



Experience-based decisions and brain activity: three new gaps and partial answers

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Experience-based decisions can be defined as decisions emanating from direct or vicarious reinforcements that were received in the past. Typically, in experience-based decision tasks an agent repeatedly makes choices and receives outcomes from the available alternatives, so that choices are based on past experiences, with no explicit description of the payoff distributions from which the outcomes are drawn. The study of experience-based decisions has long roots in the works of mathematical psychologists during the 1950s and 1960s of the last century (e.g., Estes and Burke, 1953; Bush and Mosteller, 1955; Katz, 1964). This type of task has been viewed as a natural continuation of the behaviorist tradition involving animals as subjects, and multiple trials in which feedback is obtained on each trial. During the 1970s and 1980s seminal studies focusing on choices among descriptive gambles began to dominate the field of Judgment and Decision Making, paving the way for the successful and influential works of Tversky and Kahneman (e.g., Kahneman and Tversky, 1979). Indeed, a review of the decision making literature from 1970 to 1998 conducted by Weber et al. (2004) shows prominent use of description-based tasks over experience-based tasks.

Yet the study of experience-based decisions has continued to evolve. Some of the workers in this subfield were neuropsychologists who used experience-based tasks as a natural way to evaluate individual differences owing to these tasks having many choice trials (e.g., Bechara et al., 1994). Others were interested in the complex relations between learning and decision making (Erev and Roth, 1998). An interesting finding that has finally defined the importance of contrasting the two types of tasks – experience-based decisions and description-based decisions, was obtained by Ido Erev and his colleagues. Kahneman and Tversky (1979) showed that individuals overweight small probability events in their decisions

from description. For instance, in selecting between an alternative producing \$3 for sure or a gamble producing 10% chance to receive \$32 (and otherwise zero), most people pick the riskier alternative, behaving as if they give greater weight to the relatively rare event (see Hau et al., 2009). Erev and colleagues have demonstrated a reverse phenomenon in decisions from experience (Barron and Erev, 2003; Hertwig et al., 2004; Yechiam et al., 2005). People tend to experientially select alternatives as if what happens most of the time has more weight than the rare event. Thus, people overweight small probability events in decisions from description while underweighting them in decisions from experience. This has been referred to as the description–experience (D–E) gap (Hertwig et al., 2004). The studies exploring the D–E gap were followed by further investigations examining the divergent and convergent processes in these task types (e.g., Rakow et al., 2008; Barron and Yechiam, 2009; Wu et al., 2011).

In parallel to the recent advancements in experience-based decisions within the field of Judgment and Decision Making, there have been numerous studies of this type of decisions in Neuroscience. For example, the feedback-based error-related negativity (fERN; see below; e.g., Gehring and Willoughby, 2002) and the role of non-declarative knowledge in selecting advantageously (Bechara et al., 1997) were found in experience-based decisions. Several studies have explicitly showed that that experience-based tasks result in higher correlation between studied brain variables and over behavior. For example, in Aharon et al.'s (2001) fMRI study, participant evaluated the attractiveness of face images either descriptively or by making choices and receiving feedback. Brain activation levels in the reward circuitry (particularly, the nucleus accumbens) matched the evaluation patterns only in the experiential condition. Similarly, severe damage to the

orbitofrontal cortex was found to lead to decision impairments in experience-based tasks, but not in description-based tasks (Leland and Grafman, 2005). Still, many of the investigations of these neuroscientific aspects have borrowed their theoretical underpinning from the study of decisions from description, and have not been guided by relevant theories of experience-based decisions. At the same time, many of the decision making studies of experience-based tasks have taken place without awareness of the relevant brain studies using this paradigm.

In an attempt to highlight the necessity of integrating the two bodies of research (JDM and neuroscience studies), we present three dissociations (or “gaps”) between brain activation patterns and behavioral choices in these tasks. The majority of this paper is devoted to describing the three gaps in order to encourage further research. Additionally, we also suggest some directions for exploring and explaining these inconsistencies.

THREE BRAIN-BEHAVIOR GAPS IN EXPERIENCE-BASED DECISIONS BRAIN ACTIVATION AND BEHAVIORAL RESPONSES TO RARE EVENTS

The very famous “oddball” paradigm examines people's brain responses following low-probability events compared to more frequent events. The typical result is an elevated fronto-central signal approximately 300 ms following the rare event, which is known as P300. The original oddball paradigm normally required a response following the rare event, and thus confounded the rarity of the event and its performance requirements (Squires et al., 1975). Yet the same findings were also replicated in task-irrelevant rare events (Debener et al., 2005) and in reward prediction tasks (Karis et al., 1983). The elevated neural activation following the rare event appears to be inconsistent with the tendency to *underweight*

rare events in experience-based decisions. One might argue, though, that the dependent variable in decision tasks (i.e., the choice proportion) is also affected by the size of the rare payoff, and this component may be insufficiently integrated upon making choices. Still, this would be inconsistent with the standard way in which the underweighting phenomenon is explained (Hertwig et al., 2004). Moreover, as we shall see below, inconsistency between brain activation

and behavior also emerges when the target event (e.g., a loss) is similar in size to the control event (e.g., a gain).

BRAIN ACTIVATION AND BEHAVIORAL RESPONSES TO LOSSES

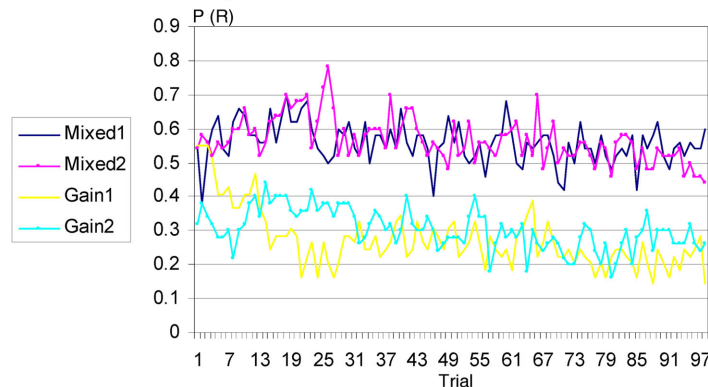
In a seminal EEG study, Gehring and Willoughby (2002) demonstrated that a large portion of the frontal cortex exhibits greater rapid activation following losses than following equivalent gains. This

event-related brain potential (ERP) has been referred to as medial frontal negativity (MFN; Gehring and Willoughby, 2002) or fERN (Yeung and Sanfey, 2004). Gehring and Willoughby (2002) suggested that the existence of the increased cortical response following losses is consistent with the behavioral principle of “loss aversion,” which denotes an increased subjective weight of losses compared to gains (Kahneman and Tversky, 1979). Furthermore, they argued

The payoffs in Ert and Yechiam (2010):

Condition	Safe alternative	Risky alternative
Mixed1	Get 0	50% to win 1000, 50% to lose 1000
Mixed2	Get 0	50% to win 2000, 50% to lose 2000
Gain1	Win 1000	50% to win 2000, 50% to get 0
Gain	Win 2000	50% to win 4000, 50% to get 0

The results in Ert and Yechiam (2010):



The payoffs in Yechiam and Telpaz (in press):*

Condition	Safe alternative	Risky alternative
Mixed	Get 0	50% to win 200, 50% to lose 200
Gain	Win 200	50% to win 400, 50% to get 0
Loss	Lose 200	50% to lose 400, 50% to get 0

* A noise factor of -1,0, or +1 was added to each outcome.

The results in Yechiam and Telpaz (in press):

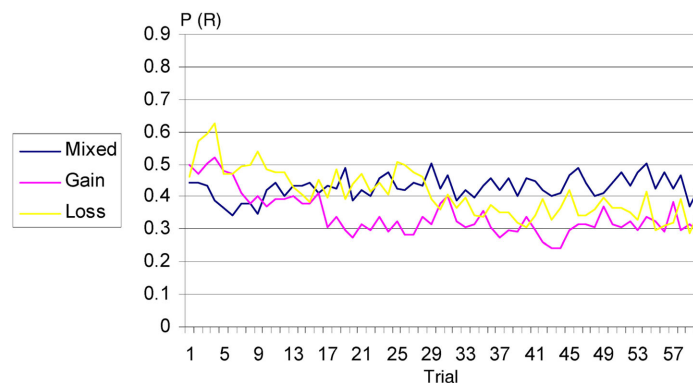


FIGURE 1 | Risk taking in two studies of experience-based decisions. Top: Ert and Yechiam (2010). Bottom: Yechiam and Telpaz (in press). Each task involves the selection among a Safe option (S) and a Risky option (R). The results show

the mean proportion of selections from the risky alternative in each trial [P(R)] in different conditions. The participants take less risk over time when payoffs are predominantly gains or losses but not in mixed gains and losses.

that the asymmetric fERN response to losses represents the brain mechanism directly contributing to the representation of subjective value, or “instant utility.” However, in Gehring and Willoughby’s (2002) research, as in other studies of experience-based decisions (e.g., Erev et al., 2008; Silberberg et al., 2008; Hochman and Yechiam, 2011; Yechiam and Telpaz, 2011, in press), participants actually made behavioral choices as if they were loss neutral and not loss-averse. Specifically, the fERN was observed in choices between an alternative producing +5 or –5 US cents and a second alternative producing +5 or –25 cents. Loss aversion implies that in choice between a pair of alternatives with symmetric gains and losses, individuals should prefer the alternative producing lower losses. However, the two choice alternatives were selected at about the same rate.

This gap was replicated in follow-up ERP studies, some using higher payoffs (e.g., Nieuwenhuis et al., 2004; Yeung and Sanfey, 2004; Masaki et al., 2006). It has also been demonstrated in studies of autonomic arousal: Losses were found to have greater effect on pupil diameter and heart rate, even in the absence of reliable loss aversion (Hochman and Yechiam, 2011; Yechiam and Telpaz, 2011). Interestingly, the ERP studies noted above did not make a big issue out of this discrepancy, and did not consider it as deserving special attention. Yet we feel that it is a critical issue because participants make experiential choices as if they are loss neutral while their brain acts as if it is loss sensitive.

THE EFFECT OF EXPERIENCE ON RISK TAKING

The third brain–behavior gap we would like to draw attention to involves a discrepancy between what is known about the dynamic function of the dopaminergic system and experiential choice behavior. Under current models of the striatum, the dopaminergic system adapts to reinforcement using a “Delta” learning rule (Rumelhart et al., 1986), whereby a new outcome from a given alternative is compared to the expectancy of the alternative prior to the outcomes, and the expectancy is updated as a function of the difference between the new outcome and the old expectancy. Brain areas within the striatum were found to exhibit activation patterns consistent with the implied mechanism of the delta rule (Schultz et al.,

1997). This rule axiomatically leads to a clear behavioral prediction involving the effect of experience on risk taking behavior (Niv et al., 2002; Denrell, 2007): Under the Delta rule, decision makers should be more risk averse with experience because they invariably sample the risky alternative in a biased fashion. For example, say that in an experience-based decision you have a choice between getting zero for sure and a risky alternative producing equal chances to win or lose \$10. In the first 10 trials in which the risky alternative is chosen there is about 40% chance that *in reality* the likelihood of winning \$10 will be less than 50%. This can lead participants to avoid the risky alternative in future choices. Moreover, as soon as the risky alternative is avoided, there is no mechanism that reduces this bias. The chance of biased sampling from the risky alternative continues in the next trials as well, and under the Delta learning rule, it is expected to slowly lead participants away from the risky alternative. But this is not how participants behave in experiential tasks! In several studies involving such symmetric risky alternative (with equal chance of winning or losing) participants were found to show remarkable flatness in their learning curves (see **Figure 1**). This gap between the mechanism considered to govern learning and actual experiential behavior in tasks involving mixed gains and losses bears some similarity to the issue of loss sensitivity because in both cases the brain activation pattern is in the direction of avoiding risk (and potential losses) while behavior leans toward risk neutrality¹.

PARTIAL ANSWERS

A technical way out of these gap involves the typically different temporal resolution of brain activation measures and behavioral choices. The fERN patterns, for instance, were revealed in the first 300 ms after the choice outcomes are presented. However, in most studies, decision makers are given much more time to make behavioral decisions. Thus, behavioral loss neutrality might be the product of delayed brain processes implicated in executive control. For instance, some executive functions of verbal working

memory have been known to result in activation peaks approximately 600 ms after the relevant stimuli (Gunter et al., 2000) and even later (Tu et al., 2009). Still, while this is a possible interpretation for these gaps, it is quite tentative as the relevant delayed processes have not been uncovered.

An alternative suggestion is that the rapid fronto-central activation following monetary outcomes does not represent “instant utility” weighting of these outcomes (as proposed, for instance, by Gehring and Willoughby, 2002). Possibly, it could represent an attentional phenomenon. We (Yechiam and Hochman, 2011; Yechiam and Telpaz, 2011) suggested that an encompassing increase in frontal activation may represent the intensity of the attentional orienting response. Attention may be drawn by losses for instance, and this may increase the overall investment of cognitive resources in the task, in a symmetric fashion to both gains and losses. A related explanation involves the surprise value of incentives (Nevo and Erev, 2011). Under these explanations, the noted gaps are accounted for by the assertion that brain activation to incentives may represent cognitive processes that do not have a direct effect on the subjective valuation of the stimuli that have elicited them.

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¹Risk neutrality over time is also inconsistent with Kahneman and Tversky’s (1979) “loss aversion” hypothesis. As noted in Section “Brain Activation and Behavioral Responses to Losses,” studies of experience-based decisions (e.g., Erev et al., 2008) typically do not find reliable behavioral manifestations of loss aversion. The studies reported in Figure 1 replicate this pattern.

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