>C**, and B>D***), suggesting that both groups had PDB phenomenon.

Indeed, the data in a three-way ANOVA analyzing block-by-block learning process indicated no main effect of group and block, but it indicated that the main effect of deck

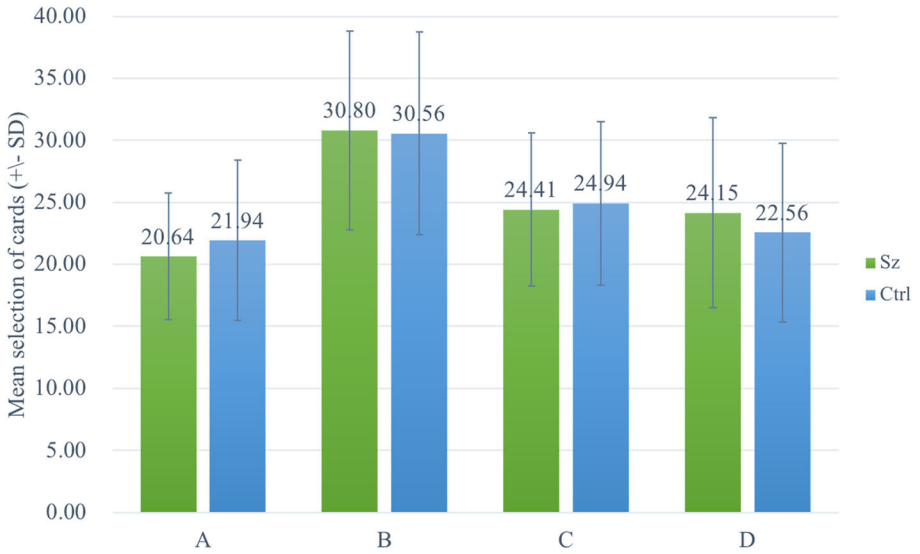

FIGURE 1 | Selective patterns of Sz and control. Green bars represent the Sz group, whereas blue bars represent the control group. Both groups selected more cards from deck B than from the other decks.

TABLE 3 | Four-deck format patterns in Sz and control.

	A	B	C	D	*F*	*p*	η_p^2	*Post-hoc*
Sz	20.64 (5.11)	30.80 (8.00)	24.41 (6.17)	24.15 (7.66)	17.56	< 0.001***	0.23	B>A***, B>C***, B>D***
Control	21.94 (6.47)	30.56 (8.19)	24.94 (6.59)	22.56 (7.23)	14.03	< 0.001***	0.19	B>A***, B>C**, B>D***

*The distribution did not meet the spherical hypothesis, and the Greenhouse–Geisser correction was adopted. The Scheffe method was used in the post-hoc analysis. **$p < 0.01$, ***$p < 0.001$.*

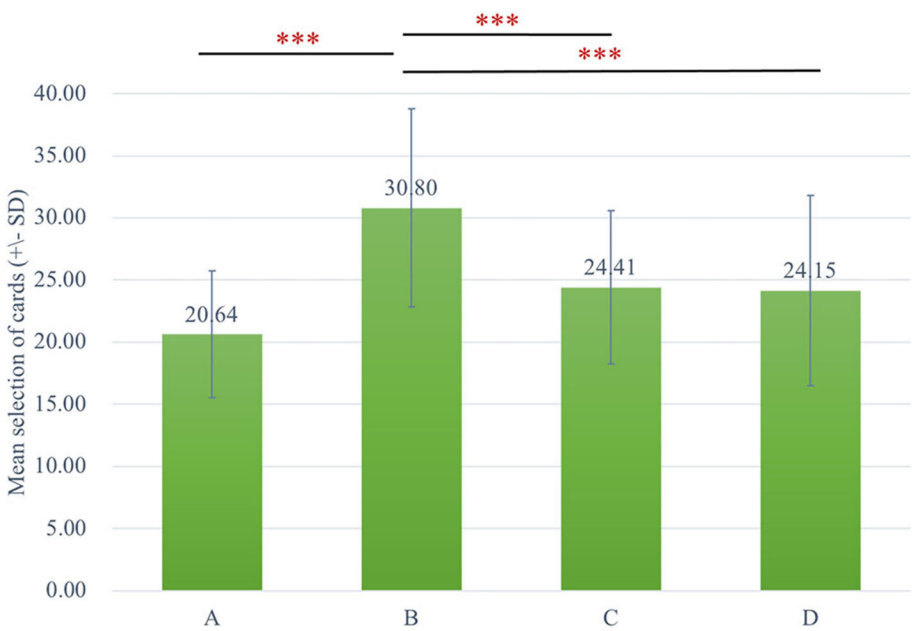

FIGURE 2 | The selective pattern of Sz. Green bars represent the four-deck format of the Sz group, and the number of selections from deck B is significantly larger than the other three decks. ***$p < 0.001$.

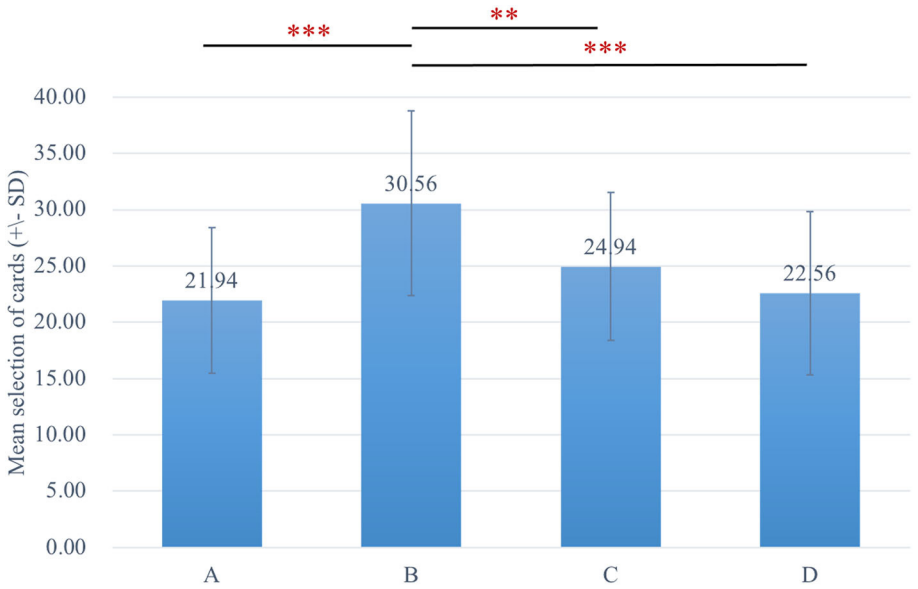

FIGURE 3 | The selective pattern of control. Blue bars represent the four-deck format of the control group, and the number of selections from deck B is significantly larger than the other three decks. $^{**}p < 0.01$, $^{***}p < 0.001$.

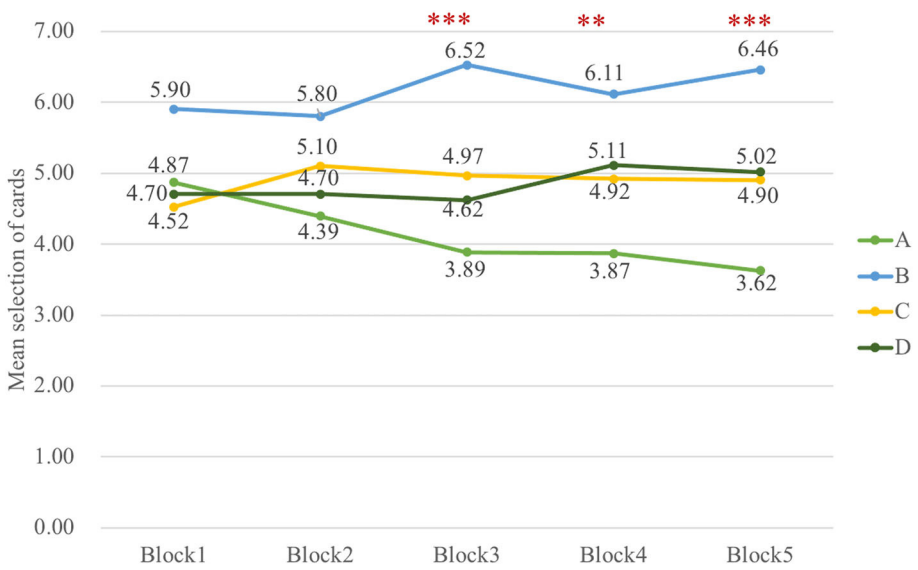

FIGURE 4 | The selective pattern of Sz in five blocks. The number of cards from deck B is significantly larger than deck A over block 3 [$F_{(3,\ 493)} = 7.18$, $p < 0.001$], block 4 [$F_{(3,\ 493)} = 4.92$, $p = 0.002$], and block 5 [$F_{(3,\ 493)} = 7.87$, $p < 0.001$] in Sz. $^{**}p < 0.01$, $^{***}p < 0.001$.

[$F_{(3,\ 326)} = 30.72$, $p < 0.001$, $\eta_p{}^2 = 0.20$] and interaction of block and deck [$F_{(8,985)} = 2.51$, $p = 0.01$, $\eta_p{}^2 = 0.02$] were significant. To examine the selective patterns of both groups in learning progress, two-way ANOVAs were carried out in Sz and control groups, respectively. The outcomes illustrated the main effect of deck [$F_{(3,\ 154)} = 17.53$, $p < 0.001$, $\eta_p{}^2 = 0.23$] and interaction of deck and block [$F_{(6,339)} = 2.26$, $p = 0.04$, $\eta_p{}^2 = 0.04$] in Sz cases and only a main effect of deck [$F_{(3,\ 167)} = 14.05$, $p < 0.001$, $\eta_p{}^2 = 0.19$] in control participants. The results in **Figure 4** also revealed that Sz cases had more selections from deck B than other decks over block 3 [$F_{(3,\ 493)} = 7.18$, $p < 0.001$, $\eta_p{}^2 = 0.04$], block 4 [$F_{(3,\ 493)} = 4.92$, $p = 0.002$, $\eta_p{}^2 = 0.03$], and block 5 [$F_{(3,\ 493)} = 7.87$, $p < 0.001$, $\eta_p{}^2 = 0.05$] (see **Figure 5**). PDB became more dominant in the late learning phase in Sz cases; however, this pattern was not seen in control participants. Two-way ANOVAs were also performed to examine the group and block effects across all the behavioral outcome measures, but no group differences were found.

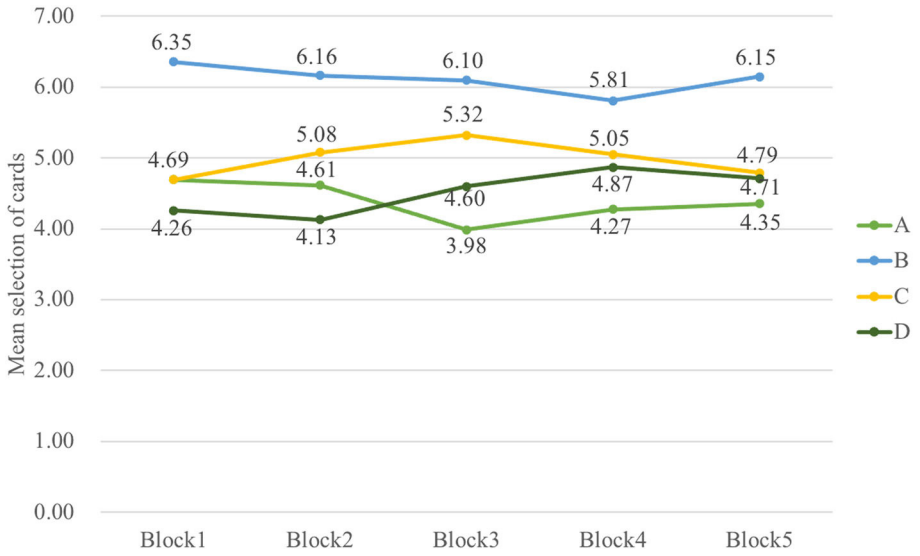

FIGURE 5 | The selective pattern of control in five blocks. No significant results are shown from the learning curve in control. The control group did not learn to choose fewer cards from disadvantageous deck B, but they tended to choose fewer cards from deck A over the last three blocks.

TABLE 4 | Results of correlation of IGT and WCST in Sz.

	A	B	C	D	(C+D)-(A+B)	(B+D)-(A+C)
TE	−0.10	−0.22	−0.05	0.33**	0.27*	0.10
PR	−0.04	−0.02	−0.08	0.12	0.05	0.09
PE	−0.05	−0.03	−0.07	0.12	0.06	0.09
NE	−0.07	0.30*	0.16	0.23	0.33**	−0.08
CC	−0.21	−0.23	−0.08	0.44***	0.35**	0.20
CL	−0.19	−0.23	−0.02	0.37**	0.33**	0.14
TFC	0.15	0.12	0.12	−0.32*	−0.21	−0.19

*TE, Total errors; PR, Perseverative response; PE, Perseverative errors; NE, Non-perseverative errors; CC, Categories completed; CL, Conceptual level; TFC, Trials to first category. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

Correlation Analysis

Results from analyses of correlations between IGT and WCST performance metrics in Sz are presented in **Table 4**. Positive significant correlations were observed between deck D and TE ($r = 0.33$, $p = 0.008$), CC ($r = 0.44$, $p < 0.001$), and CL ($r = 0.37$, $p = 0.01$), while TFC were inversely correlated with deck D ($r = -0.32$, $p = 0.01$). Deck B was positively correlated with NE ($r = 0.30$, $p = 0.02$). Positive correlations between net score and TE ($r = 0.27$, $p = 0.03$), NE ($r = 0.33$, $p = 0.01$), CC ($r = 0.35$, $p = 0.01$), and CL ($r = 0.33$, $p = 0.01$) were also showed. No correlations were found between measures of the severity of symptom and IGT. Reward-based decision-making performance in IGT was related to the executive function in WCST rather than clinical symptoms in Sz cases.

DISCUSSION

This is the first study to examine whether IGT has feasible outcome measures for identifying risky decision-making behavior and pinpointing the role of PDB in IGT for Sz cases. We found no suitable primary measures in IGT to identify decision-making process deficits of Sz cases relative to the control group. However, the Sz group demonstrated the decision-making pattern with substantially more choices from the disadvantageous deck B than other decks, particularly in the later phase of the learning processing. Thus, individuals with Sz showed a robust and stable PDB phenomenon with evidence in our study, suggesting decision-making behavior under risk in the Sz cohort was highly guided by GLF, and this effect got enhanced in the learning process.

Our results were supported by a review and empirical studies, which did not find significant differences across the net score, deck A, deck B, deck C, and deck D (Wilder et al., 1998; Sevy et al., 2007; Glick et al., 2021). A categorical score (categorical score = 1 if Σ net scores for trials 1–60 or trials 61–100 $\geq$ 0, and = 0 if Σ net scores for trials 1–60 or trials 61–100 $<$ 0) was defined in Sevy et al. study, and it showed a significant difference between Sz and control groups (Sevy et al., 2007);

however, Sz preferring deck B was also observed, which was not reported by authors. Two Sz-IGT meta-analysis studies showed significant differences in EV and GLF measures (Betz et al., 2018; Li et al., 2019). Li et al. found a moderate-sized effect of the net score for Sz compared to healthy individuals in a meta-analytic approach (Li et al., 2019); nevertheless, this study did not examine the potential heterogeneous sources and the effects of four decks. In contrast, Betz et al. performed a meta-analysis study for all IGT outcome measures in Sz and showed significant effects of the net score (block 2 to 5) and significant effect sizes across decks A, B, and D (Betz et al., 2018). Unfortunately, the present study did not replicate these results. One potential reason is that some particular studies derived the results of meta-analyses. For example, in deck analyses, findings of meta-regression were driven by Zhang et al. (2015) and the results were no longer significant once this study was omitted (Betz et al., 2018). Additionally, the above meta-analysis studies only included studies published after 2000, and one crucial clinical trial (Wilder et al., 1998) was omitted, which may affect the results of meta-analyses. Furthermore, Lee et al. (2020) recollected over 900 IGT-related studies and found out 86 studies of them reported data with the four-deck format and their observation demonstrated over half of the studies (58/86, 67.44%) presented the PDB phenomenon in healthy/control groups. Namely, the PDB phenomenon and the preference of participants for disadvantageous deck B have profoundly affected the explanation of IGT performance. Accordingly, it is worth noting the presence of the PDB phenomenon not only in the healthy/control group but also in the patient group (see also **Supplementary Figure 3**).

PDB Phenomenon

A noticeable preference for the deck B with frequent gains and rare large losses, over the deck of moderate losses (deck A), is consistent with several previously reported findings in Sz cases (Ritter et al., 2004; Bark et al., 2005; Rodríguez-Sánchez et al., 2005; Shurman et al., 2005; Kester et al., 2006; Lee et al., 2007; Martino et al., 2007; Kim et al., 2009, 2012, 2016; Wasserman et al., 2012; Hori et al., 2014; Brown et al., 2015; Matsuzawa et al., 2015; Zhang et al., 2015; Pedersen et al., 2017). Even if the net score of Sz was significantly lower than control in some studies, Sz group still presenting a robust PDB phenomenon was well in line with the general pattern of responses of Sz cases in the analysis of previous studies (Kim et al., 2009, 2016; Wasserman et al., 2012; Matsuzawa et al., 2015; Zhang et al., 2015) (see also **Supplementary Figure 3**).

Notably, previous IGT studies usually deciphered the PDB phenomenon in accordance with the definition of the study of Bechara et al. (1994) and tended to report that patients appeared to choose more cards from disadvantageous decks fitting the assumption of EV viewpoint but overlooked the significant disparity between decks B and A with the same negative EV. The first Sz-IGT study observed that Sz cases made more choices from deck B than deck A (Wilder et al., 1998), in line with other Sz-IGT studies (Brown et al., 2015), supporting the GLF viewpoint. Sevy et al. did not find the group difference among a wide range of IGT behavioral measures but observed that the Sz group preferred deck B rather than deck A (Sevy et al., 2007). A newly published study displaying the four-deck format also revealed the group difference on the net score and also showed that Sz cases had the tendency of selecting high gaining frequency decks (Saperia et al., 2019). A meta-analysis study provided the evidence that net scores between Sz and control groups were significantly different; nevertheless, the Sz and control groups both preferred to choose deck B as well (Betz et al., 2018) (see also **Supplementary Figure 3**).

These outcomes indicate that net score as a derivative behavioral measure consisting of four decks glosses over the choices of each deck. This might partly explain why the PDB phenomenon was not initially discovered. In particular, the integration of net score could not properly reveal that participants preferred deck B with negative EV (Horstmann et al., 2012). Some studies suggest that the four-deck format should be measured and presented along with other IGT measures (Horstmann et al., 2012; Zhang et al., 2015). Simply observing net score overlooks the PDB phenomenon, which is completely contradictory to the EV viewpoint proposing that VMPFC-impaired cases cannot acknowledge the concept of EV and select more cards from disadvantageous decks with negative EV, while the control group can progressively learn the concept of EV and prefer advantageous decks with positive EV. Importantly, Pan et al. (2010) applied simplified IGT, (i.e., AACC and BBDD versions), and found that the Sz group choosing equally from decks B and D was insensitive to EV, violating the basic hypothesis of IGT. This suggests that GLF may be the dominant factor affecting the decision-making process of Sz cases (Pan et al., 2010).

The remarkable PDB phenomenon of Sz may stem from insensitivity to large monetary penalties (Heerey et al., 2008; Brown et al., 2013). Brown et al. designed an experiment based on the framing effect and found that Sz had risker behavior under a negative frame than controls under uncertain scenarios due to insensitivity to losses (Brown et al., 2013). Brown et al. assessed Sz cases with IGT and the Balloon Analog Risk Task (BART) and argued that Sz cases are more likely to have a reinforcement learning deficit, specifically involving the integration of frequencies and magnitudes of rewards and punishments in the trial-by-trial estimation of EV (Brown et al., 2015). A recent study also claimed that Sz cases demonstrated intact lose–shift behavior, but significantly reduced win–stay rates compared to healthy controls in IGT (Saperia et al., 2019). Failure to learn a successful strategy in the IGT may be linked to deficits in reversal learning in Sz (Fellows and Farah, 2004; Dunn et al., 2006). Researchers using distinct decision-making tasks suggested that Sz cases have impaired reversal learning ability, leading to value-based decision-making and reinforcement learning dysfunction (Fellows and Farah, 2004; Waltz and Gold, 2007; Sterzer et al., 2019).

Unstable Factors in IGT

Extensive analyses on a wide range of IGT outcome measures used in Sz-IGT studies show that EV measures are not suitable for discriminating the Sz group from the control group. This is consistent with several previously reported findings in relation

to Sz (Wilder et al., 1998; Bark et al., 2005; Evans et al., 2005; Rodríguez-Sánchez et al., 2005; Turnbull et al., 2006; Martino et al., 2007; Sevy et al., 2007; González-Blanch et al., 2008; Shirayama et al., 2010; Choi et al., 2011; Carvalho et al., 2012; Ayesa-Arriola et al., 2013; Premkumar et al., 2015; Pedersen et al., 2017). Likewise, GLF measures cannot be discriminative behavioral measures, consistent with three studies that found no significant difference in GLF measures (Rodríguez-Sánchez et al., 2005; Kester et al., 2006; Carvalho et al., 2012; Brown et al., 2015). Comparisons among several assessments specific to VMPFC dysfunction frontotemporal dementia cases revealed that IGT was not capable of detecting VMPFC impairment relative to other assessments (Bertoux et al., 2013).

Surprisingly, the same level of decision-making capability was shown in both Sz and control groups even if multiple lines of evidence suggested OFC dysfunction in cases with Sz, including evidence of reduced volumes (Larquet et al., 2010; Kanahara et al., 2013), task-evoked hypoactivity (Quintana et al., 2003), and impairments in reversal learning (Waltz and Gold, 2007). In addition to the Sz exhibiting the notable PDB, control showing a robust PDB is also observed (see **Figure 1**), which has been proved to be a stable phenomenon in a series of studies concerning original, modified, and clinical versions of IGT (Lin et al., 2007, 2009, 2012, 2013; Chiu et al., 2012; Fernie and Tunney, 2013). IGT performance of control had a considerable variation (Chiu et al., 2012), and another review paper also supported this line of thought (Steingroever et al., 2013). This might reveal a gap in IGT performance and an unstable selective pattern of control groups existing in Sz-IGT studies [detail review and analyses please see Xu (2018)]. The inconsistent observation of the IGT selective pattern of control is likely due to the heterogeneity of healthy participants with various demographic variables (Dunn et al., 2006; Chiu et al., 2012; Steingroever et al., 2013). Gender makes significant difference in deck selections, as women make more choices from deck B than from deck D compared to men (Overman, 2004; Singh et al., 2020). High-education and low-education groups perform significantly differently in terms of net score in the last two blocks (Evans et al., 2004). The older subjects preferred to choose more cards from disadvantageous deck A (Carvalho et al., 2012).

Correlations

It is reasonable to observe the correlation between WCST and IGT (deck B, deck D, net score) as some neuroimaging studies have reexamined that IGT is related to VMPFC and DLPFC (Fellows and Farah, 2004; Maia and McClelland, 2004; Lin et al., 2008; Li et al., 2009). Moreover, previous Sz-IGT studies also reported that the net score was related to WCST (Lee et al., 2009; Yip et al., 2009; Brambilla et al., 2013; Nestor et al., 2014), but only one study found deck D negatively correlated with perseverative errors (Shurman et al., 2005). The correlation between four decks and the WCST has been neglected in previous studies, which explains why few of them have found a relationship between decks with high winning frequency and the WCST. Every correct feedback as a reward imposes an impact on a selection made by the participants in assisting them to learn the rule and completing one category. The frequency of "right" feedback on WCST and the frequency of gains in IGT significantly affect the learning process.

On the other hand, we did not observe meaningful correlations between performance in IGT and the severity of positive symptoms in line with most published studies (Evans et al., 2005; Lee et al., 2007, 2009; Martino et al., 2007; Premkumar et al., 2008; Kim et al., 2009, 2012; Fond et al., 2013; Hori et al., 2014; Stratta et al., 2015; Pedersen et al., 2017), and the absence of correlation for negative symptoms is also supported by previous studies (Ritter et al., 2004; Evans et al., 2005; Kester et al., 2006; Lee et al., 2007; Martino et al., 2007; Premkumar et al., 2008; Kim et al., 2009, 2012; Struglia et al., 2011; Fond et al., 2013; Hori et al., 2014; Brown et al., 2015; Stratta et al., 2015; Pedersen et al., 2017) in Sz cases, which may be due to the generally low severity of symptoms of the Sz cases in our sample. Sz cases with delusion proneness selected more advantageously on the IGT relative to those scoring lower without delusion proneness (Runyon and Buelow, 2019). Participants in our study are chronic patients with relieved positive symptoms (i.e., delusion), and their decision-making behavior may not be guided by positive symptoms at this stage. An alternative explanation may be that the risky decision-making ability in IGT is not necessarily correlated with clinical symptoms.

Limitations and Future Directions

The first limitation of this study concerns the potential confounding effects that come from antipsychotic medication and doses of usage on IGT performance. Group difference on IGT performance was found in Sz cases under different drug therapies (Beninger et al., 2003). Betz and colleagues performed a meta-analysis study and showed that a higher dose of antipsychotic medication was associated with decreased net scores during early blocks and diagnosis was associated with a lower net score and moderated immediate gains in Sz (Betz et al., 2018). As our study included both Sz and SA disorders, different diagnoses likely affected decision-making performance in IGT. Second, the education level of Sz and control were not well-matched, which might be a potential confounding factor. Some evidence suggested that participants with lower education levels showed better performance on the IGT than those with higher education levels (Evans et al., 2004). Third, as for the study design, we did not counterbalance the order of IGT and WCST.

An adequate assessment of these issues is only possible in the context of a controlled clinical trial with randomized assignment to identical diagnoses, identical drugs, and well-matched education. Future studies should also consider making reasonable classifications, for example, different types of antipsychotic medicines, if the characteristics of the participants are diverse. The IGT version utilized in this study was the original version (1994) developed by Bechara's group instead of a clinical version: PAR IGT (2007) which has been claimed to examine reward-based decision-making deficit across 13 different neuropsychological disorders (Bechara, 2007). PAR IGT showed that participants made fewer deck B selections during the early trials (1–40) and later trials (41–100) relative to the original IGT (Buelow and Barnhart, 2017). However, the selective patterns of PAR and original IGT in the study by Buelow were

similar to our findings. Lin et al. recruited 72 healthy participants to investigate whether deck B was preferred in PAR IGT, and it turned out that PDB was stable in this clinical version (Lin et al., 2013). Further investigation regarding PDB in Sz is required to verify our findings in PAR IGT.

Conclusions

Both Sz and control groups exhibited the PDB phenomenon, and the net score, a combination of four decks, based on the EV viewpoint does indeed obscure the PDB phenomenon of Sz and control, making it difficult to observe the PDB phenomenon. GLF potentially imposes a considerable effect on two populations. IGT as a research tool enables researchers to observe the risky decision-making behaviors of participants under the guidance of several factors; however, it is not qualified as a clinical assessment to evaluate the decision-making functioning only judging based on the EV makers, since the PDB violates the EV hypothesis. Hence, future investigations should prioritize empirical experiments on clinical IGT and to confirm these observations reflected in Sz cases. In clinical scenarios, we strongly advise against evaluating and diagnosing decision-making dysfunction purely on the basis of net score on the clinical IGT.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board of Kaohsiung Medical University Chung-Ho Memorial Hospital [No. KMUHIRB-SV(I)-20150075]. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MX, W-KL, C-HK, Y-CC, and C-HL contributed to the conceptual innovation, literature review, experimental design, statistical analysis, and drafting of the study. More than two authors were involved in intense and frequent discussions whenever disagreements appeared. MX initially conducted the literature review, experimental design, data analysis, and data collection and finally drafted the initial study. W-KL concentrated on checking data, and provided constructive suggestions and thoughtful ideas in the draft of the study. C-HK screened eligible participants and provided suggestions regarding recruitment institutes and clinical assessments. Y-CC was constructed the whole study, provided partial research studies, gave critical suggestions, and revised the study. C-HL worked on constructing the structure of this study, data analysis, interpretation, provided vital ideas in discussion, development and refining of the study. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.619855/full#supplementary-material

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CONCEPTUAL ANALYSIS
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Reanalyzing the Maia and McClelland (2004) Empirical Data: How Do Participants Really Behave in the Iowa Gambling Task?

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Background: Since 2007, the Iowa Gambling Task (IGT) has been a standardized clinical assessment tool for assessing decision behavior in 13 psychiatric/neurological conditions. After the publication of Maia and McClelland's (1) article, there were two responses in 2005 from Bechara et al. and Maia and McClelland, respectively, discussing whether implicit emotion or explicit knowledge influences the development of foresighted decision strategies under uncertain circumstances (e.g., as simulated in the IGT).

Methods and Results: We reanalyze and verify the data obtained by Maia and McClelland (1) in their study "What participants really know in the Iowa Gambling Task" and find that decision-makers were lured into shortsighted decisions by the prospect of immediate gains and losses.

Conclusion: Although the findings of this reanalysis cannot support any arguments concerning the effect of either implicit emotion or explicit knowledge, we find evidence that, based on the gain–loss frequency in the IGT, participants behave myopically. This is consistent with most IGT-related articles (58 out of 86) in Lee et al.'s (2) cross-cultural review. Alternatively, under uncertain circumstances, there is probably no such thing as foresighted decision strategy irrespective of the proposed mechanisms of implicit emotion or explicit knowledge.

Keywords: implicit emotion, explicit knowledge, gain–loss frequency, Iowa Gambling Task, myopic, foresight, somatic marker hypothesis

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INTRODUCTION

Emotion has long been perceived as an uncontrollable horse (3) (e.g., in Plato's *Phaedrus*), the opposite of rationality. The Eighteenth-century philosopher Hume proposed the view that rationality is subservient to emotion (4). While a variety of arguments regarding the tension between emotion and rationality have been made in philosophy, literature (especially Shakespeare's works) (5), and psychology (e.g., Darwin and James) (6, 7), few studies [e.g., (8)] used an empirical approach to explore the influence of emotion and rationality on decision-making. In light of this omission, Damasio (9) and other researchers (10, 11) sought to address this gap by proposing the

somatic marker hypothesis (SMH), which holds that emotion is not subservient to rationality and, instead, has a positive effect on how rationality operates.

Bechara et al. (10) designed the **Iowa Gambling Task** (IGT) to verify the SMH (9) formulated by their University of Iowa research team, thereby creating an important theory and a tool for studying issues relating to emotion and decision-making. However, its conceptualization has also attracted a series of critiques (12), of which Maia and McClelland's (1) is one of the most prominent. Bechara et al. (10, 11) proposed that **implicit emotion** would help a healthy decision-maker in an IGT experiment to develop foresighted decision strategies allowing gains to be made. However, Maia and McClelland (1) argued that a participant could develop such strategies without having to tap into their emotions, as they would have already acquired **explicit knowledge** regarding gains during the earlier phases of the experiment. Among researchers, this debate has become the classic framework within which to examine the SMH, first developed by Damasio et al. (9–11).

In 2005, a research focus article (13) and a corresponding research focus response (14) were published debating whether implicit emotion or explicit knowledge dominate prescient decision behavior (e.g., pursuing the choice of a positive final outcome) in conditions of uncertainty. Following up on Maia and McClelland's (1) earlier critique, Bechara et al. (13), in their article, sought to address the issues that had been raised with respect to their original work (10, 11). Bechara et al. (13) considered that Maia and McClelland's (1) behavioral illustration was consistent with many economists' findings that decision-makers could be guided to the deviate choice depending on the guidance of prior knowledge. Therefore, they considered Maia and McClelland's (1) finding not to be harmful to the SMH. The SMH demonstrated that emotion plays a key role in decision-making under the unconscious and conscious process and provided the possible physiological evidence to illustrate this (13).

However, Maia and McClelland (14) countered that Bechara et al.'s latest account (13) elicited "many questions but no answers." Maia and McClelland (14) emphasized that their research finding (1) did not aim to show that the SMH was inaccurate but demonstrated that there are relatively simple alternative explanations regarding healthy decision-makers' behavior in the IGT. Healthy decision-makers developed explicit knowledge of the decks of cards in the very early stage that Bechara et al. (10, 11) observed. In other words, the SMH was not necessary to explain the decision behavior in the IGT. Therefore the IGT was redundant (14). The two research teams had not reached a consensus, and a significant issue remained unresolved.

In the present study, we discuss the unresolved issue in detail, and we reanalyze Maia and McClelland's (1) original data. We found that the data did not support the basic viewpoints of Maia and McClelland (14) or Bechara et al. (13) in terms of long-term outcomes. This issue initially arose in Maia and McClelland's (1) arguments against Bechara et al.'s IGT studies (10, 11). Our study reanalyzed the 2004 raw data (15) generated by Maia and McClelland (1) and found that the participants in that experiment preferred frequent and immediate gains, leading them to adopt myopic and ultimately loss-making strategies. This finding indicates that the implicit emotion and explicit knowledge components proposed by Bechara et al. (10, 11) and by Maia and McClelland (1), respectively, cannot provide a clear explanation concerning the participants' adoption of myopic decision strategies. Therefore, through a reanalysis of Maia and McClelland's (1) raw data, the present study sought to reinterpret these data from the perspective of **gain–loss frequency.**

Participants' Knowledge in the Iowa Gambling Task

Four decks of cards are used for the IGT (Decks A, B, C, and D; see **Table 1**), and each deck has a different gain–loss structure. With each block consisting of 10 trials, every time a card is drawn from Decks A or B, it is possible to win \$100 or lose money. The number of times a participant can lose money is not fixed. For the first 10 trials of Deck A, the third, fifth, seventh, ninth, and tenth cards could lead to a loss of \$150, \$300, \$200, \$250, and \$350, respectively. When drawing cards from Deck B, the ninth card could lead to a loss of \$1,250. Every time a card is drawn from Deck C or D, it is possible to win \$50 or lose money. For the first 10 trials of Deck C, the third, fifth, seventh, ninth, and tenth cards could lead to a loss of \$50. For Deck D, the tenth card could lead to a loss of \$250.

TABLE 1 | IGT gain–loss structure.

Deck type / Trial (1–10)	A Bad deck		B Bad deck		C Good deck		D Good deck	
1	100		100		50		50	
2	100		100		50		50	
3	100	**−150**	100		50	**−50**	50	
4	100		100		50		50	
5	100	**−300**	100		50	**−50**	50	
6	100		100		50		50	
7	100	**−200**	100		50	**−50**	50	
8	100		100		50		50	
9	100	**−250**	100	**−1,250**	50	**−50**	50	
10	100	**−350**	100		50	**−50**	50	**−250**
Final outcome (expected value)	**−250**		**−250**		**250**		**250**	
Number of gains/losses	**10 wins 5 losses**		**10 wins 1 loss**		**10 wins 5 losses**		**10 wins 1 loss**	
Net gain-loss	**5 wins 5 losses**		**9 wins 1 loss**		**5 wins 5 ties**		**9 wins 1 loss**	

Trials (1–10) *= the gain–loss state for each card in the four decks (Decks A, B, C, and D) under the original IGT's 10-trial gain–loss structure, participants would gain and loss money at the same time each trial. For example, the ninth trial of Deck B could lead to a gain of \$100 and a loss of \$1,250. However, when the IGT was performed using a 20-trial gain–loss structure, there were slight changes in the order of the cards and the corresponding amount of gains or losses (**Trials 11–20**). For example, in the 11th to the 20th trials for Deck B, the 14th trial could lead to a gain of \$100 and a loss of \$1,250.* ***Final outcome (expected value)*** *= tallied results for gains and losses over 10 trials.* ***Number of gains/losses*** *= total number of wins and losses over 10 trials.* ***Net gain–loss*** *= tallied results obtained after adding the amount gained and lost for each card over 10 trials. Source: Table content is based on (10, 16).*

Assuming that a block consisting of 10 trials is used as the standard for calculations, a participant who continues to choose Decks A or B for 10 trials will suffer a loss of $250 (final outcome/expected value), while a participant who chooses Decks C or D for 10 trials will win $250 (final outcome). Based on the final outcomes, Decks A and B are considered "bad" or disadvantageous decks. In terms of numbers of gains and/or losses and net gain–loss, Deck A generates five wins and five losses. Deck B contains many cards that lead to gains (i.e., nine wins and one loss). However, the card that could lead to a loss results in a considerable loss (i.e., $1,250). Decks C and D are considered "good" or advantageous decks, with Deck C having a net gain–loss of five wins and five ties, and Deck D containing many cards that lead to gains (nine wins and one loss). Although Deck D also contains a card that could lead to a significant loss (i.e., $250), the amount involved is much lower than the Deck B loss (i.e., $1,250). The net gain–loss values for Decks B, C, and D indicate that these decks offer frequent gains and infrequent losses (see **Table 1**). If a participant favors Deck B—a bad deck—during an IGT, this preference is referred to as a **prominent Deck B phenomenon** (PDB phenomenon) (17, 18).

Bechara et al.'s Research Results

Damasio et al. and Bechara et al. (9, 10) believed that the high degree of uncertainty in our world makes it difficult to rely solely on logical reasoning to manage ever-changing and complex situations. They also proposed that, in an appropriate situation, implicit emotion could help us make decisions. This view was tested by Bechara et al. (11) in their IGT experiment, which tracked the deck selection behavior of patients with **ventromedial prefrontal cortex** (vmPFC) lesions and of non-patients ("healthy" participants). They also measured participants' **galvanic skin responses** (GSR) during the deck selection process.

During the IGT experiment, a participant could choose to draw cards from any of the four decks, and immediate gain–loss feedback was provided when a card was drawn (see **Table 1**). The experimental process comprised 100 trials. However, the participants did not know the number of trials involved. At the start of the experiment, the two groups of participants showed a preference for the bad decks (A and B), which offered higher gains and losses but eventually led to losses. However, the healthy participants gradually gravitated toward the good decks (C and D), which offered lower gains and losses but ultimately led to gains. In contrast, the vmPFC patients continued to choose the bad decks. During the deck selection process, the healthy participants experienced changes in their GSR levels, while the vmPFC patients' GSR levels remained low. These findings indicated that, when faced with a bad deck, healthy participants were guided by their implicit emotion toward making advantageous decisions. In contrast, the vmPFC patients were unable to resist the bad decks due to their lack of implicit emotion, eventually causing them to suffer losses.

Bechara et al.'s (11) study demonstrated that, for normal participants, their gain–loss experience was recorded by their implicit emotion systems each time they drew a card. Between the early and late stages of the game, these participants gradually acquired knowledge about the pros and cons of each deck, and as a result, even though they were initially unsure about the quality of each deck, their somatic markers gradually guided them away from the disadvantageous decks and to the advantageous ones. Bechara et al. (11) stressed the importance of implicit emotion in rational decision-making as follows:

> The results suggest that, in normal individuals, nonconscious biases guide behavior before conscious knowledge does. Without the help of such biases, overt knowledge may be insufficient to ensure advantageous behavior.
>
> Bechara et al. (11) (p. 1293)

Maia and McClelland's Research Results

Concerning the IGT experimental structure, Maia and McClelland (1) conceived that normal participants would not have to rely on their implicit emotion when engaging in decision-making, because a decision-maker could acquire knowledge of the game during an early stage of the experiment. They argued that Bechara et al. (11) had been unable to observe participants' understanding of game knowledge because the questionnaire they used to measure the game knowledge of decision-makers was not sufficiently sensitive.

During the IGT experiment, to measure the level of game knowledge they had acquired, Bechara et al. asked the participants about their knowledge and feelings. Maia and McClelland (1) posited that these open-ended questions were too vague and made it difficult for participants to provide proper answers regarding their game knowledge. For this reason, Maia and McClelland (1) designed a new questionnaire with items that allowed participants to evaluate the quality of each deck, to provide the reasons behind their evaluations, and to indicate whether they understood the average net result, average win and loss result, and the number of losses expected over 10 trials for each deck. The items in this revised questionnaire enabled Maia and McClelland (1) to measure the participants' understanding of game knowledge directly.

Maia and McClelland's experiment (1) involved two groups. The first group participated in the replication experiment, in which the approach of Bechara et al. (11) (IGT experiment and two-item questionnaire) was utilized (**Supplementary Figure 1**). The second group participated in line with Maia and McClelland's approach (1) (IGT experiment and newly designed questionnaire). Each group had 20 participants, and no vmPFC patients or GSR measurements were included in the two approaches. The participants each underwent 100 trials, and their deck selection preferences for the four decks were recorded. Using Maia and McClelland's methodology, the corresponding questionnaire was used to measure participants' understanding of game knowledge. The experimental results revealed the following: First, there was a consistent relationship between participants' deck selection preferences and their game knowledge for those participants using Maia and McClelland's (1) approach [see Figure 2 in (11); **Supplementary Figure 2**]. Second, participants following the procedures of Bechara et al. (11) and Maia and McClelland (1) drew from the good decks 58.6 and 63.55 times, respectively (see **Table 2**). Third, no differences

TABLE 2 | Deck selection frequency: Bechara et al. (11) vs. Maia and McClelland (1).

IGT decks	Experimental approach	
	Bechara et al. (11)	Maia and McClelland (1)
Deck A	14.40	14.50
Deck B	27.00	21.95
Bad decks (Deck A+B)	*41.40*	*36.45*
Deck C	30.65	30.95
Deck D	27.95	32.60
Good decks (Deck C+D)	*58.60*	*63.55*

between the two groups were identified concerning the frequency with which the good decks were selected (see p. 2 of the Online Supplemental Information on Maia and McClelland's research). Although the questionnaire used in (1) contained many in-depth items, this did not influence the participants' deck selection preferences. The study by Maia and McClelland (1) successfully replicated the results obtained by Bechara et al. (11), whereby the preference for good decks among the healthy participants was the same:

> This analysis shows that, by using the methods of Bechara et al. … we replicated their statistically significant results; specifically, participants behaved advantageously when they were classified according to the criteria of Bechara et al. as being in either the hunch or conceptual periods (our Levels 1 and 2, respectively).
>
> Maia and McClelland (1) (p. 16077)

Maia and McClelland's (1) questionnaire (**Supplementary Figure 2**) also generated more precise measurements relative to Bechara et al.'s (11) questionnaire. This key study indicated that, during the early period of the experiment, participants already possessed explicit knowledge regarding the good and bad decks, and that this was reflected in their subsequent deck selection preferences. Accordingly, Maia and McClelland (1) inferred that implicit emotion is not required for the decision-making process—thereby clearly contradicting the SMH position. The respective studies adopted different positions concerning the role of implicit emotion and explicit knowledge in the formulation of foresighted strategies under uncertain circumstances.

Table 2 shows our analysis of participants' deck selection behavior under the two approaches [i.e., as reported in (11) and (1)]. The data indicate that cards were drawn from Deck B 27.00 and 21.95 times, respectively. In the two approaches, participants demonstrated a stronger preference for the bad Deck B than for the bad Deck A. However, based on the SMH, healthy participants should be (a) avoiding Decks A and B, and (b) showing similar preference levels for Decks A and B, as the results in the original IGT study showed (10).

Maia and McClelland's results (1) did not indicate the frequency with which the four decks were selected. Neither did they provide a direct description or verification of the preference for Deck B, as observed for the two approaches. However, our study reanalyzed Maia and McClelland's (1) data and created **Table 2**, which shows the number of times the four decks were selected and confirms the participants' preference for Deck B.

METHODS

A Reanalysis of Maia and McClelland's Research

Our study reanalyzed Maia and McClelland's data (1), specifically the number of times the participants selected each of the four decks. The data were first analyzed based on Maia and McClelland's open data (1) published in Steingroever et al. (15), but the participants' approaches were not clearly identified in this data. Therefore, to obtain the original data, Maia and McClelland (1) were contacted directly. The data extracted from (15) were then rechecked and rearranged in line with the original data (1). **Supplementary Table 1** shows the data rearranged for easy comparison and statistical testing.

RESULTS

Two-way ANOVA (conditions * decks) performed in our study indicated that there were no interaction effects between conditions (Maia vs. Bechara) and decks (A, B, C, D) (the analysis showed that the distribution did not meet the spherical hypothesis, and the Greenhouse–Geisser correction was adopted). However, the main effect of decks was shown to be significant [$F_{(1.836,\ 69.766)} = 9.343$, $p < 0.001$, $\eta_p{}^2 = 0.197$].

We conducted further *post hoc* analysis using a repeated measures method (one-way ANOVA) to analyze participants' deck selection preferences under each of the two approaches (19–21). Significant differences were identified in the results for the Maia and McClelland's study (1) [$F_{(1.640,\ 31.162)} = 5.483$, $p < 0.05$, $\eta_p{}^2 = 0.224$] and for the Bechara et al.'s study (11) [$F_{(2.003,\ 38.057)} = 4.448$, $p < 0.05$, $\eta_p{}^2 = 0.190$], concerning the number of times each of the four decks was selected (see **Figure 1**) (both distributions did not meet the spherical hypothesis, and the Greenhouse–Geisser correction was adopted). An LSD *post hoc* analysis indicated that, for the Maia and McClelland's study (1), the number of times Deck A was selected was significantly lower compared to the number of times Decks B ($p < 0.001$), C ($p < 0.01$), and D ($p = 0.001$) was selected. There was nonsignificant difference between Decks B and C, and between Decks C and D, in terms of the number of times they were selected, although the number of times Deck B was selected was significantly lower compared to the number of times Deck D ($p < 0.05$) was selected. For the Bechara et al. (11) study, the LSD *post hoc* analysis indicated that the number of times Deck A was selected was significantly lower compared to the number of times Decks B ($p < 0.001$), C ($p = 0.001$), and D ($p < 0.01$) was selected. Between Deck B, C, and D, the mean number of card selection was a lack of statistical significance.

In order to compare further the effect of conditions [Maia and McClelland (1) vs. Bechara et al. (11)] on the number of times that each deck (Decks A, B, C, and D) was selected and the good deck (Decks C and D) indicators, we performed the independent

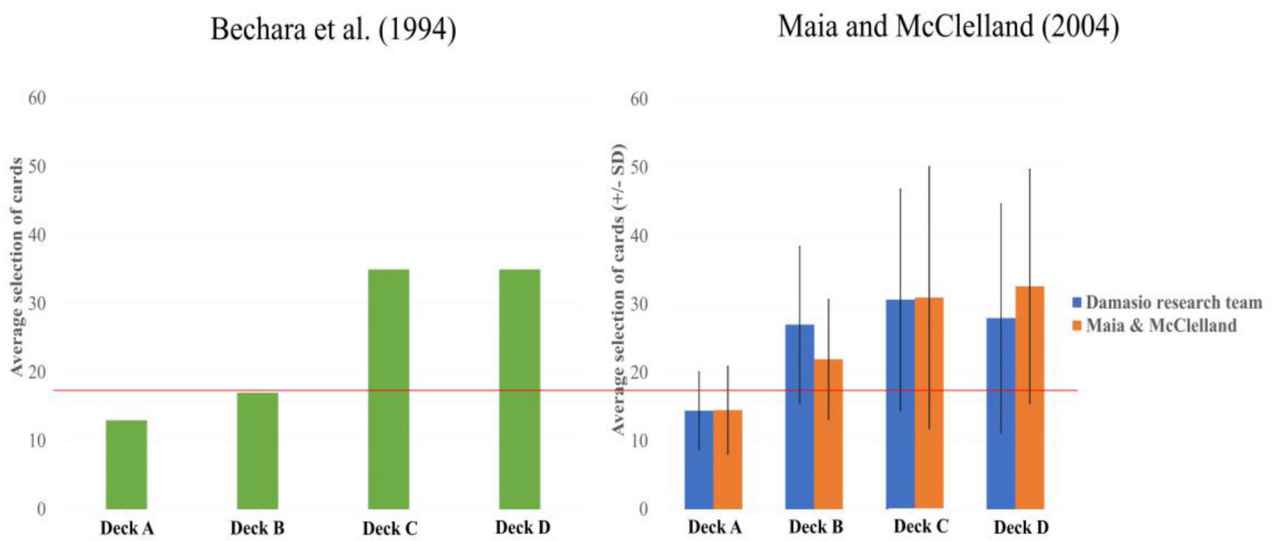

FIGURE 1 | The average deck selection frequency for the four IGT decks. Left-hand chart: data from the original experiment, as generated from Bechara et al. (10). Right-hand chart: the orange bars represent the data from Maia and McClelland (1), while the blue bars represent the results obtained by Maia and McClelland when they replicated the Bechara et al. (11) approach. This chart was generated from Maia and McClelland's (1) original data. The right-hand chart presents the average deck selection frequency in Bechara et al. (11) and the study of Maia and McClelland (1), taking their different methodologies (see also **Supplementary Figures 1, 2**) into account. The analysis shows that, following Bechara et al.'s (11) procedures, there was no difference in terms of participants' preferences for Decks B, C, and D. However, participants showed a lower preference for Deck B than for Deck D, indicating that Maia and McClelland's questionnaire had influenced participants by alerting them to the negative properties of Deck B, thereby reducing the frequency with which Deck B was selected. It should be noted that participants in both studies selected Deck B more often than Deck A, a result that counters the original hypothesis proposed by Damasio and by Bechara et al. (9–11), as well as the view held by Maia and McClelland that participants possessed explicit knowledge relating to gains. The color bars represent the mean number of card selections in each deck, and the error bars mark the 1 positive/negative standard deviation from the mean selection number of each deck. Due to the limited number of participants in Maia and McClelland's study, the error bars are only for presentation purposes and not for data correction.

samples *t*-test. The results indicated that, regarding the number of times each deck was selected and the good deck indicators, there were no statistically significant differences between the approaches of (11) and (1).

DISCUSSION

This reanalysis of Maia and McClelland's (1) data revealed two new phenomena. First, the questionnaire designed by Maia and McClelland allowed participants to focus better on the final outcome (expected value), with the bad Deck B being selected less often (21.95) than the good Deck D (32.60) (see **Table 2**), whereas, in the Bechara et al. (11) data, no differences were found between the bad Deck B and Decks C and D, thereby challenging the contention of Maia and McClelland (1) that the use of the questionnaire would only have a slight impact on participants' deck selection preferences. In addition, a separate study indicated that the Maia and McClelland questionnaire (1) does influence participants' decision-making (22, 23). Second, under the methodologies of (11) and (1), participants not only demonstrated a preference for Decks C and D (which offered frequent gains) and avoided Deck A (which led to frequent losses) but also exhibited a preference for Deck B (which offered frequent gains but ultimately led to losses); in other words, the PDB phenomenon. In addition, the Yen (23) study adopted the paradigm of the Maia and McClelland (1) experiment and also observed that the number of times Deck B was selected was more often than Deck A.

The Maia and McClelland study (1) did not generate results that were consistent with the views proposed in the original research conducted by Damasio et al. (10, 11) (see the chart on the left in **Figure 1**). All the participants, under the two approaches, demonstrated a preference for the bad Deck B. This is counter to the proposition that healthy participants will prefer the good decks and adopt a foresighted strategy. The consistent preference of participants for Decks B, C, and D and their avoidance of Deck A indicates that the gain–loss frequency factor was better able to guide participants' decision-making behavior—more than the implicit emotion and explicit game knowledge concepts proposed in Bechara et al. (11) and Maia and McClelland (1), respectively.

While the results from our reanalysis of Maia and McClelland's (1) data do not correspond to the argument proposed in that study, our finding that gain–loss frequency influenced the IGT performance of participants is not novel. It matches the findings of several prior studies (18, 24–26) that questioned the foresighted strategy concept proposed by Damasio and by Bechara et al. (9–11). The results obtained from our reanalysis of Maia and McClelland's (1) data are consistent with those from studies that revealed a preference for Deck B (2).

Random Deck Selection

Our analysis of the additional research data released to us by Maia and McClelland indicated that two participants, participants no. 36 and no. 41 [see p. 9–12, 15 of the Online Supplemental Information (1)], exhibited inconsistencies in their preference-related decision behavior and game knowledge. Maia and McClelland (1) defined this alternative preference-related behavior as **random deck selection**. For example, during the 30th trial, participant no. 41 experienced a second major loss with Deck B, after which they appeared to select the decks in a random manner. A further examination of participant no. 41's deck selection behavior revealed that Decks A, B, C, and D were selected 22, 32, 17, and 29 times [analysis based on data generated by Maia and McClelland (1), Supplementary Figure 7 on p. 9 of the Online Supplemental Information], indicating that participant 41 favored the bad Deck B and the good Deck D, both of which offered frequent gains.

According to the Online Supplemental Information containing Maia and McClelland's (1) research [(17), p. 9–12], participant no. 36 selected Deck B 11 times during the first 20 trials, resulting in a loss and a negative net final outcome. Although Deck B accounted for the biggest losses suffered by this participant, the description they provided regarding this choice revealed an understanding of Deck B as a deck that could lead to sudden and substantial losses, but also to substantial gains. Therefore, participant no. 36 determined that Deck B was a good deck and not a bad deck regarding the potential overall gains and losses (final outcome/expected value). In participant no. 36's oral report, they made the following observations regarding this matter:

> Because it seems good, because I won a lot of money in the beginning, and then all of a sudden, I lost, but it seemed like you could win a lot of money.
>
> [Maia and McClelland (1); Online Supplemental Information, p. 13]

Maia and McClelland (1) concluded that participants 36 and 41 had adopted a random selection strategy. Their behavior contradicted the researchers' hypothesis that participants would acquire knowledge regarding the good and bad decks during the early stage of the experiment. However, the two participants' deck selection behavior regarding Decks B and D also reflected their preference for frequent and immediate gains, matching the researchers' observations regarding gain–loss frequency (2). When we investigated the number of times Deck B was selected by the participants who followed Bechara et al.'s procedures (11) (27 times) and those of Maia and McClelland (1) (21.95 times), it is clear that Deck B was selected significantly more often than Deck A, and that both decks accounted for approximately a quarter (48.95/200) of the 200 trials—or, roughly, the average selection frequency for the four decks. These findings suggest that the participants in the study (1) did not strongly perceive Deck B to be a bad deck (see **Table 2** and the chart on the right in **Figure 1**). The various analyses—including those regarding participants 36 and 41, the analysis of the participants' preference for Deck B in both (11) and (1), and the analysis of the differences between the participants' preference for Decks A and B under both methodologies—that were carried out all indicated that the participants' deck selection strategy was not random. In addition, the gain–loss frequency had influenced their adoption of a **myopic decision strategy** when engaging in deck selection. This observation regarding gain–loss frequency contradicts the positions advanced in Bechara et al.'s (13) article and Maia and McClelland's response (14) concerning implicit emotion and explicit knowledge.

The Myopic Decision Strategy and Its Significance

Maia and McClelland (1) concluded that their questionnaire could effectively measure game-related explicit knowledge. Based on the assumption that participants could acquire gain-related knowledge through their deck selection experience during the early stage of the experiment, the researchers theorized that participants would not need to rely on their implicit emotions to develop a strategy characterized by a preference for good decks. Our study reanalyzed Maia and McClelland's (1) experimental data (1) and discovered that participants in that study had demonstrated a preference for bad Deck B over bad Deck A (i.e., the PDB phenomenon), suggesting that Maia and McClelland had not replicated the results from the original study (11), but had obtained results that contradicted prior views relating to implicit emotion and explicit knowledge. Although Maia and McClelland classified participant no. 41's decision-making behavior as a random strategy, it seems that this behavior was guided by gain–loss frequency and was not random. Similarly, participant no. 36's preference for Deck B during the early stage of the experiment (as indicated in the oral report) also indicates the influence of gain–loss frequency (2). Moreover, Maia and McClelland (1) believed that their questionnaire did not influence the participants' IGT performance. This is because Maia and McClelland analyzed the good decks (C and D) as a single entity. They did not examine participants' preferences for each of the four decks. However, our study considered the number of times each of the four decks was selected. We found that participants following Maia and McClelland's methodology selected the bad Deck B less often than those adhering to the approach identified in the study by Bechara et al. (11) (**Table 2**), a finding that suggests that the questionnaire influenced the experiment.

In proposing the concept of explicit knowledge and questioning the necessity of implicit emotion, Maia and McClelland's research (1) became a classic study used to examine the SMH. However, our analysis of Maia and McClelland's original data revealed that the participants had adopted a myopic decision strategy, thereby contradicting the inferences regarding explicit knowledge and implicit emotion. We posit that, compared to explicit knowledge and implicit emotion, gain–loss frequency should enable a more reasonable explanation. Moreover, it is consistent with the PDB phenomenon that several recent IGT-related studies have proposed (2, 17, 18, 24–26).

Cross-Cultural PDB Phenomenon and Clinical Implications

Lee et al. (2) considered 86 IGT-related studies that presented their data in the four-deck format, which allowed the mean number of each deck to be clearly compared and analyzed. This review showed that 58 out of 86 studies indicated the presence of the PDB phenomenon.

The above research shows that the performance of the control group is the basic reference point for comparison with clinical cases. Therefore, in our review, we revisited 41 out of these 86 studies, including the experimental groups of clinical cases diagnosed by the DSM or ICD system and the clinical cases of individuals with brain injuries (41/86 articles, 47.67%).

In the 41 IGT clinical studies, for the control groups, there were 23 studies where the mean number of Deck B selections was greater than 25, indicating that the PDB phenomenon was present (23/41, 56.1%). However, 28 studies had a significant net score difference between the experimental and control groups, indicating that, based on this survey, the net score might still be an effective differential index in most IGT clinical studies (28/41, 68.29%). Notably, 12 studies simultaneously revealed the PDB phenomenon and a significant net score between the experimental and control groups (12/41, 29.27%). This observation indicated that about 1/3 of studies revealed that two contradictory phenomena co-exist in the same studies. In addition, in 37 studies, the mean number for Deck B selection was larger than 20 (37/41, 90.24%) for the control group. An additional survey indicated that five studies identified that the mean number for Deck B selection was significantly larger than that for Deck A (5/41, 12.2%). Four studies indicated that the mean number for Deck B selection was significantly larger than for Deck A, and the mean number for Deck B selection was significantly larger than 20 (4/41, 9.76%). Moreover, only two studies demonstrated that Deck B selection was significantly larger than Deck A selection and that the net score was significant (2/41, 4.88%). Only one study (27) completely matched the results of Maia and McClelland (1) (B $>$ 20, B $>$ A, significant net score in control group).

In short, the present survey found that bad Decks B and A are not consistently avoided by the control group, as assumed in the original literature (1, 10, 11). This may be the main factor indicating that some clinical literature cannot distinguish between the behavioral performance of the experimental and the control groups based on the net score index (11/41, 26.83%). Nevertheless, the net score can distinguish effectively between the experimental and control groups in over 50% of studies (28/41, 68.29%). Therefore, the net score is not completely irrelevant. The PDB phenomenon that is identified is only inconsistent with the original assumption that the control group is assumed to choose more cards with high long-term outcomes (10). Consequently, this means that gain–loss frequency might be the most dominant guiding factor in decision behavior under uncertainty (2) and that the final outcome/expected value might be a secondary factor. Furthermore, an increasing number of IGT clinical studies compared the selection strategies of neurological/psychiatric patients and control groups found that the control group participants chose Deck B significantly more often than Deck A (24, 27–31). The number of clinical cases exhibiting the PDB phenomenon during IGT has yet to be established. There is a need for a global survey of experimental groups in IGT clinical studies.

Back to Plato's Chariot Allegory

Even though the emergence of SMH has led to a stronger focus on emotion-related topics, an increasing number of studies that contradict the hypothesis seem to be returning to the supposition that the role of emotion in decision-making is, as in Plato's allegory, a "difficult-to-control chariot." Explicitly, it is difficult to rein in emotions through the application of rationality. This could be due to development strategies derived from emotion and adapted to the limitations of life. In an ever-changing or uncertain environment, the fact that decisions are influenced by the prospect of immediate gains and losses could constitute a valuable survival strategy. Therefore, the myopic nature of such decisions may have survival-related significance. From the perspective of a limited life and bounded rationality (32), it would not be entirely irrational for decision-makers to develop myopic strategies based on gain–loss frequency.

The concepts of somatic markers and explicit knowledge, which were, respectively proposed by Damasio, Bechara et al. (10, 11), and Maia and McClelland (1), assumed that decision-makers are rational economic individuals (13, 14) who adopt foresighted strategies (1). The difference between gain–loss frequency and somatic markers and explicit knowledge is not unlike the difference between myopia and foresight, debates regarding which have been the focus of decision-making research discussions for the last 70 years (32, 33). A series of empirical results (34) gradually strengthened earlier hypotheses (32) regarding the role of bounded rationality in human decision-making. In an uncertain situation, a decision-maker may deal with the prospect of immediate gains and losses in a myopic but rational manner. Given the above-noted limitations of life, the implementation of myopic strategies could be a response to sudden changes in the environment, as well as to a rational rule of survival. We derived this alternative inference through our observation of participants' myopic decision strategies in the reanalysis in the present study of Maia and McClelland's original data. It is noteworthy that the clinical version of the IGT has been gradually utilized to assess, mostly based on the "foresighted" perspective, decision behavior for 13 types of psychiatric/neurological conditions. However, decision behavior cannot be said with certainty to be driven by "implicit emotion" or "explicit knowledge." It should be noticed when experimenters or clinical psychiatrists interpret decision behavior by considering the "foresighted" perspective in the clinical version of the IGT (35, 36).

CONCLUSIONS

Based on the basic assumption of long-term outcome, the research teams of Damasio and Maia and McClelland argued,

respectively, that in the "late or early stage," healthy decision-makers "have a hunch or know" the gain–loss structure of IGT. However, the present reanalysis points out that this argument might not be a critical issue. The key issue should be the study of why healthy decision-makers behave myopically in the IGT. Our reanalysis identified that the findings of studies (1, 10, 11), which maintain the same foresighted standpoint, were incongruent with those we obtained from the reanalyzed data of Maia and McClelland. Therefore, according to the present analysis, the Bechara et al. vs. Maia and McClelland debate, as featured in the April 2005 issue of *Trends in Cognitive Sciences* (13, 14), was unwarranted and should be reformulated. In short, we suggest that the issue of "What do participants in the IGT really know?" may still be controversial. However, we identified that participants behave based on gain–loss frequency.

AUTHOR CONTRIBUTIONS

Y-CC and C-HL initiated the present academic topic and literature review, defined the controversial issue, arranged the main structure, and refined the manuscript. Y-CC drafted the preliminary draft. W-KL and C-HL provided the data reanalysis, statistical testing, and parts of the data interpretation. J-TH, Y-CC, C-JL, and C-HL engaged in several rounds of critical discussion. C-HL and C-JL provided the final corrections and confirmations for all references. Y-CC, C-HL, W-KL, C-JL, and J-TH were responsible for the overall discussion and the final manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyt.2022.788456/full#supplementary-material

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