EATING BEHAVIOR AND FOOD DECISION MAKING IN CHILDREN AND ADOLESCENTS

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EDITORIAL
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Editorial: Eating Behavior and Food Decision Making in Children and Adolescents

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Keywords: eating behavior, food choice, food preferences, dietary self-control, pediatric obesity, energy intake, children, adolescents

Editorial on the Research Topic

Eating Behavior and Food Decision Making in Children and Adolescents

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Obesity is a persistent societal health problem that has lasted for several decades. Developing healthy eating habits early in life is one of the major keys in establishing healthy lifestyles and preventing and treating obesity. Despite our current efforts to reduce the rate of obesity in children, trends project that more children and adolescents will be affected by obesity than previously seen. Encouragingly, scientists and health professionals have identified obesogenic characteristics of adults with obesity and have targeted those characteristics for obesity interventions. However, precursors or obesogenic characteristics of childhood obesity have not been fully identified. Early prevention and intervention could be crucial to reduce the prevalence of obesity and to improve the physical and mental health of individuals early in life. Therefore, more proactive approaches are needed. These could include promoting the development of healthy eating habits and identifying children at high risk of developing obesity to allow for early intervention prior to excessive weight gain. Further investigation on behavioral characteristics and neural mechanisms of pediatric obesity is warranted for effective obesity prevention and treatment.

Food decision-making is a complicated process involving an interplay between internal factors (e.g., interoceptive signals of hunger, dietary self-control) and external factors (e.g., family eating practices, food marketing). Healthy food choices are more demanding in children because food taste is a primary determinant, while food healthiness is far less considered. Dietary self-control does not work effectively at this developmental period to delay gratification resulting in food choices that satisfy immediate urges to eat energy-dense, highly palatable foods. In addition, appetitive traits reflect comparatively passive food experiences through parental eating behavior and feeding practices from prenatal periods. These challenges raise questions regarding how children learn to integrate all those signals, and how they learn to make healthy eating decisions and eventually build healthy eating habits. Therefore, this Research Topic aims to display the multifaceted mechanisms underlying the development of eating behavior and food choices from infancy to adolescence. The goal of this Research Topic is to illuminate effective strategies for promoting healthy eating and decreasing obesity in young populations.

OVERVIEW OF CONTRIBUTIONS

Food Choices

The first line of contributions focuses on the development of food choices in children and adolescents. Particularly, Eagleton et al. examined how the relative reinforcing value of high energy-dense foods (i.e., cookie) and that of low energy-dense foods (i.e., fruit) were related to obesity in children aged 3–5 years from low-income families attending Head Start. Their results suggested that developing the high reinforcing value of high energy-dense foods may contribute to obesity in boys with increasing age. Fuchs et al. conducted a within-subjects laboratory food intake study to examine how food decision-making processes influence energy intake and weight status in children aged 7–11 years. Their results suggested that children with a perseverance tendency in decision-making (i.e., repeating the same choice after a positive/rewarding experience) tend to consume high energy, which may contribute to weight gain. Serrano-Gonzalez et al. examined developmental changes of food perception (health and taste attributes) and food preferences in individuals aged 8–23 years. Their results suggested that children and adolescents with higher central adiposity are more likely to develop preferences for high-calorie foods and higher taste importance in food choices over time. Papantoni et al. conducted a longitudinal study of examining taste sensitivity, taste liking, dietary intake, and BMI percentiles of adolescents aged 14–16 years over 4 years. Their results suggested that adolescents with lower sweet taste sensitivity have a higher hedonic response to high-sugar foods, and those with high daily fat consumption are more likely to develop a preference for high-fat/high-sugar foods. In addition, food rejection was examined from a food decision-making perspective. Pickard et al. examined how food rejection would be associated with the development of taxonomic (e.g., bread and pasta) and thematic (e.g., bread and butter) food knowledge in children aged 3–6 years. Their results suggested that children are more likely to reject food with poor thematic food knowledge possibly due to a lack of exposure to various foods and associations. Foinant et al. examined how positive and negative reasoning of food health-related properties influences food choices in children aged 3–6 years. Results suggested that food neophobic children may make lower-risk food choices by generalizing negative reasoning to prevent potentially harmful consequences from consuming foods. These contributions suggest that children and adolescents who have developed taste- or reward-oriented decision-making would display high unhealthy food intake and/or weight gain. In addition, children who have developed negative reasoning about food or less exposure to different food would show high food rejection.

Self-Regulation

The second line of contributions focuses on self-regulation and eating in the absence of hunger in children. Giuliani and Kelly investigated how dietary self-regulation (i.e., delay of gratification) and general self-regulation (i.e., attentional control and inhibitory control) would predict eating behaviors after 1 year in children aged 3–6 years. They reported that longer delay of gratification was related to high caloric intake in the absence of hunger, but the effect of delay of gratification was not significant when general self-regulation was controlled. Children with a poor delay of gratification and inhibitory control consumed the most calories. Philippe et al. examined how children's weight status, inhibitory control, and maternal feeding practices were associated with eating in the absence of hunger in children aged 2–6 years. They reported that children with higher BMI z-scores, lower inhibitory control, and higher maternal control were more likely to eat in the absence of hunger. Mason et al. proposed that decline in physical activity in middle childhood and poor inhibitory control would contribute to loss of control eating when children transit into adolescence. These contributions suggest that children who have developed poor dietary and/or general self-regulation are inclined to consume high energy in the absence of hunger, which could contribute to weight gain.

Parents and Peers

The third line of contributions focuses on parental and peer influences on children's eating behaviors. Kong et al. reported that infants aged 9–15 months were exposed early to hyper-palatable foods (e.g., foods with high fat and sodium, high fat and sugar, or high carbohydrates and sodium) as they transitioned to adult foods offered by caregivers. Trevino et al. reported that emotional eating was more likely to be transmitted from parent to child with more use of maternal restrictive feeding practices and paternal emotion regulation, instrumental, and restrictive feeding practices in children aged 5–13 years. Solano-Pinto et al. reported that body dissatisfaction of boys aged 9–11 years was related to both own and maternal desire for ideal body image, approach to change through diet, and BMI, whereas body dissatisfaction of girls was only related to own factors, which may suggest that pressure to ideal body image would be internalized earlier in girls. Ziegler et al. reported on food-related behaviors in which adolescents aged 13–17 experience a range of autonomy. They also showed that factors such as time with peers and parental control can enhance or infringe on this autonomy. These contributions suggest that parental feeding practices, eating behaviors, and peer influence impact the development of eating habits in children and adolescents.

Intervention

The last line of contributions in this issue focuses on intervention to promote healthy food choices. Porter et al. conducted food-specific inhibition training using a Go/No-Go task for children aged 4–10 years. Their results suggested that improving inhibitory control to energy-dense foods via food-specific inhibition training would promote healthy food choices. Ha et al. conducted a food advertising literacy intervention using cognitive and affective narratives presented after food commercials in videos in children aged 8–12 years. Their results suggested that enhancing resilience to food commercials by improving cognitive skepticism and critical thinking toward food advertising would promote less taste-oriented, more self-regulated eating decisions. These contributions suggest that providing intervention targeting to improve inhibitory control and cognitive defenses to external food cues would promote healthy food decision-making in children.

FUTURE DIRECTIONS

Contributions to this Research Topic provide ample implications for future studies that would advance our understanding of the development of eating behaviors and food decision-making. First, the results of studies that examined food choices warrant further investigation on how children develop a reward-oriented or risk-aversive food decision-making pattern that contributes to high energy intake and obesity or food rejection, respectively. Next, studies that examined the role of self-regulation in eating in the absence of hunger suggest that more research is needed to delineate both unique and common effects of various self-regulation skills on the development of healthy and unhealthy eating behaviors. The results of studies that examined parent and peer influences on eating behaviors demand future studies that explore how parent and peer influences increase risks of unhealthy eating and weight gain at a different age, sex, or sociocultural environment. Last, results of intervention studies aimed to improve healthy food choices urge the development of timely and effective prevention and intervention programs bound to scientific research to promote healthy eating and weight management in children and adolescents. Contributions to this Research Topic sheds light on mechanisms underlying the development of eating behaviors and food decision-making in young populations.

AUTHOR CONTRIBUTIONS

O-RH wrote the first draft of the editorial. All authors contributed to manuscript review and editing.

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MINI REVIEW
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New Insights Into Causal Pathways Between the Pediatric Age-Related Physical Activity Decline and Loss of Control Eating: A Narrative Review and Proposed Conceptual Model

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Research consistently suggests that loss of control (LOC) eating in children and adolescents is a key factor contributing to pediatric obesity and eating disorders. However, causes of pediatric LOC eating are yet unclear, and there is a lack of longitudinal research investigating the developmental processes contributing to LOC eating and related outcomes in youth. Physical activity is an understudied behavior that declines during middle childhood to adolescence and may exert an influence in the development of LOC eating *via* its impact on executive functioning. While physical activity levels and executive functioning have been linked to regulation of eating, no research has examined the mechanistic processes by which these domains may together impact LOC eating during childhood and adolescence. In the current narrative review, a model is proposed that suggests how physical activity and executive functioning influence LOC eating and related outcomes during childhood and adolescence. This model has the potential to influence future theoretical models of pediatric LOC eating and guide future prevention and intervention efforts.

Keywords: loss of control eating, physical activity, executive functioning, inhibitory control, pediatrics

INTRODUCTION

As children transition from childhood to adolescence, they become increasingly responsible for their own eating behavior – including types of food eaten, how much food is eaten, and when they eat (Bassett et al., 2008). In the obesogenic food environments that are omnipresent in modern society, ability to self-regulate eating and control responses to food are critical for prevention of negative pediatric health outcomes including obesity, type 2 diabetes, and eating disorders. Loss of control (LOC) eating is a behavior that is characterized by a subjective sense of LOC over what or how much one is eating (irrespective of quantity consumed) and is associated with elevated caloric intake particularly from snacking and intake of energy-dense foods (e.g., fast food and sweets) as well as eating disorder pathology and mood and anxiety disorders (Goldschmidt et al., 2017).

LOC eating begins to emerge across middle childhood into adolescence, with recent data showing that up to 30% of children and adolescents with overweight or obesity report LOC eating with similar prevalence across sex (He et al., 2017). Importantly, children who report LOC eating are more likely to gain weight over time and develop full syndrome eating disorders and/or mood and anxiety disorders (Goldschmidt, 2017; Byrne et al., 2019). Specifically, previous data show that LOC eating predicts sub- or full-threshold binge-eating disorder diagnosis and greater global eating disorder psychopathology (Tanofsky-Kraff et al., 2011; Hilbert et al., 2013). Despite the prognostic relevance of LOC eating for longer-term psychological and physical health, the etiology and maintenance of LOC eating in youth remains poorly understood, as predominant theoretical models of disordered eating (e.g., affect regulation and interpersonal models) have not held up consistently in children and adolescents (Hilbert et al., 2009; Ranzenhofer et al., 2014; Goldschmidt et al., 2018b). This is a crucial problem for prevention and intervention efforts, which is further evidenced by the limited efficacy of existing weight management and eating disorder interventions in children.

PHYSICAL ACTIVITY DECLINE IN MIDDLE CHILDHOOD AND ADOLESCENCE

Alongside observed increases in LOC eating during middle childhood and adolescence, there is a well-documented age-related decline in physical activity levels as children enter middle childhood and puberty, such that only 24.8% of youth ages 12–15 meet physical activity guidelines of daily moderate-to-vigorous physical activity for at least 60 min (Fakhouri et al., 2014). This decline is not well-understood, but may be driven by biological factors (Belcher et al., 2013; Spruijt-Metz et al., 2013), environmental and psychosocial factors (Sallis et al., 2000), or decreases in participation in organized sports (Perez et al., 2017; Kemp et al., 2019). In addition to decreasing physical activity, sedentary behaviors increase during adolescence. Taken together, middle childhood through adolescence are critical years during which LOC eating develops and physical activity levels are simultaneously declining.

PHYSICAL ACTIVITY AND PEDIATRIC LOC EATING

Although physical activity and LOC eating share intriguingly similar developmental timeframes during which significant changes in these behaviors occur, they are almost entirely studied apart from one another. Consistently, recent reviews of the literature on LOC eating in youth did not discuss physical activity as relevant risk factor for LOC eating (Byrne et al., 2019; Tanofsky-Kraff et al., 2020). Nevertheless, mounting evidence suggests that higher overall physical activity may exert beneficial effects on eating behavior, and this is supported by studies in adults showing that higher levels of physical activity are related to better appetite regulation, reduced food cue responsivity, and less binge eating (Joseph et al., 2011; Luo et al., 2018). Similarly, among children and adolescents, higher accelerometer-assessed physical activity was negatively correlated with naturalistically-assessed LOC eating, overeating, stress- and emotion-related eating, and hunger (Smith et al., 2020a,b). Given such data, physical activity has been termed a "gateway behavior" that may facilitate improvements in related health behaviors, including eating. These findings are especially relevant for youth with overweight or obesity given that LOC eating and physical inactivity are more prevalent in this group compared to peers of lower weight (Harriger and Thompson, 2012; Prentice-Dunn and Prentice-Dunn, 2012; He et al., 2017). Thus, it is possible that higher physical activity levels could have beneficial effects on eating patterns that in turn mitigate poor long-term outcomes among children.

Importantly, the influence of physical activity on eating may occur both at the momentary level (e.g., minutes to hours) and over extended time periods (e.g., months to years). At the momentary level, in children and adults, acute bouts of activity have been shown to attenuate appetite and urges to consume palatable food and have been linked to decreases in energy intake in children and adults (Thayer et al., 1993; Maraki et al., 2005; Taylor and Oliver, 2009; Thivel and Chaput, 2014). Further, prior naturalistic research among adults with obesity found that dietary lapses and temptations were less likely to occur after exercising (Carels et al., 2004). Also, elevated momentary moderate-to-vigorous physical activity predicted less stress-related eating in adolescents with higher BMI-z and predicted less positive emotional eating in adolescents with lower BMI-z (Smith et al., 2020b). Conversely, physical inactivity may have detrimental short-term effects on eating regulation. While directionality cannot be inferred, an ecological momentary assessment (EMA) study of high school adolescents found that consumption of sweet snacks was concurrently associated with sedentary activities such as watching television and using electronic media at the same prompt (Grenard et al., 2013).

In addition to these momentary associations, longitudinal research in adults has shown that adults participating in exercise interventions experience greater increases in healthy eating patterns (i.e., increased fruit and vegetable intake and decreased junk food consumption) relative to non-intervention conditions (Oaten and Cheng, 2006; Fleig et al., 2011). Among adults with overweight and obesity, higher lifestyle physical activity, measured at the end of a 12-month behavioral weight loss program, was also related to greater flexible dietary restraint, less disinhibited eating, and less perceived hunger at 12- and 36- month follow-up assessments (Carraça et al., 2013). In sum, there is evidence that physical activity may have both short- and long-term beneficial effects on eating. However, there remains a dearth of literature that has examined such relationships in children and adolescents, particularly with respect to key behaviors (i.e., LOC eating) that are linked to current and future physical and mental health problems.

EXECUTIVE FUNCTIONING AS A MECHANISM LINKING ACTIVITY AND LOC EATING

Moreover, the mechanisms underlying associations between physical activity and eating regulation have yet to be elucidated. While several factors have been posited to contribute to these relationships, burgeoning evidence indicates acute and long-term physical activity behavior enhance executive functioning, and poor executive functioning increases risk for the development of LOC eating (Verburgh et al., 2014; Goldschmidt et al., 2015; Alvarez-Bueno et al., 2017; Tanofsky-Kraff et al., 2020). Executive functions refer to "top-down" cognitive processes that guide goal-directed behavior and allow for adaptations to changing circumstances, and which are rooted in circuitry within the prefrontal cortex (Diamond, 2013). These executive functions develop throughout adolescence and are critically important for adaptive self-regulatory processes, including eating and physical activity behaviors (Hofmann et al., 2012; Dohle et al., 2018). In particular, inhibitory control deficits (i.e., reduced ability to suppress or interrupt prepotent responses) can interfere with self-regulation processes, including the ability to modulate the types and amount of food consumed (Liang et al., 2014) and are a specific facet of executive functioning that may be related to LOC eating. In fact, a recent study found that inhibitory control deficits, assessed with the stop-signal task, were the only executive functioning measure associated with caloric consumption during a laboratory test meal – an objective measure of LOC eating (Kelly et al., 2020).

While studies of inhibitory control in children and adolescents have most commonly utilized self-report measures and behavioral tasks, cognitive neuroscience research has begun identifying brain pathways associated with inhibitory control deficits. Neuroimaging studies using functional magnetic resonance imaging (fMRI) to examine inhibitory control reliably implicate frontostriatal circuitry, including areas of the lateral prefrontal cortex (Dias et al., 1997; Aron et al., 2004). In adolescents with obesity, disinhibited eating has been linked to reduced integrity of frontal lobe, specifically lower orbitofrontal cortex volume (Maayan et al., 2011). Another recent study found that after completion of a food-specific inhibitory control task, overweight adolescents showed reduced activation in frontal inhibitory regions, including the superior frontal gyrus, middle frontal gyrus, ventrolateral prefrontal cortex, medial prefrontal cortex, and orbitofrontal cortex, compared to adolescents of lower weight (Batterink et al., 2010). Thus, it appears that less activation in the prefrontal cortex, important for inhibition control when trying to inhibit response to palatable food, is associated with greater weight and as an extension more dysregulated eating behaviors, such as LOC eating.

In addition to inhibitory control predicting LOC eating, research suggests that physical activity improves inhibitory control in children and adolescents. Several studies of children or adolescents found that physical activity was associated with acute improvements in inhibitory control (Chang et al., 2014; Browne et al., 2016; Franco-Alvarenga et al., 2019). Further, adolescents who completed an 8-week exercise program had increased inhibitory control following the intervention compared to a control group (Ludyga et al., 2018). While cognitive neuroscience research is limited (Belcher et al., 2020), one study found that physical activity may enhance prefrontal cortex functioning in children (Chaddock-Heyman et al., 2013). In addition, in a separate fMRI study, children with higher fitness level had more efficient brain networks associated with inhibitory control compared to children with lower fitness level (Voss et al., 2011).

MODEL OF PHYSICAL ACTIVITY DECLINE, EXECUTIVE FUNCTIONING, AND PEDIATRIC LOC EATING

Given current limitations, we introduce a hypothesized model (**Figure 1**) that posits that developmental changes in physical activity patterns and executive functioning together influence self-regulation from childhood into adolescence, such that declines in physical activity have negative short- and long-term effects on behavioral and neural markers of executive functioning, which in turn increases risk for subsequent LOC eating and poor health outcomes (e.g., obesity and eating disorder pathology) over time. While there is likely a bi-directional relationship between executive functioning and physical activity such that executive functioning also precipitates regular physical activity, there is a more substantial literature on the predictive association from physical activity to executive functioning in children (Hillman et al., 2011; Verburgh et al., 2014; de Greeff et al., 2018). In addition, studies using accelerometers to obtain objective measurements of physical activity have shown that children who engaged in more physical activity had better executive functioning (Syväoja et al., 2014; van der Niet et al., 2015).

Physical activity has also been shown to alter neurobiological processes associated with inhibitory control. For example, children with overweight and obesity who underwent a 3-month aerobic exercise intervention, compared to a control group, evidenced increased recruitment of the bilateral prefrontal cortex during an inhibitory control (i.e., antisaccade) task that was completed at baseline and post-intervention (Davis et al., 2011). Further, physical activity has been shown to be particularly effective at improving executive functioning in children with obesity (Logan et al., 2020), whom are more at-risk for LOC eating (He et al., 2017).

The proposed model has not been extensively studied and stems from connecting the available literatures on physical activity and LOC eating in children and adults. Investigation of this model has several potential theoretical and clinical implications. Research has implicated a number of factors in relation to LOC eating in children; however, little is known about the developmental origins of LOC eating (Byrne et al., 2019). That is, much more is known about how children who exhibit LOC eating differ from children who do not exhibit LOC eating opposed to the mechanisms that explain the initial onset of LOC eating. Although, research has yet to study differences in physical activity between children with

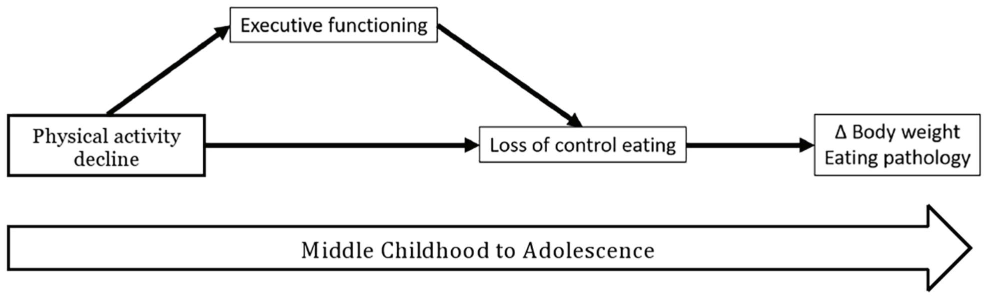

FIGURE 1 | Model of activity, executive functioning, loss of control eating, and long-term outcomes.

vs. without LOC eating. One of the risk factors associated with LOC eating in children is impairments in general and food-specific aspects of executive functioning (Allen et al., 2013; Goldschmidt et al., 2015; Goldschmidt et al., 2018a; Stojek et al., 2018; Van Malderen et al., 2018). This proposed model is the first to suggest that a decline in physical activity that occur in middle childhood may be a biobehavioral mechanism that explains the onset of LOC eating in childhood.

In addition to theoretical implications, the proposed biobehavioral model could have high clinical significance. There have been limited studies investigating treatments for LOC eating in children. Those that have been conducted have studied psychological therapies (e.g., cognitive-behavioral therapy) as a treatment for LOC eating and have reported these therapies to be successful (Byrne et al., 2019). Examples of possible clinical implications of our theoretical model might be using physical activity as a stand-alone intervention or as part of psychotherapy to treat LOC eating in children. However, empirical research will be needed to determine appropriate clinical recommendations – including types of activity, duration, and frequency that are needed to change executive functioning and behavior. Further, from a preventive standpoint, while we know that it is crucial for children to remain physically active throughout childhood and adolescence to reduce negative physical and psychological outcomes, testing of the hypothesized model can provide information about physical activity as a preventive measure for LOC eating.

This model also may inform the combination and sequencing of prevention and intervention components, particularly if strategies that promote physical activity exert a transfer effect on eating regulation *via* enhancing executive functions. Furthermore, consistent with precision medicine initiatives, analysis of momentary, real-time data will be crucially important to inform tailored treatments. New preventions or treatments could target certain *types* of children or traits (e.g., children high vs. low in inhibitory control) or target the specific *moments* at which a child is most prone to engage in LOC eating (e.g., states of physical inactivity and reduced inhibitory control). Further, it is critical for pediatricians to screen for children's adherence to physical activity recommendations in early childhood and utilize behavior change techniques with children and parents to increase adherence.

It is important to acknowledge limitations and other considerations. The key limitation of this review and proposed conceptual model is that it is based on a small number of studies, and we draw on some studies from the adult literature given the comparatively sparse pediatric literature base. In addition, this is a proposed conceptual model that is intended to guide further research direction and has not yet been tested, and thus, empirical research will be needed in order to make clinical recommendations. The model described is intentionally parsimonious to guide initial research in this area, yet there is a plethora of other variables that should be considered in the context of this model moving forward. For example, emotion regulation is an important factor related to physical activity and LOC eating (Goldschmidt et al., 2017; Bernstein and McNally, 2018), and emotion regulation abilities are modulated by executive functioning (Calkins and Marcovitch, 2010; Sudikoff et al., 2015). Therefore, emotion regulation abilities likely play an important role in this model. Further, other trait and dispositional variables are key to examine as moderators and mediators within the context of this model including personality (e.g., health consciousness and impulsivity), familial factors (e.g., parenting practices), and environment (e.g., proximity to fast food outlets or parks).

Finally, while reviews of physical activity and executive functioning (Hillman et al., 2011; Verburgh et al., 2014; de Greeff et al., 2018) have all shown evidence for relationships between physical activity and executive functioning, there have been inconsistent findings regarding acute vs. chronic activity effects on executive functioning, depending upon measure used. Verburgh et al. (2014) concluded that acute physical activity (i.e., single bout of activity) predicted improved executive functioning using task-based measures but chronic physical activity (i.e., long-term exercise programs) did not; though, there were a limited number of chronic physical activity studies. Conversely, Hillman et al. (2011) reported that acute (i.e., single bout of activity) and chronic (i.e., fitness level) physical activity both predicted improved executive functioning using task and event-related potential measures. de Greeff et al. (2018) also found that acute (i.e., single bout of activity) and chronic (i.e., long-term exercise program) physical activity both predicted improved executive functioning using task measures, but results differed across tasks. These reviews demonstrate the importance for studying possible effects of both acute and chronic activity. Importantly, future studies testing this model should use objectively measured accelerometer physical activity, which measures children's total volume of activity and can account for all activity that children perform.

In sum, establishing causal pathways and micro-temporal associations among physical activity, executive functioning, and LOC eating in youth has the potential to inform new prevention and intervention strategies for a host of pediatric outcomes. Future studies using multi-method designs, including psychological interviews, ambulatory assessment, and cognitive assessment, across middle childhood and adolescence will be needed to test the proposed model. Research on moderators and facets of executive functioning will also be needed to refine the model.

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TM and KS: conceptualized the idea and wrote the first draft of the manuscript. BB, GD, and SL: revised subsequent drafts and provided critical feedback. All authors contributed to the article and approved the submitted version.

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Promoting Resilience to Food Commercials Decreases Susceptibility to Unhealthy Food Decision-Making

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Children are vulnerable to adverse effects of food advertising. Food commercials are known to increase hedonic, taste-oriented, and unhealthy food decisions. The current study examined how promoting resilience to food commercials impacted susceptibility to unhealthy food decision-making in children. To promote resilience to food commercials, we utilized the food advertising literacy intervention intended to enhance cognitive skepticism and critical thinking, and decrease positive attitudes toward commercials. Thirty-six children aged 8–12 years were randomly assigned to the food advertising literacy intervention or the control condition. Eighteen children received four brief intervention sessions via video over 1 week period. In each session, children watched six food commercials with interspersed embedded intervention narratives. While watching food commercials and narratives, children were encouraged to speak their thoughts out loud spontaneously ("think-aloud"), which provided children's attitudes toward commercials. Eighteen children in the control condition had four control sessions over 1 week, and watched the same food commercials without intervention narratives while thinking aloud. The first and last sessions were held in the laboratory, and the second and third sessions were held at the children's homes. Susceptibility to unhealthy food decision-making was indicated by the decision weights of taste attributes, taste perception, food choices, *ad libitum* snacking, and cognitive and affective attitudes toward food commercials. As hypothesized, the intervention successfully decreased susceptibility to unhealthy food decision-making evidenced by reduced decision weights of the taste in food decisions, decreased tasty perception of unhealthy foods, and increased cognitive skepticism and critical thinking toward food commercials. In addition, as children's opinions assimilated to intervention narratives, their cognitive skepticism and critical thinking toward commercials increased. The aforementioned results were not shown in the control condition. However, this brief intervention was not enough to change actual food choices or food consumption. Results of this study suggest that promoting resilience to food commercials by enhancing cognitive skepticism and critical thinking effectively reduced children's susceptibility to unhealthy food-decision making.

Keywords: food decisions, eating behavior, advertising literacy, children, obesity, food commercials

INTRODUCTION

Children are highly susceptible to unhealthy foods. Pre-disposed sweet and salty taste preferences and bitter and sour taste rejections, innate preferences for high caloric foods, and early experience rewarding those predispositions make children be inclined to eat unhealthy foods high in sugar, salt, and fat (Birch and Fisher, 1998; Mela, 2001; Beauchamp and Mennella, 2009; De Cosmi et al., 2017). As previous food decision research has shown, children primarily incorporate taste attributes, while they barely consider health attributes (Bruce et al., 2016; Lim et al., 2016; Ha et al., 2019). Such heavily weighted taste-oriented food decisions are often linked to unhealthy food preferences, overeating, and a risk of developing obesity in children and adolescents (Neumark-Sztainer et al., 1999; Shannon et al., 2002; Boyland and Halford, 2013).

Food commercials add more layers of complexity to healthy eating, and children are vulnerable to the undesired effects of advertising. Exposure to food commercials provokes hedonic food cue processing and eating behavior on multiple levels including heightened visual attention to unhealthy foods (Spielvogel et al., 2018), hedonic eating (Harris et al., 2009), requests for and consumption of the advertised foods (Gorn and Goldberg, 1982; Utter et al., 2006), and preference for and consumption of high-fat, high-sugar, energy-dense foods (Boyland et al., 2011, 2016). Children-targeted advertising featuring high-caloric, low-nutrient food are related to the prevalence of childhood obesity (Linn and Novosat, 2008; Goris et al., 2010). Even exposure to commercials featuring healthier meal options of familiar fast food brands or commercials featuring unfamiliar fast foods with healthy messages failed to improve food healthiness perception but resulted in increased fast food preferences (Boyland et al., 2015; Harris et al., 2018). Neuroimaging research has demonstrated that food brand logos have high attentional salience (Masterson et al., 2019b), and food brand logos and food commercials activate the brain's reward system (Bruce et al., 2014, 2016; Gearhardt et al., 2020; Ha et al., 2020). The greater activation of the reward system often links to overeating and body fat gain in children and adolescents (Stice and Yokum, 2016; Adise et al., 2018).

Enhancing resilience to the adverse effects of food commercials could be critical for the development of healthy eating habits and weight management in children and adolescents. While limiting food commercials and media time would reduce the chances to be exposed to harmful advertising effects (Smith et al., 2019), establishing life-long strategies for regulating eating decisions in the presence of unhealthy food cues in commercials during the course of development could increase resilience to food advertising (Buijzen and Valkenburg, 2005). Advertising literacy is one of the abilities central to children's understanding of marketing (Malmelin, 2010). The response and understanding of advertising includes cognitive and affective components (Burton and Lichtenstein, 1988). Advertising literacy consists of cognitive advertising literacy, for increasing understanding selling, persuasive intent and advertising skepticism, and affective advertising literacy, for increasing negative affective attitudes toward commercials (Rozendaal et al., 2011; Hudders et al., 2016). Children develop a rudimentary understanding of advertisements as a differentiated entity after 5 years of age, and their understanding of selling and persuasive intent and tactics develops between 8 and 12 years of age (Blosser and Roberts, 1985; Livingstone and Helsper, 2006). Children's understanding of advertising literacy is poor until adolescence (Oates et al., 2002; Rozendaal et al., 2010) and develops at a pace consistent with other cognitive and information processing capacities (Moses and Baldwin, 2005; Hudders et al., 2016). The activation of advertising literacy knowledge as a cognitive defense is not spontaneous and requires retrieval cues for 8- to 12-years-old children (Brucks et al., 1988; Rozendaal et al., 2012). Children in this age range (8–12 years) are most affected by televised food marketing (Gantz et al., 2007). Intervention strategies using advertising literacy narratives or information as cues to activate advertising literacy have been shown to effectively enhance defenses against adverse advertising effects in children (Buijzen, 2007; Rozendaal et al., 2016; De Jans et al., 2017). Particularly, factual (cognitive) narratives are shown to increase cognitive defenses by delivering advertising knowledge and skepticism. Increased advertising knowledge and skepticism decrease susceptibility to commercials (i.e., attitude toward the brand and products, such as intended product request) by increasing negative attitudes toward the commercials. Evaluative (affective) narratives decrease susceptibility to commercials by increasing negative attitudes and facilitating negative affective responses (Buijzen, 2007). When children critically process advertising using "think-aloud" approaches, which encourage spontaneous speech, they exhibit both increased cognitive defenses and negative affective attitudes that decrease their susceptibility to commercials (Rozendaal et al., 2012).

Research has mainly examined the effect of advertising literacy interventions in decreasing positive attitudes toward the advertising and susceptibility to the commercials from the perspective of consumer behaviors. Considering that exposure to television food commercials increases food consumption (Harris et al., 2009; Russell et al., 2019) and contributes to the development of childhood obesity (Kelly et al., 2010), it is important to test how advertising literacy interventions influence food decision-making and consumption to prevent obesity. Specifically, promoting resistance to advertising effects on food taste attributes will ultimately be beneficial for healthy eating.

Children show strong taste preferences to advertised foods. Children perceive that the same foods taste better when those foods are in fast-food brand or cartoon character packaging, especially when children have more frequent television exposure and fast food consumption experiences (Robinson et al., 2007; Enax et al., 2015). Furthermore, our previous research has shown that exposure to food commercials increases the relative importance (decision weights) of taste attributes in food decisions (Bruce et al., 2016). To find strategies for resisting this undesired effect from commercials in food decision-making, we previously tested the feasibility of a food advertising literacy intervention (Ha et al., 2018). This pilot study's results suggested that the food advertising literacy intervention could reduce the relative importance of the taste attribute in food decisions.

Yet, whether the decreased relative importance of taste attributes in food decisions is related to changes in the processing of unhealthy food taste remains unanswered. To validate whether the intervention influences children to process unhealthy foods less tasty, further investigation is necessary. Furthermore, whether an advertising literacy intervention reduces actual snack consumption needs to be examined. In our previous study (Ha et al., 2018), the advertising literacy intervention did not change children's food choices in computerized tasks. Thus, it is important to examine how an advertising literacy intervention would impact actual snack consumption. We primarily focused on unhealthy food taste processing and snack consumption because reducing consumption of tasty but unhealthy foods with high sugar, salt, and fat will have short- and long-term benefits for healthy eating and weight management (Piernas and Popkin, 2010; Ha et al., 2019). In addition, we made a few modifications to test the effectiveness of the intervention with more challenges and control. First, to add the *ad libitum* snack food consumption task, we replaced two commercials that advertised non-fast food restaurants targeting adult consumers (i.e., Chili's® and Applebee's®) with new commercials that advertised snack food items targeting children (i.e., Chips Ahoy® and Oreo®). This replacement served to test whether the intervention effect would be demonstrated with commercials that specifically target children. Secondly, in our previous work, we randomized group assignments, but the study was not double blind. To ensure the intervention effect was not related to an experimenter bias, further control with a double-blind design was applied. In the present study, to confirm and expand the initial feasibility testing of the food advertising literacy intervention, we tested how the food advertising literacy intervention impacts children's food decision-making focusing on the relative importance of the taste attributes, taste processing of unhealthy and healthy foods, and *ad libitum* snacking in a double-blind intervention procedure. In addition, we speculated children's spontaneous attitudes toward commercials and intervention narratives using the think-aloud method.

We hypothesized that food advertising literacy training would decrease positive attitudes toward commercials in children. We also hypothesized that the food advertising literacy intervention would decrease the susceptibility to unhealthy food decision-making as indicated by (1) the reduced relative decision weights of taste attributes in food decisions, (2) reduced tasty perception and categorization of unhealthy foods, (3) healthier food choices, and (4) decreased amounts of snack food consumption. We expected no such changes among children in the control condition.

MATERIALS AND METHODS

Participants

Thirty-six healthy children (21 girls, 15 boys) aged 8–12 years ($M = 10.51$ years, $SD = 1.45$) with normal or corrected-to-normal vision and hearing participated. Children with a history of neurological conditions, clinically significant psychopathology, or learning disabilities reported by parents were excluded. All participants were recruited from the Kansas City metropolitan and nearby rural areas, and spoke English as their first language. Upon arrival at the laboratory for the first session, a parent gave written informed consent, and a child gave written assent. Then, children's heights and weights were measured in light indoor clothing and stocking feet using a Perspective Enterprises standard stadiometer (PE-WM-60-84; Portage, Michigan) and a Befour scale (PS6600 ST; Saukville, Wisconsin). Body mass index (BMI) scores were converted to age- and sex-specific BMI-for-age percentiles ($M = 63.82$, $SD = 32.20$, range 5.7–99.3). Based on the Centers for Disease Control and Prevention (CDC) guidelines, children's BMI-for-age weight status was categorized as healthy weight ($n = 23$; 64%), overweight ($n = 4$; 8%), or obese ($n = 10$; 28%). Children's pubertal growth was assessed by parent report on the Pubertal Development Scale (Petersen et al., 1988; Carskadon et al., 1993). On average, girls were in mid-pubertal growth (mean PDS score = 2.11, $SD = 0.73$; mean PDS category score = 5.86, $SD = 2.63$), and boys were in early pubertal growth (mean PDS score = 1.52, $SD = 0.56$; mean PDS category score = 4.13, $SD = 1.36$), which reflected a typical pattern that pubertal growth begins earlier for girls than boys (Petersen and Crockett, 1985). There was no significant difference for age, $t_{(34)} = -0.72$, $p = 0.477$, $d = -0.25$, or BMI-for-age percentiles, $t_{(34)} = -0.60$, $p = 0.550$, $d = -0.21$, between girls and boys. Participants consisted of 18 White (50%), 12 Multiracial (33.3%), 4 Black or African American (8.3%), and 3 Hispanic or Latina/o (8.3%).

The sample size was at the expected level (18 ≥ for each group) according to an a *priori* power analysis, based on the effect size ($d = 0.71$, two-tailed) of our previous study tested the feasibility of the advertising literacy intervention in changing children's food decision-making (Ha et al., 2018) with a statistical power of 0.80. Children were randomly assigned to either the intervention condition ($n = 18$; 11 girls, 7 boys; $M = 10.06$ years, $SD = 1.37$; $M = 57.21$th BMI percentile, $SD = 31.36$), or the control condition ($n = 18$; 10 girls, 8 boys; $M = 12.90$ years, $SD = 1.43$; $M = 70.43$th BMI percentile, $SD = 32.52$) after the baseline assessment. The group assignment was double-blinded so that neither participants nor the main experimenter were aware of the group assignment. The age, $t_{(34)} = 1.91$, $p = 0.065$, $d = 0.66$, BMI-for-age percentile, $t_{(34)} = 1.24$, $p = 0.223$, $d = 0.43$, and sex-ratio, $\chi^2_{(1,N=36)} = 0.11$, $p = 0.735$, were not significantly different between the two groups. Eleven additional children were recruited but excluded from analysis due to the completion of the first session only ($n = 5$), procedure errors by experimenters ($n = 3$), task non-compliance (a lack of response variety by responding trials with the same response in food ratings and choices; $n = 2$), and not paying attention (whining and crying during the post-intervention session; $n = 1$). This study was approved by the Human Subjects Committee at the University of Kansas Medical Center and approved for a request to rely on the Institutional Review Board of the University of Missouri–Kansas City (FWA00003411). All parents of participants in this study gave written informed consent and child participants gave written assent.

Procedure

Food Advertising Literacy Intervention

Pre-intervention

To ensure children's adequate hunger levels for realistic eating choices, children were instructed to fast for 2 h before coming to the laboratory. Upon children's arrivals to the laboratory, the first experimenter measured children's height and weight. To measure the intervention effect, the computerized food rating and choice tasks (Bruce et al., 2016; Ha et al., 2016, 2018, 2019; Lim et al., 2016) were completed at pre-intervention (i.e., before children watching the intervention video at the first session) and post-intervention (i.e., after children watching the intervention video at the last session) in the laboratory. At pre-intervention, the first experimenter asked children to report their hunger levels using an 11-point visual analog scale for hunger (King et al., 1994). Next, the first experimenter instructed children to complete food rating and choice tasks for measuring children's baseline food health and taste ratings and decision weights in food decision-making. To ensure children's motivation for realistic eating choices, children were told that they would receive one of the food items that they selected to eat in the choice task after completing the session, and they received one item from their choices at the end of the session. After completing the baseline measurement, the second experimenter randomly assigned children to one of two groups.

Intervention

Research has shown that interventions that utilize narratives for activating advertising literacy successfully increase cognitive skepticism and negative attitudes toward commercials, which reduces susceptibility to the adverse effect of television food advertising in children ages between 8 and 12 years (Buijzen, 2007; Rozendaal et al., 2016; De Jans et al., 2017). Extending our previous work, we administered a food advertising literacy intervention (Ha et al., 2018) to test whether promoting resilience to advertising reduces unhealthy food decision-making.

The intervention consisted of a total of twelve factual (cognitive) narratives for enhancing cognitive defenses, i.e., understanding of selling and persuasive intent of advertisers and cognitive skepticism toward television food advertising, and evaluative (affective) narratives for decreasing positive affective attitudes toward television food advertising (Buijzen, 2007; Rozendaal et al., 2012) (see **Table 1**). The intervention was delivered using a video containing six television food commercials and 12 factual and evaluative narratives (see **Figure 1**). Each food commercial clip was followed by two narrative statements one-by-one. To help children pay attention to and engage with narratives, a statement in colored text moved side-to-side on the black screen, which was accompanied by an adult female voice reading a statement in child-directed speech. To make each narrative distinctive, an animated video stimulus with small bubbles on a gray screen was presented briefly (1 s) between two narratives. We adopted television commercials for advertising fast food restaurants or unhealthy snack brands (i.e., Chips Ahoy®, Denny's®, McDonald's®, Subway®, Oreo®, and Wendy's®) that were used in a child eating study (Gearhardt et al., 2014), and these commercials were used for our previous work testing children's commercial exposure and food decision-making as well (Bruce et al., 2016; Lim et al., 2016; Ha et al., 2018). Each commercial was 15 s long and the narrative part was presented for ∼12 s. In total, two intervention videos were created, and each video used different commercials for the same six brands. The order of food commercials and narratives were pre-randomized for each video. Children watched one of two videos in each session, and the order of videos were counterbalanced across children (e.g., 1212, 2121).

Overall, children had four brief intervention sessions over a 1-week period. Because children had to complete the computerized food decision-making tasks that provided the baseline and intervention effect measurements of food decision-making in the laboratory, children visited the laboratory twice during the 1-week period. The first session was done following the baseline measurement at pre-intervention and the fourth session was done before the intervention effect measurement at post-intervention in the laboratory. To ensure children received advertising literacy information frequently, the second and third sessions were done at home with parent assistance. To boost active information processing, children were instructed to speak aloud while watching the intervention video ("think-aloud"). Children completed surveys on advertising knowledge and attitude toward commercials after watching the video in each session. After having the intervention session in the laboratory during the first and fourth sessions, children had an *ad-libitum* snack consumption task.

More specifically, children had the first intervention session in a quiet room in the laboratory. The second experimenter

TABLE 1 | Narratives for the food advertising literacy intervention.

Factual (cognitive) narratives	Evaluative (affective) narratives
• Foods look and taste differently in reality.	• These foods don't make you have fun.
• The advertisers want you to go and eat these foods.	• Those foods are disgusting.
• These commercials are intended to sell.	• People in these commercials aren't cool.
• The advertisers are trying to trick you.	• These foods don't make you happy.
• These commercials aren't telling the truth.	• These foods are bad for you.
	• Those foods are not delicious.
	• Those foods are so unhealthy.

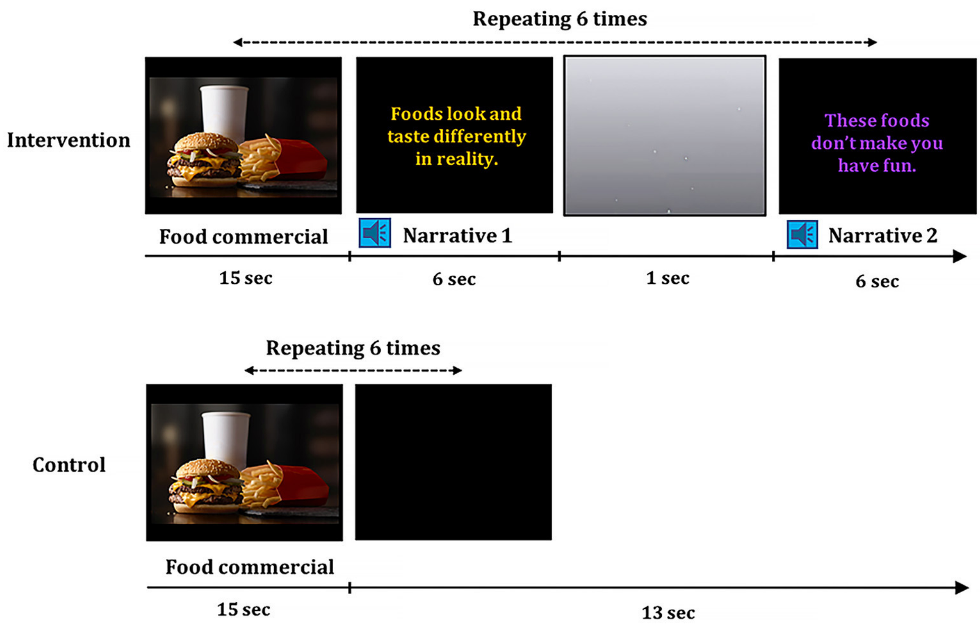

FIGURE 1 | Intervention and control video stimuli. A video for the intervention condition was consisted of six food commercials with embedded 12 factual and evaluative narratives. Each food commercial was followed by two narratives. Narrative statements in colored text moved side-to-side and was accompanied by a female voice. A video for the control session was consisted of the same six food commercials, but no narratives were delivered.

played the video, stepped out of the room, not closing the door all the way and waited in front of the door to encourage children to speak their thoughts out loud while watching a video ("think-aloud"), to prevent the first experimenter across the room from overhearing the audio, and to be able to go back to the room when children needed help. Then children filled out food commercial questionnaires that consisted of multiple short surveys for providing advertising literacy and attitudes toward commercials and the advertised foods (Rozendaal et al., 2012; Gearhardt et al., 2014). While completing the questionnaires, children had an *ad libitum* snack-consumption task (Harris et al., 2009). Lastly, the first experimenter explained instructions for home sessions to a parent. To assist in ensuring the sessions be held without forgetting, the experimenter asked the parent to pick two dates for the home sessions and those dates were written on the instruction document. The parent took the videos saved on a USB flash drive, and food commercial questionnaires for home sessions, which were put in an envelope. Email reminders were sent the day before picked dates.

The second and third sessions were held at home. Children watched one of two videos in each session following pre-counterbalanced order described above. Parents reminded children to think aloud while watching a video, and recorded children's think-aloud vocalizations using apps on smart phones. After watching a video, children completed the food commercial questionnaires in each session.

For the fourth session, children revisited the laboratory at the end of the 1 week period ($M = 7.21$ days, $SD = 0.51$). Children were again instructed to fast for 2 h, and completed the visual analog scale of hunger ($M = 5.68$, $SD = 2.97$). Children watched a video and filled out the food commercial questionnaires.

Post-intervention

At post-intervention, right after having the fourth session in the laboratory, children reported their hunger levels using an 11-point visual analog scale for hunger. And then they completed the food rating and choice tasks, which were the same tasks they completed at pre-intervention but in a different, randomized order of trials, to provide food health and taste ratings and decision weights in food decision-making after completing the intervention. Lastly, children had the *ad libitum* snack-consumption task.

Control Condition

Similar to the intervention condition, children in the control condition had four control sessions over 1 week ($M = 7.39$ days, $SD = 0.70$). All materials and procedures were identical to the intervention condition except for two control videos that did not include the narratives embedded into commercials, which were replaced with a black screen without any text or sound. Children's hunger levels at the pre-control session in the control group ($M = 6.07$, $SD = 2.32$) were not different from those at pre-intervention in the intervention group ($M = 5.39$, $SD = 3.10$), $t_{(34)} = 0.74$, $p = 0.466$, $d = 0.25$. Children's hunger levels at post-control session in the control group ($M = 6.45$, $SD = 2.85$) were not different from those at post-intervention in the intervention group ($M = 5.68$, $SD = 2.97$), $t_{(33)} = 0.78$, $p = 0.440$, $d = 0.27$.

Think-Aloud

Children were instructed that researchers were interested in what they were thinking when they watched the video clip and were encouraged to speak out loud any words that came to mind while watching the video. Spoken responses were recorded. Children's spoken words during each session were coded following the coding scheme (Rozendaal et al., 2012). In particular, spoken words were coded based on relevance of thought (*relevant* to commercials or *irrelevant* to commercials), and origin of thought (*message-originated*, description of commercials or *recipient-generated*, original reactions to commercials). Only relevant, recipient-generated responses were further considered based on (1) nature of thought (*cognitive* beliefs, e.g., "But it's fake" or *affective* responses, e.g., "It's gross!"); (2) polarity of thought (*positive* favorable thoughts, e.g., "That looks so good," *neutral* thoughts, or *negative* unfavorable thoughts, e.g., "People make bad choices to eat those unhealthy foods"); and (3) advertising understanding (*understanding* or *no understanding* of advertising intentions and tactics) (Rozendaal et al., 2012; Ha et al., 2018). Two research staff members coded children's spoken words independently, and a third research staff member coded disagreed items and finalized coding. We computed Cohen's kappa (k) for intercoder reliability for each coding category in each participant. The mean kappa was 0.91 ($SD = 0.16$) for relevance of thought, 0.86 ($SD = 0.18$) for origin of thought, 0.96 ($SD = 0.06$) for nature of thought, 0.96 ($SD = 0.10$) for polarity of thought, and 0.94 ($SD = 0.04$) for advertising understanding. The average interrater agreement was 96.1% ($SD = 3.5\%$).

To measure children's cognitive skepticism and critical thinking toward commercials, we computed the ratio of negative cognitive responses, i.e., negative cognitive/(negative cognitive + positive cognitive), and the ratio of negative affective responses, i.e., negative affective/(negative affective + positive affective). A higher negative cognitive response ratio indicated the relatively higher cognitive skepticism and critical thinking toward commercials, and a higher negative affective response ratio indicated the relatively higher negative affective attitudes toward commercials.

Questionnaires

Food Commercial Questionnaires

We used the modified (1) belief of the commercial scale (2-item; a higher mean score across items indicates higher beliefs for commercials) to measure beliefs toward commercials, (2) liking of the commercial scale (5-item; a higher mean score across items indicates liking of commercials) to measure affective responses toward commercials, and (3) positive attitude toward the brand scale (2-item; a higher mean score across items indicates positive attitudes toward commercials) to measure attitude toward the advertised food (Rozendaal et al., 2012) on 5-point scales (e.g., "not at all" to "very much"). Children provided their responses for each food commercial they watched (a total of six commercials in each session), and the mean value of the six responses represented the score for the specific item. In addition, we measured children's (4) perceived advertising influence on food preferences (1-item; a higher score indicates higher advertising impacts on food preferences), and (5) perceived advertising influence on food choices (1-item; a higher score indicates higher advertising impacts on food choices) on a 5-point scale ("not at all" to "very much"). For the last two scales, responses were not obtained for each food commercial to measure overall perception of advertising impact on their food liking and choices.

Ad libitum Snack-Consumption Task

While completing questionnaires at the end of the first and last sessions, children were given a total of three plates where each plate had 1.5 servings of Chips Ahoy® cookies (48 grams), Oreo® cookies (51 grams), or Goldfish® crackers (45 grams) based on serving sizes on each snack item's nutrition facts label. Chips Ahoy® and Oreo® cookies were snack items advertised in the videos. Goldfish® crackers was chosen based on the previous study tested children's *ad libitum* snack food consumption, and to make the total amounts of three snack items would be similarly matched to the amount tested in the previous study (Harris et al., 2009). The amounts of food items were measured using an Ozeri Pronto digital multifunction scale. Children were instructed to eat freely at the end of first and fourth sessions, and plates were removed if the child finished all the snacks or after 20 min of eating.

Food Rating and Choice Tasks

We measured children's perceived food health and taste attribute ratings, and food choices using computerized tasks (Bruce et al., 2016; Lim et al., 2016; Ha et al., 2018, 2019) (**Figure 2**). Sixty colored food images with high resolution (72 dpi, 300 X 300 pixels; 30 healthy and 30 unhealthy foods items) were presented one-by-one on a white-background in the center of the screen in a randomized order. Children rated health attributes ("very unhealthy" to "very healthy," or "very healthy" to "very unhealthy") and taste attributes ("very bad" to "very good," or "very good" to "very bad") for each food item on a 4-point scale by pressing a key on a keyboard. Children were asked to provide health ratings regardless of taste attributes, and taste ratings regardless of health attributes. Health rating and taste rating were measured separately, and the order of two rating tasks was counterbalanced across children. Then children made food choices ("Do you want to eat?") for each food item on a 4-point scale ("strong no" to "strong yes," or "strong yes" to "strong no"). Each task began with an initial instruction displaying a specific task under session, and a food image remained on the screen until a response button was pressed. Each trial was separated by a fixation point of 1 s duration. Four-point rating scale options in black text on a gray box were displayed in the bottom center below the food image. When children chose an option, it turned into yellow to provide visual feedback. Presentation® software (version 20; Neurobehavioral Systems, Berkley, California; RRID: SCR_002521) controlled the stimulus presentation and response collection.

Statistical Analyses

Following our previous statistical analysis model (Bruce et al., 2016; Lim et al., 2016; Ha et al., 2018, 2019) that detected the determinants of children's food decision-making, we computed the decision weights of taste and health attributes in food choices by fitting a linear regression model that taste and health ratings predicted food choices at the individual level. Taste and health ratings were entered in

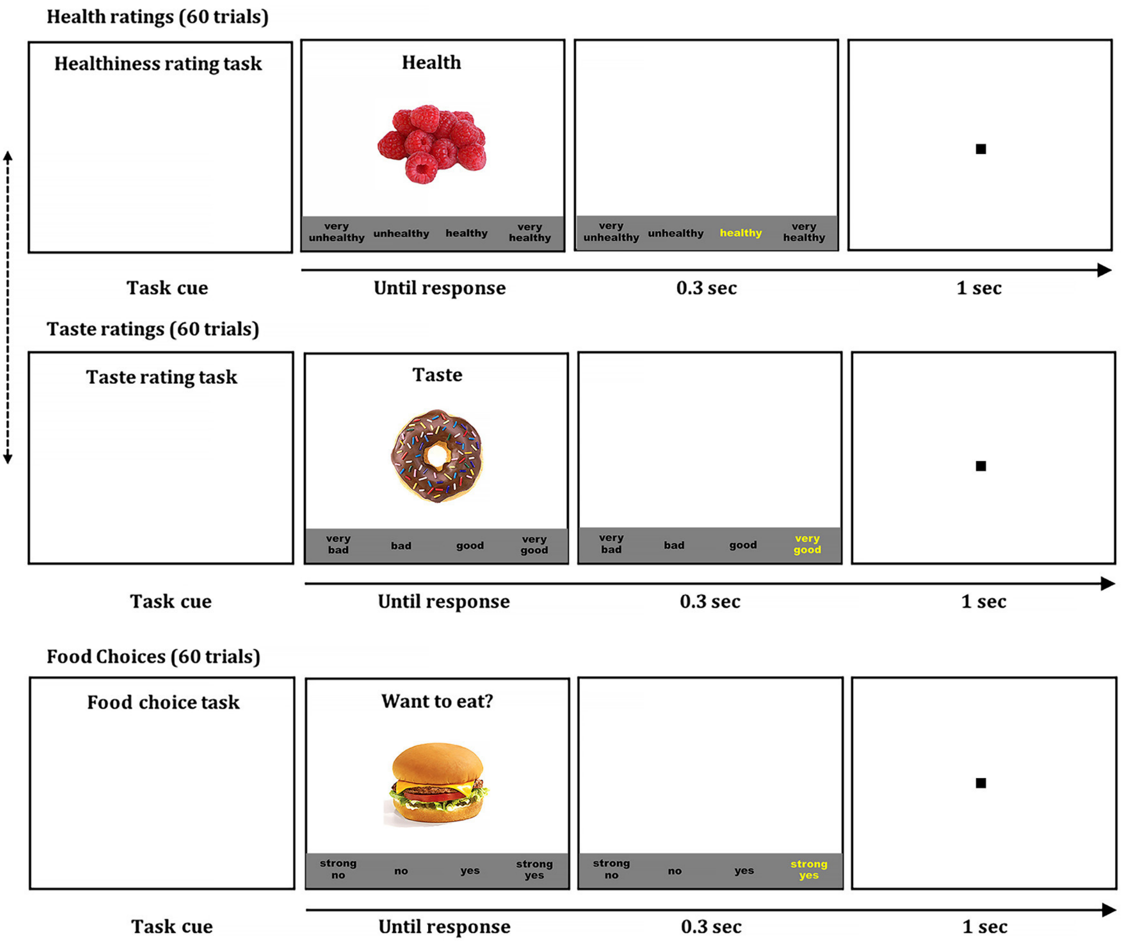

FIGURE 2 | Food ratings and choice tasks. Children rated food healthiness and taste of 60 food items (30 unhealthy and 30 healthy) using four-point scales (health: very unhealthy, unhealthy, healthy, very healthy; taste: very bad, bad, good, very good). Then, children made food decisions on the same 60 food items using a four-point scale (strong no, no, yes, strong yes). Each task began with a task cue. When children pressed a space bar, a colored food image was presented on a white background in the center of the screen that remained on the screen until children made a response, and options of a four-point scale were shown at the bottom. When children chose an option, the selected option was briefly highlighted in yellow to provide visual feedback of their selection. A fixation point was presented for 1 s before the beginning the next trial. The order of food items was randomized in each task, and the order of health and taste ratings were counterbalanced across children.

the regression model simultaneously. Each child's estimated regression coefficient of taste attributes indicated the relative decision weights of the taste in food decisions, and an estimated regression coefficient of health attributes indicated the relative decision weights of the healthiness in food decisions.

RESULTS

Food Decision-Making

Mean estimated regression coefficients, ratings, and choices are listed in **Table 2**. To examine the impact of food taste and health attributes on children's food decisions, we conducted t tests with the estimated regression coefficients of taste attributes for pre- and post-intervention separately in each group. Taste attributes significantly predicted food decisions for both the intervention group, $t_{(17)} = 9.38$, $p < 0.001$, $d = 2.21$, and the control group, $t_{(17)} = 13.02$, $p < 0.001$, $d = 3.02$, at pre-intervention. Taste attributes significantly predicted food decisions for both the intervention group, $t_{(17)} = 9.45$, $p < 0.001$, $d = 2.23$, and the control group, $t_{(17)} = 8.77$, $p < 0.001$, $d = 2.07$, at post-intervention as well. Similarly, we conducted t tests with the estimated regression coefficients of health attributes for pre- and post-intervention separately in each group. Health attributes did not significantly predict food decisions for the intervention group, $t_{(17)} = 0.68$, $p = 0.508$, $d = 0.16$, nor the control group, $t_{(17)} = 0.06$, $p = 0.955$, $d = 0.07$, at pre-intervention. Health attributes did not significantly predict food decisions for the intervention group, $t_{(17)} = 0.28$, $p = 0.78$, $d = 0.07$, nor the control group, $t_{(17)} = -0.34$, $p = 0.737$, $d = -0.08$, at post-intervention. These results suggest that children mainly utilize taste information, but not health information, for their food decisions.

TABLE 2 | Mean and standard deviations of beta coefficients, ratings, and choices.

Group	Mean estimated regression coefficients β (SD)				Mean taste ratings (SD)				Mean health ratings (SD)				Mean choices (SD)			
	Taste		Health		Unhealthy foods		Healthy foods		Unhealthy foods		Healthy foods		Unhealthy foods		Healthy foods	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Intervention	0.75 (0.34)	0.59 (0.27)	0.02 (0.24)	0.01 (0.16)	3.42 (0.35)	3.19 (0.39)	3.01 (0.38)	2.93 (0.46)	1.93 (0.36)	2.01 (0.38)	3.41 (0.29)	3.27 (0.33)	3.19 (0.37)	3.07 (0.48)	2.83 (0.39)	2.86 (0.36)
Control	0.68 (0.22)	0.57 (0.28)	0.003 (0.19)	−0.01 (0.17)	3.33 (0.28)	3.17 (0.33)	2.93 (0.38)	2.87 (0.47)	2.01 (0.53)	2.19 (0.64)	3.22 (0.44)	3.18 (0.52)	3.09 (0.29)	3.09 (0.37)	2.66 (0.37)	2.76 (0.44)

The Intervention Effect

Decision Weights of Taste and Health Attributes

To examine the effect of food advertising literacy intervention or control sessions on the relative decision weights of taste attributes, we compared the mean estimated regression coefficient of taste attributes between pre- and post-session within each group. Planned comparisons revealed that the estimated regression coefficient of taste attributes was significantly decreased in the intervention group after completing the intervention, $t_{(17)} = 2.15$, $p = 0.046$, $d = 0.51$, which confirmed the hypothesis 1 (see **Figure 3**). In contrast, the estimated regression coefficient of taste attributes was not significantly changed after completing control sessions in the control group, $t_{(17)} = 1.65$, $p = 0.118$, $d = 0.39$. We also examined the effect of food advertising literacy intervention or control condition on the relative decision weights of the healthiness within each group. The estimated regression coefficient of health attributes was not significantly after completing the intervention in the intervention group, $t_{(17)} = 0.45$, $p = 0.661$, $d = 0.11$, nor after completing the control sessions in the control group, $t_{(17)} = 0.48$, $p = 0.639$, $d = 0.11$. These results suggest that the advertising literacy intervention effectively reduces the relative importance of the taste in children's food decisions, which was not observed in the control condition. It is noteworthy to mention that these results replicated our previous work testing the feasibility of the food advertising literacy intervention (Ha et al., 2018).

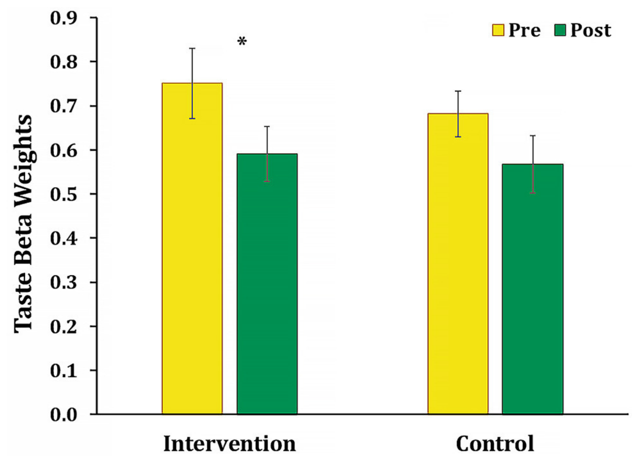

FIGURE 3 | Mean taste beta coefficients in the intervention and control groups. The mean regression beta coefficients of taste attributes was significantly decreased between pre- and post-intervention sessions in the intervention group (*$p = 0.046$). There was no significant change of the mean regression beta coefficients of taste attributes between pre- and post-control sessions in the control group.

Taste and Healthiness Perceptions

To explore the effect of intervention or control sessions on food taste and healthiness perceptions, we compared the mean taste and health ratings of unhealthy (30 food items) and healthy foods (30 food items) separately between pre- and post-session within each group. For the intervention group, comparisons demonstrated that unhealthy foods taste ratings significantly decreased after completing the intervention, $t_{(17)} = 2.55$, $p = 0.021$, $d = 0.60$, whereas unhealthy foods health ratings were not changed, $t_{(17)} = -1.43$, $p = 0.171$, $d = -0.34$. Healthy foods taste ratings, $t_{(17)} = 0.91$, $p = 0.376$, $d = 0.21$, and healthy foods health ratings, $t_{(17)} = 1.73$, $p = 0.102$, $d = 0.41$, were not significantly changed. These results suggest that children perceive unhealthy foods as less tasty after receiving the intervention. For the control group, unhealthy foods taste ratings significantly decreased, $t_{(17)} = 2.47$, $p = 0.024$, $d = 0.58$, meanwhile unhealthy foods health ratings significantly increased, $t_{(17)} = -2.79$, $p = 0.013$, $d = -0.66$, after completing the control sessions. Healthy foods taste ratings, $t_{(17)} = 0.85$, $p = 0.408$, $d = 0.20$, and healthy foods health ratings, $t_{(17)} = 0.79$, $p = 0.439$, $d = 0.19$, were not significantly changed. These results suggest that children in the control condition, who were exposed to food commercials without intervention, show an adverse effect of evaluating unhealthy foods healthier. Considering the association between unhealthiness and tastiness (Raghunathan et al., 2006; Ha et al., 2019), perceiving unhealthy foods less tasty could be linked to adverted food healthiness evaluations.

Tasty Categorization

To confirm the intervention effect of perceiving unhealthy foods less tasty, we compared tasty categorizations of unhealthy (30 food items) and healthy foods (30 food items) separately between pre- and post-session within each group. Based on children's taste ratings, food items were categorized as *tasty* (i.e., "good" or "very good" ratings), or *not-tasty* (i.e., "bad" or "very bad" ratings), for unhealthy and healthy foods separately. Then, we examined the percentages of *tasty* and *not-tasty* food items for unhealthy foods. In the intervention group, the percentages of *unhealthy/tasty* food items significantly decreased from pre-intervention (M = 90.9%, SD = 9.1) to post-intervention (M = 84.6%, SD = 12.7), $t_{(17)} = 2.52$, $p = 0.022$, $d = 0.59$, which also reflected the significant increase of the percentages of *unhealthy/non-tasty* foods items from pre-intervention (M = 9.1%, SD = 9.1) to post-intervention (M = 15.4%, SD = 12.7), $t_{(17)} = -2.52$, $p = 0.022$, $d = -0.59$, which confirmed the hypothesis 2. In the control group, there was no significant changes of the percentages of *unhealthy/tasty* food items between pre-control session (M = 90.2%, SD = 10.5) and post-control session (M = 87.0%, SD = 12.7), $t_{(17)} = 1.40$, $p = 0.179$, $d = 0.33$, which reflected no significant percentage changes of *unhealthy/non-tasty* foods items between pre-control session (M = 9.8%, SD = 10.5%) and post-control session (M = 13.0%, SD = 12.7%), $t_{(17)} = -1.40$, $p = 0.179$, $d = -0.33$. These results suggest that the intervention influences children to perceive unhealthy foods less tasty.

Additionally, we compared the percentages of *tasty* and *non-tasty* food items for healthy foods between pre- and post-session within each group. In the intervention group, there was no significant percentage changes of *healthy/tasty* foods items between pre-intervention (M = 75.4%, SD = 17.2) and post-intervention (M = 73.1%, SD = 19.8), $t_{(17)} = 0.74$, $p = 0.473$, $d = 0.17$, which reflected no significant percentage changes of *healthy/not-tasty* foods items between pre-intervention (M = 24.6%, SD = 17.2) and post-intervention (M = 26.9%, SD = 19.8), $t_{(17)} = -0.74$, $p = 0.473$, $d = -0.17$. In the control group, there was no significant percentage changes of *healthy/tasty* foods between pre-control session (M = 74.8%, SD = 16.7%) and post-control session (M = 70.9%, SD = 19.2), $t_{(17)} = 1.51$, $p = 0.149$, $d = 0.36$, which reflected no significant percentage changes of *healthy/not-tasty* foods items between pre-control session (M = 25.2%, SD = 16.7%) and post-control session (M = 29.1%, SD = 19.2), $t_{(17)} = -1.51$, $p = 0.149$, $d = -0.36$.

Attitudes Toward Commercials

We examined children's beliefs, liking, positive attitudes toward commercials as well as advertising impact on food preferences and food choices using children's self-report on food commercial questionnaires for each group (see **Supplementary Table 1** for descriptive statistics). For the intervention group, children's perceived advertising influence on food preferences significantly decreased between the first session and the last session, $t_{(17)} = 2.32$, $p = 0.033$, $d = 0.55$, suggesting that children perceived food commercials as having less impact on their food preferences after completing the intervention. For the control group, the liking of the commercial significantly decreased between the first session and the last session, $t_{(17)} = 2.69$, $p = 0.016$, $d = 0.63$, suggesting that children perceived food commercials they watched as less likable after completing the control sessions. Results of other attitudes measured using food commercial questionnaires were not significant.

To further investigate how the intervention influenced children's cognitive skepticism and critical thinking and affective responses toward commercials at the time of exposure, we examined children's spoken thoughts while watching food commercials obtained using the think-aloud method (see **Supplementary Table 2** for descriptive statistics). During four sessions, children showed more affective responses than cognitive responses relevant to food commercials while watching commercials in the intervention group, $t_{(17)} = 3.86$, $p < 0.001$, $d = 0.91$, as well as in the control group, $t_{(17)} = 4.10$, $p < 0.001$, $d = 0.99$. The percentages of negative cognitive responses estimated the relative cognitive skepticism and critical thinking toward commercials in cognitive responses, and the percentages of negative affective responses estimated the relative negative affective attitudes toward commercials in affective responses. For the intervention group, the percentages of negative cognitive responses toward commercials were significantly increased from the first session to the last session, $t_{(17)} = -2.68$, $p = 0.016$, $d = -0.63$, but the percentages of negative affective responses toward commercials were not significantly different between the first session and the last session, $t_{(17)} = -0.89$, $p = 0.388$, $d = -0.21$ (see **Figure 4**). For the control group, the percentages of negative cognitive responses toward commercials were not significantly different between the first session and the last session, $t_{(17)} = -1.19$, $p = 0.0249$, $d = -0.28$, nor the percentages of negative affective responses toward commercials were not significantly different between the first session and the last session, $t_{(17)} = -0.38$, $p = 0.710$, $d = -0.21$. These results suggest that the intervention effectively enhances children's cognitive skepticism and critical thinking toward commercials.

Opinions on Advertising Literacy Narratives

To explore children's cognitive and affective attitudes toward intervention narratives, we examined children's spoken words while listening to narratives between commercials using the think-aloud method in the intervention group. The percentages of negative cognitive responses toward narratives were not significantly different between the first session and the last session, $t_{(17)} = -1.89$, $p = 0.077$, $d = -0.45$. The percentages of negative affective responses toward narratives were not significantly different between the first session and the last session, $t_{(17)} = -1.14$, $p = 0.270$, $d = -0.27$.

We observed that children often expressed opinions about the narratives. We coded children's spoken words relevant to narratives as disagreement (e.g., "It's your opinion."; "Don't lie."), neutral (e.g., "confused"; "I didn't know that."), and agreement (e.g., "That's true."; "exactly") opinions about narratives. We computed the percentages of disagreement (M = 44.3%, SD = 32.8), neutral (M = 8.6%, SD = 15.9), and agreement (M = 36.0%, SD = 33.7) across sessions within each individual. Then, we explored how children's overall opinions to narratives were related to changes in cognitive and affective attitudes toward commercials between the first and the last sessions (i.e., the percentages of cognitive or affective responses at the last session—the percentages of cognitive or affective responses at the first session). The percentages of disagreement to narratives significantly predicted the change in the percentages of negative

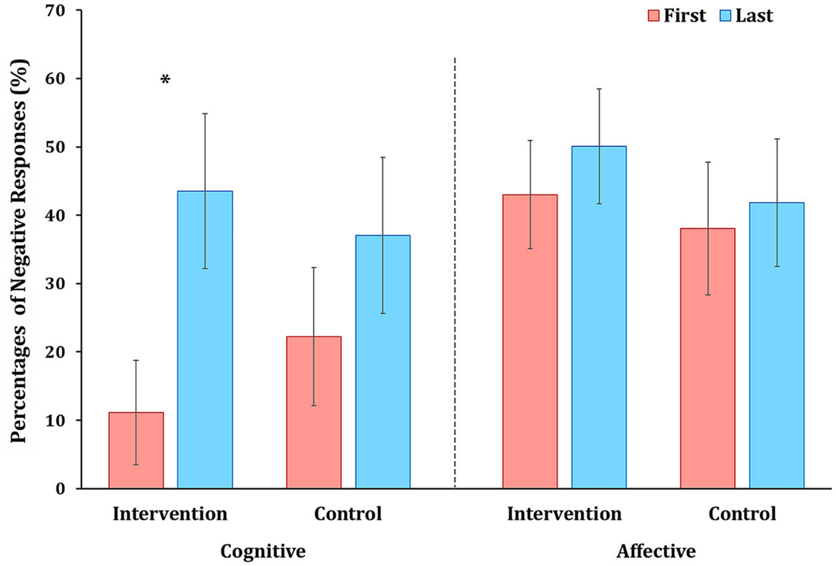

FIGURE 4 | Mean percentages of negative cognitive and affective responses toward commercials. The mean percentage of relative negative cognitive toward commercials was significantly increased between the first and last sessions in the intervention group (*$p = 0.016$), while no significant change was found in the control group. There were no significant changes of relative negative affective responses in both groups.

cognitive responses toward commercials, $b = -0.758$, $SD = 0.34$, $t_{(16)} = -2.22$, $p = 0.041$, $R^2 = 0.235$. As the relative disagreement to narratives decreased, the relative negative cognitive responses toward commercials increased. This finding suggests that as children accept advertising literacy knowledge over the intervention period, their cognitive skepticism and critical thinking toward commercials were enhanced.

Food Choices and *ad libitum* Snacking

To explore the intervention effect on food choices, we compared the mean food choices of unhealthy and healthy foods separately between pre- and post-session within each group. For the intervention group, there was no significant changes in unhealthy food choices between pre-intervention ($M = 3.19$, $SD = 0.37$) and post-intervention ($M = 3.07$, $SD = 0.48$), $t_{(17)} = 1.33$, $p = 0.200$, $d = 0.31$, nor in healthy food choices between pre-intervention ($M = 2.83$, $SD = 0.39$) and post-intervention ($M = 2.86$, $SD = 0.36$), $t_{(17)} = -0.49$, $p = 0.630$, $d = -0.12$, which did not confirm the hypothesis 3. Similarly, for the control group, there was no significant changes in unhealthy food choices between pre-control session ($M = 3.09$, $SD = 0.29$) and post-control session ($M = 3.09$, $SD = 0.37$), $t_{(17)} = 0.11$, $p = 0.912$, $d = 0.03$, nor in healthy food choices between pre-control session ($M = 2.66$, $SD = 0.37$) and post-control session ($M = 2.76$, $SD = 0.44$), $t_{(17)} = -1.80$, $p = 0.090$, $d = -0.42$.

Then, we compared the percentages of children's self-regulated decisions between pre- and post-session. Self-regulated decisions were made when children successfully resisted eating tasty but unhealthy food items (i.e., "no" or "strong no" decisions for *unhealthy/tasty* food items) and chose to eat not-tasty but healthy food items (i.e., "yes" or "strong yes" decisions for *healthy/not-tasty* food items) (Ha et al., 2016; Lim et al., 2016). For the intervention group, there were no significant changes in the percentages of self-regulated decisions between pre- ($M = 13.5\%$, $SD = 12.4\%$) and post-intervention ($M = 18.0\%$, $SD = 19.5\%$), $t_{(17)} = -1.49$, $p = 0.156$, $d = -0.36$. Similarly, for the control group, there were no significant changes in the percentages of self-regulated decisions between pre- ($M = 9.71\%$, $SD = 11.0\%$) and post-intervention ($M = 12.5\%$, $SD = 9.80\%$), $t_{(17)} = -1.41$, $p = 0.177$, $d = -0.34$.

Further, we examined the relations between the attitude toward commercials and food choices. The increase in negative cognitive responses toward commercials observed during think-aloud between first- and last-sessions predicted a concomitant increase in the percentage of self-regulated decisions between pre- and post-intervention in the intervention group, $b = 0.120$, $SD = 0.05$, $t_{(16)} = 2.21$, $p = 0.042$, $R^2 = 0.234$. In contrast, in the control group, the increase of relative negative cognitive responses toward commercials did not significantly predict the increase of the percentages of self-regulated decisions, $b = -0.002$, $SD = 0.04$, $t_{(16)} = -0.06$, $p = 0.956$, $R^2 = 0.0002$. These findings suggest that as children's cognitive skepticism and critical thinking increased, self-regulated decisions increased.

Lastly but importantly, we examined food consumption behaviors for each group to test ecological validity of the intervention effect. The amounts of snack consumption were not significantly different between the first session ($M = 93.29$g, $SD = 28.63$) and the last session in the intervention group ($M = 101.88$g, $SD = 57.48$), $t_{(16)} = -0.72$, $p = 0.484$, $d = -0.17$, which did not confirm the hypothesis 4. Also, the amounts of snack consumption were not significantly different between the first session ($M = 68.56$g, $SD = 36.64$) and the last session in the control group ($M = 62.22$g, $SD = 39.53$), $t_{(17)} = 1.10$, $p = 0.287$, $d = 0.26$. These findings suggest that the advertising literacy training did not change the amount of snack food consumption.

DISCUSSION

In this study, we examined how enhanced resilience to the adverse effect of food commercials influenced susceptibility to unhealthy food decision-making in children ages 8–12 years. For promoting resilience to food commercials, we utilized the food advertising literacy intervention—four-session, 1-week intervention held in both the laboratory and home environment (Ha et al., 2018). This intervention was intended to improve cognitive and affective defenses against food advertising by delivering factual and evaluative narratives. Indeed, children demonstrated higher cognitive skepticism and critical thinking toward the advertising tactics and the advertised foods after completing the intervention, and perceived advertising influence less on their food liking. As hypothesized, the food advertising literacy intervention reduced susceptibility to unhealthy food decision-making. For children who received the intervention, the relative decision weights of taste attributes were significantly decreased in their food decisions, which replicated results of our pilot study (Ha et al., 2018). In addition, children categorized lower number of unhealthy food items as tasty (i.e., *unhealthy/tasty*) after completing the intervention, which suggests reduced tasty processing of unhealthy foods. The results based on changes between the baseline and the completion of intervention suggest that the rate of food choices or the amounts of snack consumption were not changed. But, the speculation on the relations between children's attitudes toward commercials and food decision-making demonstrates that as children's cognitive defenses toward commercials enhanced, their self-regulated decisions are increased. These findings may suggest the advertising literacy intervention is effective in enhancing self-regulated eating decisions as children's cognitive defenses improves.

In contrast, for children in the control condition, children did not show changes in cognitive skepticism and critical thinking toward commercials. Regarding the susceptibility to unhealthy food decision-making, the relative decision weights of taste attributes were not significantly changed. Children perceived unhealthy foods as less tasty after completing the control sessions similar to children in the intervention condition. However, considering that they evaluated unhealthy foods healthier than before, decreased taste perception of unhealthy foods could be related to the adversely evaluated food healthiness. Children in the control condition reported a decreased liking of commercials they watched. Repetitive exposure to the same commercials might decrease liking for those commercials, yet, children's decision weights of taste attributes nor cognitive skepticism and critical thinking toward food commercials were not changed. Actual food choices or amounts of snack food consumptions were not changed neither.

Taken together, findings provide evidence that promoting resilience to food commercials by increasing cognitive skepticism and critical thinking toward food commercials reduce children's susceptibility to unhealthy food decision-making. Given the pervasive advertising effect on heightened attentional vigilance to food brand logos (Masterson et al., 2019b), biased taste preference to branded foods (Robinson et al., 2007), and increased liking of fast food even with the exposure to commercials featuring "healthier" fast food meal options (Boyland et al., 2015), the results of this study provide a valuable understanding of strategies for building children's resilience to adverse effects of food advertising. When considering that exposure to food commercials increases the importance of the taste attribute in food decisions (Bruce et al., 2016), the reversed, intervention effect that decreased the importance of the taste attribute in food decisions in this study emphasizes the benefits of cognitive defenses in combating undesired effects of food commercials and taste-oriented, unhealthy eating decisions.

The brief, 1-week intervention was not sufficient to change the amount of actual snack food consumption. Since snack items used in the *ad libitum* task were familiar branded snack food items (Keller et al., 2012), and television food advertising has a strong priming effect in increasing snack consumption in children (Harris et al., 2009; Russell et al., 2019), more pervasive intervention tactics may be required to change actual amounts of food consumption. One neuroimaging study that tested the influence of television food commercials on food consumption reported that watching food commercials did not significantly change the amounts of meal consumption in the laboratory, however, exposure to high-energy food items reduced brain activations in the prefrontal cortex that is involved in cognitive control in children who watched food commercials (Masterson et al., 2019a). Thus, future studies should examine how the advertising literacy intervention would influence children's brain responses to food commercials and unhealthy and healthy food decision-making and implications for actual food consumption when both healthy and unhealthy options are provided.

Additionally, there is a possibility that when and who delivers the narratives, and what specific contents are targeted matter in a food advertising literacy intervention. When Rozendaal and her colleagues (2016) created an animation character to deliver the factual narratives prior to commercials only in one session, children who had a narrative targeting manipulative intent of the advertising as a forewarning showed more negative affective attitudes toward commercials that led to lower desire to the advertised product compared to comparison groups (Rozendaal et al., 2016). Still, it is unknown whether the forewarning method may reduce the relative importance of taste attribute in food decisions.

Another important aspect to address is the advantage of a "think-aloud" method for speculating children's information processing online. The think-aloud method allowed us to explore children's spontaneous responses at the moments of food commercial exposure (Rozendaal et al., 2012). In this study, the intervention effect was related to the changes in cognitive defenses toward commercials. Unexpectedly, we observed that children often expressed opinions about the intervention narratives, and those thoughts reflected children's own perspectives and attitudes toward narratives and advertised foods. As assimilation of advertising literacy occurred, children's cognitive skepticism and critical thinking toward commercials increased. These findings suggest that especially for those children with opponent thoughts to narratives, interactive learning providing more explanations for advertising tactics and healthier food options could be helpful to enhance defenses against food advertising.

The think-aloud process itself could be effective in activating advertising literacy. From the perspective of the development of information processing that children retrieve and apply knowledge when cues are provided, the think-aloud process could act as a cue for activating cognitive defenses that decrease susceptibility to advertising (Rozendaal et al., 2012). In the present study, children in the control condition who used think-aloud with no intervention, showed a decreased liking of commercials. This decrease could be an effect of the think-aloud method. However, our findings suggest that the think-aloud method was not sufficient to decrease the susceptibility to advertising in that no changes were observed in cognitive skepticism and critical thinking. Moreover, think-aloud itself was not effective in reducing susceptibility to unhealthy food decision-making in that these children did not demonstrate changes in the importance of taste attributes in food decision-making, tasty categorization of *unhealthy/tasty* food items, and food choices. Future studies should examine how the think-aloud method alone and the combined narratives and think-aloud would differently impact susceptibility to commercials and unhealthy food decision-making when they are compared to a passive viewing control group.

Together, the findings of the present study suggest that cognitive defenses to advertising are activated more effectively when children are cued with narratives, and actively utilize and exercise advertising literacy information internally to deflate the undesired influence of advertising while watching food commercials. Successful defenses could be extended to reduce susceptibility to unhealthy food decision-making. In a normal viewing situation, children are less likely to exercise advertising literacy defenses on their own without external narrative cues and encouragement for active application of advertising literacy information (Brucks et al., 1988). Thus, the role of parents is highly important to teach advertising literacy and encourage children to utilize cognitive defenses actively, instead of passively receiving the advertising information, until they develop the internalized and autonomous strategies to overcome the adverse effects of food commercials (Buijzen and Valkenburg, 2005; Buijzen, 2009). A similar environment that the food advertising literacy intervention provides to promote resilience to advertising and reduce susceptibility to unhealthy eating could be built at home or weight-management clinics by having educational conversations or intervention sessions. Education would be especially helpful when parents and children are watching food commercials together. Parental roles are also critical in the development of healthy eating. Our recent work shows that children can make more self-regulated eating decisions while thinking "what my parents would want me to eat," compared to when they make eating decisions while thinking "what I like to eat" (Lim et al., 2016). These results suggest that parents' guidance on healthy eating could cue and activate self-regulated eating decisions until children's dietary self-control is internalized. Parents should set good examples for their children by exercising controls on their consumer and eating behaviors (Pettigrew et al., 2013).

School and media also need to engage in teaching advertising literacy and healthy food choices more actively so that children practice and build strategies to combat the advertising effect and reduce susceptibility to unhealthy food choices, given that food advertising and unhealthy eating habits are among the major contributing factors of childhood obesity (Kelly et al., 2010). Regulations that intended to limit unhealthy food marketing on television have not been successful in controlling exposure to unhealthy and fast food advertisements in many countries (Campos et al., 2016; Vandevijvere et al., 2017; Whalen et al., 2019). Regulating food commercials is not limited to television advertising anymore since children are exposed to food commercials through various online platforms and smartphone applications that use both direct and indirect methods (Nelson, 2018). Despite growing challenges, advertising literacy interventions have shown promise in promoting resilience to advertising in various formats (Hudders et al., 2016; De Jans et al., 2017). Thus, our society, as a whole, including advertisers and legislators, needs to focus on developing more critical strategic regulations and solutions utilizing advertising literacy, such as an embedded warning in text, especially for high-caloric, low-nutrient unhealthy foods, to regulate children's exposure to unhealthy food commercials. Efforts could include limiting advertising contents and tactics targeting children that could easily sway their attention and trigger affective responses, which could overwhelm children's developing cognitive defenses and provoke overconsumption of unhealthy foods that increase risks of developing obesity (De Jans et al., 2019).

Future studies should investigate an expanded intervention, such as a more active learning opportunity for a prolonged period, could effectively promote both negative affective and negative cognitive attitudes toward commercials that lead to changes of the decision weights of taste attribute, food choices, and food consumption with a larger scale (Hudders et al., 2016; De Jans et al., 2017). To examine whether factual and evaluative narratives influence susceptibility to unhealthy food decision-making differently, future studies should test the intervention effect of factual narratives and evaluative narratives separately. Although the sessions were held frequent, our 1-week brief intervention sessions with narratives did not have enough impact to change the actual rates of food choices and the amounts of snack consumption, similar to our previous study (Ha et al., 2018). Futures studies should further investigate how well the food advertising literacy intervention could be applied for enhancing resilience to food commercials featured in various formats including YouTube videos, social media, and mobile games, targeting children and adolescents. Additionally, considering the relations between unhealthy food decision-making and children's self-control development (Ha et al., 2016, 2019), and the improved self-regulated decisions along with the enhanced cognitive defenses, future studies should address how children's dietary self-control influences the relation between resilience to food commercials and susceptibility to unhealthy food decision-making. Lastly, future studies could utilize a think-aloud method for food choices (Ogden and Roy-Stanley, 2020), which could reveal children's thinking process underneath food decision-making.

This study has several limitations. The sample size was relatively modest. However, in the present study, we replicated the main finding of Ha et al. (2018) that children's relative decision weights of taste attributes decrease after intervention.

Across our two studies that report the intervention effect, the probability of committing two consecutive type I error is reduced to 0.0025 or 0.25% (0.05 × 0.05). The effect size of the main intervention effect on the reduced taste importance is $d = 0.51$, which indicates a medium effect size. We believe that replication of previous findings with a medium effect size in the present study could reduce the possibility of false positive and negative observations. The brief 1-week intervention we used did not change the amount of snack food consumption. The findings of this study expand our understanding of the efficacious strategies of promoting resilience to undesired effects of food commercials, which could establish healthy eating habits and less taste-oriented food decisions in children. Furthermore, the findings of this study imply that helping children to build developmentally-suited, defense mechanisms for various external food cues could be effective for prevention and intervention for childhood obesity.

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 Human Subjects Committee at the University of Kansas Medical Center and the Institutional Review Board at the University of Missouri-Kansas City. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

O-RH and AB contributed to the conception and design of the study. O-RH and HK organized the database. HK, JS, and SN collected the data. HK, SN, and O-RH performed the coding. O-RH performed the statistical analysis and wrote the first draft of the manuscript. AB, AD, and S-LL contributed to the discussion of the results and implications. All authors contributed to manuscript revision, read, 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.2020.599663/full#supplementary-material

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Strawberries and Cream: The Relationship Between Food Rejection and Thematic Knowledge of Food in Young Children

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Establishing healthy dietary habits in childhood is crucial in preventing long-term repercussions, as a lack of dietary variety in childhood leads to enduring impacts on both physical and cognitive health. Poor conceptual knowledge about food has recently been shown to be a driving factor of food rejection. The majority of studies that have investigated the development of food knowledge along with food rejection have mainly focused on one subtype of conceptual knowledge about food, namely taxonomic categories (e.g., vegetables or meat). However, taxonomic categorization is not the only way to understand the food domain. We also heavily rely on other conceptual structures, namely thematic associations, in which objects are grouped because they share spatial-temporal properties or exhibit a complementary relationship (e.g., soft-boiled egg and soldiers). We rely on such thematic associations between food items, which may not fall into the same taxon, to determine the acceptability of food combinations. However, the development of children's ability to master these relations has not been systematically investigated, nor alongside the phenomenon of food rejection. The present research aims to fill this gap by investigating (i) the development of conceptual food knowledge (both taxonomic and thematic) and (ii) the putative relationship between children's food rejection (as measured by the Child Food Rejection Scale) and both thematic and taxonomic food knowledge. A proportional (A:B::C:?) analogy task, with a choice between taxonomic (i.e., bread and pasta) and thematic (i.e., bread and butter) food associates, was conducted on children between 3 and 7-years-old ($n = 85$). The children were systematically presented with either a thematic or taxonomic food base pair (A:B) and then asked to extend the example type of relation to select the respective thematic or taxonomic match to the target (C:?). Our results revealed, for the first time, that increased levels of food rejection were significantly predictive of poorer food identification and decreased thematic understanding. These findings entitle us to hypothesize that knowledge-based food education programs to foster dietary variety in young children, should not only aim to improve taxonomic understanding of food, but also thematic relations.

Keywords: categorization, taxonomic categories, thematic relations, food cognition, food rejection, food neophobia, conceptual representation

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INTRODUCTION

A lack of dietary variety in childhood leads to enduring impacts on both physical and cognitive health (Evans et al., 2018). Consequently, establishing healthy dietary habits in childhood is crucial in preventing long-term repercussions (Jirout et al., 2019). Food rejection, namely food neophobia and pickiness, has been determined as a central psychological driver in reduced dietary variety in young children (Carruth et al., 2004; Levene and Williams, 2017). Food neophobia is defined as a fear of novel food stimuli or food-based situations and is often witnessed as a reluctance or unwillingness to try unfamiliar foods (Dovey et al., 2008; Lafraire et al., 2016; Crane et al., 2020). Food pickiness, on the other hand, is the rejection of both familiar or unfamiliar foods and textures (Dovey et al., 2008; Lafraire et al., 2016). Importantly, both food pickiness and food neophobia similarly account for inadequate food consumption and nutrient deficiencies in young children (Dovey et al., 2008; Lafraire et al., 2016; Rioux et al., 2017b). Longitudinal research demonstrates that, although food neophobia and food pickiness have an increased prevalence during childhood, such dietary habits and behaviors prevail well into adulthood (Nicklaus et al., 2005). Consequently, it is fundamental to identify the key driving mechanisms of food rejection in young children to tackle poor eating habits and behaviors (World Health Organization, 2014).

Food rejection, and in particular food neophobia, ultimately depends upon children's recognition and knowledge when they are confronted with a possible food source (Birch, 1979). A key cognitive mechanism enabling food recognition and related feelings of familiarity is categorization. Taxonomic categorization depicts classifying items into a hierarchical structure based on shared features or properties (e.g., edibility, overall shape, sweetness, et cetera); for example, an apple belongs to the category of fruits, which may be further categorized into the broader category of food (Lucariello et al., 1992; Murphy, 2002; Gelman, 2003). It allows us to group foods, generalizing their key properties (e.g., edibility, toxicity, et cetera) to novel objects based on category membership (Ross and Murphy, 1999; Nguyen, 2008; Lafraire et al., 2016; Rioux, 2020). For example, we rarely encounter the same apple twice, but having the category knowledge of an apple allows us to make the relevant inferences that it is similar to apples we have previously encountered (Murphy, 2002). However, foods, like many other categories, are multidimensional concepts and rely on different methods of association to form inferences (Ross and Murphy, 1999).

One such alternative method of inferring information is through thematic knowledge. Thematic relations group items based on a complementary or spatial-temporal relationship, such as a banana and a monkey because they form a complementary and well-known association (Gelman and Markman, 1986; Markman, 1989). Thematic categories display diverse types of associations, such as functional (e.g., soup and spoon), co-occurring (e.g., bread and butter), or even causal relations (e.g., cow and milk) (Keil, 1989; Markman, 1989). As such, thematic categories are useful in that they provide us with situational cues and inferences on the origin, use, and possible consequences of items, which is essential in the food domain. For example, knowing the thematic association of certain foods with a bowl, allows us to infer that when we encounter an unfamiliar substance served in a bowl it is likely to be edible. In contrast, thematic categorization has much less generalization power. Knowing that soup and spoon belong to the same thematic category does not mean that soup properties can be extended to spoon.

Nevertheless, both thematic and taxonomic knowledge in the food domain provides us with cues that enhance our recognition of food-based situations (such as meal times) that underpin food acceptance and rejection. Whilst a caregiver may present a variety of foods to a child, it is ultimately the child's decision whether to accept or reject the food. Poor category knowledge in the food domain lends itself to increased uncertainty and feelings of novelty in the food domain and children with less food knowledge may display higher levels of food rejection to avoid distaste or even potential toxicity (Nguyen and Murphy, 2003). The overarching purpose of the present study is to examine the relationship between children's food rejection (as measured by the Child Food Rejection Scale) with taxonomic and thematic food category knowledge.

To address the possible link between thematic and taxonomic food category knowledge and food rejection in young children, we must first establish at what age children acquire such an understanding of food categories. Studies of children's food knowledge indicate that 3-year-olds already display taxonomic understanding and can distinguish between food and non-food items (Bovet et al., 2005; Lafraire et al., 2016). Impressively, 3-year-old children are further capable of accurately identifying and distinguishing vegetables from fruits (Brown, 2010; Rioux et al., 2016). Another study witnessed that 3-year-olds displayed an above-average accuracy for taxonomic matching and showed a rapid development of taxonomic food knowledge between 3 and 7 years old (Nguyen and Murphy, 2003). Nguyen and Murphy (2003), using an induction task, demonstrated that 7-year-olds, and to a lesser extent even 4-year-olds, could selectively use taxonomic food categories (such as vegetables and fruits) to extend biochemical properties (i.e., similar food composition).

In contrast, studies of children's thematic category knowledge in the food domain are scant. A noticeable exception is a study conducted by Thibaut et al. (2016), which showed that both 4 and 9-year-olds were not likely to rely on thematic category knowledge to make inductive inferences about biological or psychological properties of food (i.e., do both strawberries and cream make Diddl feel ill). They instead observed that 9-year-old children referred to taxonomic category knowledge to make both biological and psychological inferences about the effects of certain foods (i.e., both broccoli and carrots make Diddl happy). In a simplified forced-choice triad version of the task, they showed that both 5 and 6-year-olds were capable of extending psychological and biological properties to taxonomic over thematic food categories. Whilst their results demonstrate that children as young as five have a taxonomic understanding of foods and can inductively infer common properties, there are no conclusive findings regarding the age at which children use thematic category knowledge to guide inference in the food domain. Therefore, studying the acquisition of thematic categories below 5 years of age is one purpose of the present experiment.

Developmental literature outside of the food domain indicates that children as young as 3 years old have a good ability to make thematic and taxonomic associations (Markman and Hutchinson, 1984; Huttenlocher and Smiley, 1987). However, they also evidence that there is a significant improvement in both abilities between 3 and 6 years old (Smiley and Brown, 1979; Waxman and Namy, 1997; Nguyen and Murphy, 2003; Nguyen, 2007). Based on these studies, we hypothesized that there is a significant development of thematic and taxonomic knowledge in children between 3 and 6 years old.

Considering that the acuteness of food rejection is concomitant with the rapid development in children's understanding and categorization, we argue that food rejection is closely intertwined with children's development of category-based understanding in the food domain (Lafraire et al., 2016; Rioux et al., 2016). Of the few studies into children's category knowledge in the food domain, it is only recently that work has investigated the possible link between food rejection and food categorization. Rioux et al.'s pivotal work demonstrated that 3 to 6-year-old children with strong food rejection tendencies displayed poorer performance in a fruit and vegetable forced-choice sorting task (Rioux et al., 2016). More specifically, the researchers witnessed that higher levels of food rejection predicted a higher rate of false alarms for fruit and vegetable categorizations. This indicates that children with high food rejection tendencies inaccurately over-categorize taxonomic groups, which possibly drives them to reject a much larger number of inaccurately categorized fruits and vegetables. In a later study, the same researchers also revealed that food rejection and taxonomic category-based induction performance were significantly negatively correlated (Rioux et al., 2017b, 2018). Whilst children with low food rejection tendencies referred to taxonomic categories when generalizing properties to unknown foods, high food-neophobic and picky-eaters relied on perceptual similarity when generalizing properties (Rioux et al., 2017b). According to the authors, food rejection tendencies restrict and reduce the learning opportunities concerning taxonomic food groups, resulting in a poorer system of taxonomic understanding, and ultimately uncertainty when confronted with unfamiliar food.

Their interpretation presents a central argument for the necessity to investigate the link between food rejection and children's knowledge of thematic categories in the food domain. Thematic categories rely heavily on previous exposure and a degree of familiarity, perhaps more so than taxonomic categories (Markman, 1989; Murphy, 2002). High food rejection tendencies may impede children's understanding of thematic relations because they restrict their interactions and experiences with the food domain. As such, all dimensions related to food knowledge, including familiarity, category knowledge, sensory experiences, etc. would be under-developed. However, to the best of our knowledge, the relationship between thematic category knowledge and food rejection has yet to be investigated. We argue that children with high levels of food rejection would have reduced learning opportunities and experience with food, subsequently impeding their knowledge of thematic relations. Therefore, we hypothesize that children with higher levels of food rejection will have a poorer understanding of thematic associations in the food domain. This lack of thematic knowledge reduces the child's feelings of recognition and understanding when confronted with a potential food source, ultimately perpetuating the cycle of food rejection.

To examine our two leading hypotheses, we developed a proportional analogy task of the type A is to B, what C is to D (D having to be discovered), to compare the development of young children's capabilities to make taxonomic and thematic associations within the food domain. Analogical reasoning is the ability to understand or produce common relational structures between two domains despite dissimilarities between the entities (Gentner, 1983; Hofstadter, 2001; Holyoak, 2012). The children are first exposed to one of the two relations of interest (either thematic or taxonomic) in the first pair of items (A and B; for example, apple and melon both belong to the taxonomic category of fruits) and then asked to extend the example type to choose either the thematic or taxonomic match to the food target image. In the above, the child might be shown an orange and would have to choose between a pineapple–taxonomic choice and a knife-thematic choice).

Analogical understanding is critical in cognition and a core process of discovery, problem-solving, categorization, and reasoning, elements that are all crucial to food decision-making (Gentner and Markman, 1997; Markman and Wisniewski, 1997). One defining feature of analogies is that they capture relational structures between items rather than the features these items share (Gentner, 1983). For example, the pairs car/road and train/railway share the same relation, i.e., "moves on," rather than common surface features. In our context, analogy tasks lend themselves well to investigating thematic and taxonomic knowledge because relational understanding (either thematic or taxonomic) is our central issue (Kotovsky and Gentner, 1996). The children's understanding of the analogy pair, for both taxonomic and thematic conditions, will evidence if food rejection and age predict children's thematic and taxonomic knowledge in the food domain.

MATERIALS AND METHODS

Participants

The children were recruited from an elementary school (children aged 3 to 7-years-old) in the Southeast of France. The school inspector examined the study proposal and permitted the collection of data. This study was performed in accordance with the guidelines as described in the Declaration of Helsinki and complied with international regulations for research on human subjects.

The parents/caregivers provided the consent for their child to take part through completing the consent form and the CFRS questionnaire. Oral assent, in the presence of the child's teacher, was required from all children before going with the researcher. The child was informed that they were free to stop the task and return to class at any point. 146 children between 37.6

and 81.3 months old ($M = 55.57$, $SD = 10.02$) with parental consent participated in the study. Only 85 of the 146 children, (aged between 37.6 and 81.3 months, $M = 58.54$, $SD = 10.71$) completed all elements of the study and were retained in the analysis (see section Results).

Materials and Procedure

To collect the measures of food neophobia and food pickiness, the Child Food Rejection Scale (CFRS; Rioux et al., 2017a) was distributed to the parents/caregivers of the children prior to the main study. The CFRS is a hetero-assessment scale that was developed and validated to measure food rejection in children aged 2 to 7-years-old. Six items form a subscale measuring food neophobia and five items measure picky/fussy eating behaviors. The caregivers are asked to rate their child's eating behaviors on a 5-point Likert scale. The maximum scores, indicating high food rejection behavior, are 25, 30, and 55 for pickiness, neophobia, and global CFRS score, respectively.

Material Selection

To establish an idea of the food children are already exposed to, children's books, online local school menus and food studies conducted with French children (e.g., Thibaut et al., 2016) were consulted. To assess the children's basic knowledge and familiarity with the stimulus materials, we ran a pre-test with six children between 3 and 6 years old. The children were asked to label the food stimuli to determine whether the photo was recognizable (i.e., an item-recognition control measure) and to establish the most common label used by children. The labels provided from this pre-test were used to establish whether the test participants provided an accepted label in the food identification task. The children were then asked to identify the thematic/taxonomic relations existing between the standard stimuli and the thematic/taxonomic choices in each stimulus set. Photos that were not recognized or relationships that were not identified by at least the four eldest children were not included in the further pre-tests.

As commonplace with developmental studies, a pre-test with 79 adults was conducted to select the final set of stimuli. To assess the strength of the thematic relation, the adult participants were asked to score the strength of the association that exists between the target stimulus and the associated thematic match (i.e., "on a scale of 1–7, what is the strength of the association between cereal and milk?"). Following the protocol of Ross and Murphy (1999), we calculated the mean for each pair and decided to retain those with a score above 4.0 out of 7. To determine the taxonomic knowledge of foods, participants were also asked to indicate for each of the food items whether they were good examples of their respective taxonomic categories (e.g., on a scale of 1–7, how typical is a carrot of being a vegetable?). For taxonomic food groups, items ranked above 3.5 out of 7 as typical exemplars of their respective categories were selected (a lower threshold was chosen for taxonomic belonging due to lower overall mean ratings).

The finalized set of stimuli comprised: two thematic food base pairs (pancakes:chocolate sauce and ice cream:wafer cone), two taxonomic food base pairs [banana:apple (fruits) and sardines:salmon (fish)]. One thematically associated artifact example base pair (notebook:pencil), and one taxonomically associated artifact example base pair [dog:monkey (animals)] were selected for the training task. The training triad was comprised of a soccer shoe as the target, with rain boots as the taxonomic match (footwear) and a soccer ball as the thematic choice. For the test, 16 food triads (comprised of the target food, a thematic match, and a taxonomic match) were finalized (see **Appendix A** for a complete overview of the final test stimuli). We ran a pilot on five adults to be sure that each analogy had only one unambiguous solution. The adults made no mistakes and, thus, there was no variance in the data set.

Pilot Study

A pilot test was conducted on children aged between 3 and 6 years-old ($n = 7$) to see if the younger children were: (1) able to follow and understand the analogy task, (2) identify the food stimuli in the test phase, and (3) understand the thematic/taxonomic relation presented in the analogy pair. The pilot followed the procedure of the main test; the two artifact examples and the artifact triad were provided to explain the procedure, followed by the 16 test-phase trials. After each object selection, the child was asked to name all three objects in the 16 separate trials to determine whether the child was familiar with all the presented items. All of the images were correctly identified or adequately described by at least 80 percent (six of the seven children) and thus retained for the main test as per Lucariello et al. (1992).

Food Analogy Task

The task followed a classical analogy paradigm (e.g., Rattermann and Gentner, 1998; Goswami, 2001; Thibaut et al., 2010), where stimuli A:B::C:?, are presented and participants must select a D item from two options (thematically or taxonomically related), in such a way that the C:D pair share the same type of association as the A:B pair (either thematic or taxonomic). If the child understands the relationship between images A and B, they should then apply this relation to image C to identify the appropriate choice of D, from two possible options. Selecting the appropriate response for D implies that the child has understood the type of relationship of the analogy pair and identified the pair demonstrating the same relation. The taxonomic and thematic performance scores were thus calculated as the percentage of appropriate selections when the taxonomic or thematic example, respectively, was presented.

To standardize the photographs presented to the children, each item had to be the most typical representation and contain enough detail consistent with the real-life object, whilst not being overly complicated nor ambiguous (Snodgrass and Vanderwart, 1980). The objects in each triad of photographs were scaled to correspond with the relative dimensions the three objects would have with one another in real life (i.e., the pastry case would be larger than the strawberry). Because we pit thematic against taxonomic associations, we wanted to avoid any factors that could cause a bias toward one type of association over the other. No labels were given to any of the presented stimuli because studies show that providing the labels of items increases taxonomic responses in children (Markman and Wachtel, 1988).

Research indicates that analogical reasoning ability can vary greatly in children between 3 and 6 years old (Christie and Gentner, 2014). However, cognitive development research has successfully used analogy tasks to investigate conceptual development, relational reasoning, and problem solving with pre-verbal children (Ferry et al., 2015, with 6-month-olds and Chen et al., 1997, with 13-month-olds). However, to draw conclusions on thematic and taxonomic knowledge, it was imperative that only children capable of understanding analogies of the sort we used here were included in the analyses. Consequently, we included the training task to determine which of the participants succeeded in understanding the thematic and taxonomic analogies. The two training trials used the same triad (sneaker and soccer ball or rubber boots) to demonstrate that in each triad there are two possible relationships pitted against one another (a thematic or taxonomic match). Children who seemingly failed to identify the corresponding pair in the training were removed on the assumption that if they failed to identify the correct relationship in the analogy examples, their responses to the food trials would be at random. Of the 146 children who provided assent to participate, only 85 children successfully performed the training analogies and went on to complete all trials.

Eight trials were conducted with a thematic analogy base pair (i.e., A = ice cream, B = wafer cone) and eight trials with a taxonomic base pair (i.e., A = apple, B = banana), in a pseudo-randomized order. Then, one of the 16 triads was presented, with C (referred to as the target) (e.g., beef patty) and the respective taxonomic match (e.g., chicken) and thematic match (e.g., burger bun) for the child to select from (see **Figure 1**). The task instructions followed those used in previous studies with younger French children (Thibaut et al., 2016). The procedure for the taxonomic analogy condition was as such: "in the same way that this (banana) goes with this (apple), would this (chicken) or this (burger bun) go with this (patty)?" The thematic analogy condition was identical but the example pair was changed to one of the two thematic relationships, i.e., "in the same way that this (ice cream) and this (cone) go together, would this (chicken) or this (burger bun) go with this (patty)?" All 16 triads pitted a taxonomic associate against a thematic associate, but the analogy pair priming the appropriate answer alternated between taxonomic and thematic pairs in isolation.

Post-identification Task

The literature on categorization development frequently argues that object recognition/familiarity is important to children's categorization abilities, particularly for thematic associations (Markman, 1989; Thibaut et al., 2010). Therefore, we deemed it necessary to determine what effect children's object identification had on correct thematic and taxonomic knowledge. To measure children's familiarity with the food items, after the

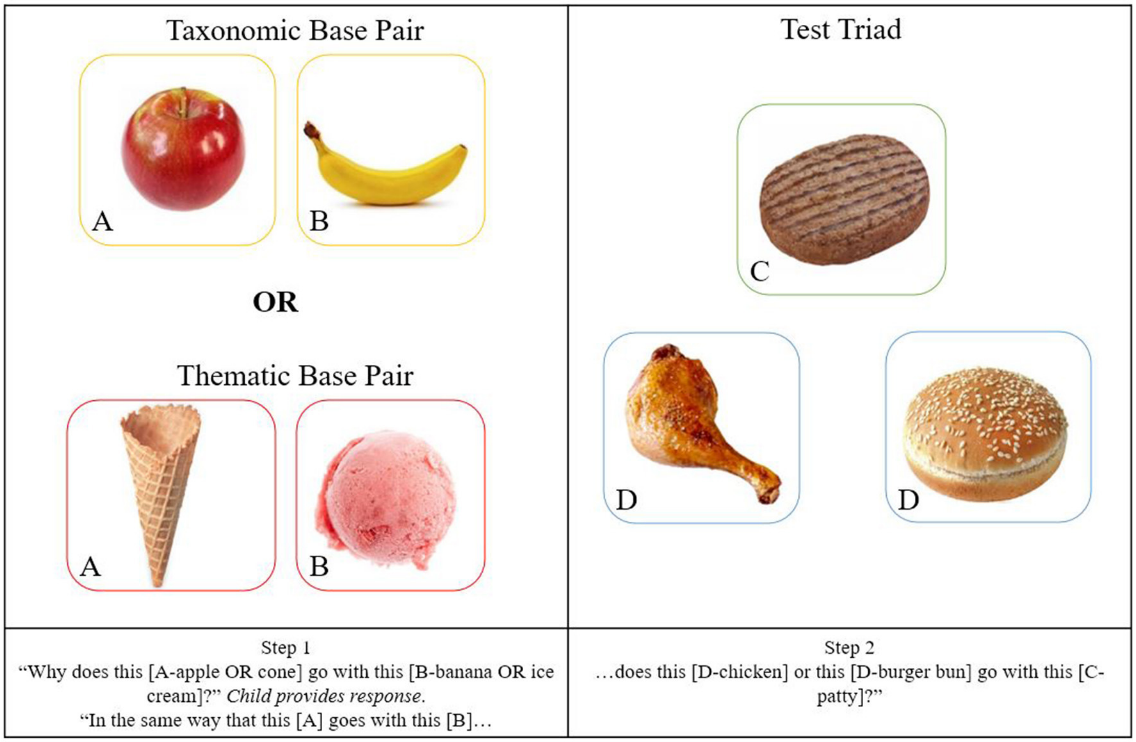

FIGURE 1 | Example of stimuli presented for both taxonomic and thematic analogy condition and example test triad.

child had completed each trial, they were asked to label the stimuli.

Statistical Analyses

To determine whether age and food rejection were predictive of taxonomic or thematic performance, general linear models were computed with taxonomic and thematic analogy scores as outcomes. Due to the expected collinearity between the neophobia and pickiness variables, separate models were run with CFRS, pickiness, and neophobia, and the Akaike Information Criterion (AIC) was used as the estimator of the relative quality of the statistical models. All descriptive and inferential analyses were performed with the software R.3.5.3, and the significance level was set to 5% ($p < 0.05$).

RESULTS

Of the 146 children, only 85 French children completed the training analogy task and went on to complete all the test trials. 83 of the 85 participants completed the identification task of the study, two participants did not respond or were incomprehensible in their replies. The subsequent analyses are based on the 83 children (35 boys and 48 girls) who completed all training trials, test trials, and the post-identification task. The 83 children were aged between 37.6 and 81.3 months old ($M = 58.5$, $SD = 10.7$).

To calculate the performance in the food analogy task, a score of 0 was assigned if participants selected the divergent choice for each triad (e.g., thematic: taxonomic pair). In contrast, a score of 1 was assigned to each trial that the participant selected the analogous choice (e.g., thematic example: thematic choice OR taxonomic example: taxonomic choice). Scores were totaled, with a maximum possible score of eight for both thematic and taxonomic performance, and a global score of 16 for all trials collapsed together. Across all participants the scores for taxonomic and thematic performance showed similar distributions ($M = 0.54$, $SD = 0.21$; $M = 0.57$, $SD = 0.21$, respectively). As there were only two options, the children had a 50% chance of guessing the correct response, which subsequently would heavily bias the total score. Therefore, we took taxonomic performance and thematic performance as dependent variables. To account for the potential preference of either taxonomic or thematic associations, the total number of thematic and taxonomic responses for all 16 trials was calculated, regardless of the analogy pair. Four participants responded significantly above chance (12 or more responses) for the taxonomic choice and eight participants for thematic responding. Overall, there was no significant difference between the response rate for thematic or taxonomic selection regardless of the analogy example ($Z = -0.731$, $p = \text{ns}$).

To score food identification in the post-task, the responses were noted and then coded post-study (1 = correct response, 0 = incorrect response or uncertainty) based on a list of correct or synonymous labels, with a total possible score of 48. Sensory properties (e.g., sour), non-descript labels (e.g., store name), or labels that did not have 100 percent consensus among the research team, were classified as incorrect. The mean score for food identification was 75.6 percent ($SD = 14.5\%$), demonstrating a good overall knowledge of the stimuli set. There were no main or interactive effects of gender or order, so these variables were not included in the subsequent analyses. There were no significant interaction effects between the variables (outside of the expected collinearity of the CFRS subscales). Across the sample, the average pickiness score was 17.7 ($SD = 4.5$) out of a possible 25, the average neophobia score was 16.69 ($SD = 5.66$).

Shapiro-Wilk analyses showed that age, pickiness, food identification, taxonomic, and thematic scores were not normally distributed, thus a Spearman's Rho matrix with bootstrapping ($B = 1{,}000$) was conducted to identify significant correlations between the variables (see **Table 1**). Age was significantly correlated with identification score ($r_s = 0.510$, $p < 0.001$, $N = 83$). Regression models, using a forward stepwise method were run to predict food identification from age, neophobia, and pickiness scores. Age was the sole significant predictor of food identification scores, $\beta = 0.292$, $t(81) = 4.99$, $p < 0.001$. Age explained a significant proportion of variance in food identification, $R^2 = 0.201$, $F(1, 81) = 20.36$, $p < 0.001$.

TABLE 1 | Spearman's Rho correlation matrix for all variables.

Variable	1	2	3	4	5	6	7	8	9
1. Taxonomic Score	–								
2. Thematic Score	0.053	–							
3. Total Score	0.683**	0.726**	–						
4. Identification score	−0.039	0.393**	0.262**	–					
5. Pickiness	−0.054	−0.320**	−0.240*	−0.082	–				
6. Neophobia	−0.002	−0.208	−0.162	−0.051	0.605**	–			
7. CFRS	−0.040	−0.247*	−0.207	−0.051	0.843**	0.922**	–		
8. Age	0.078	0.138	0.166	0.510**	−0.088	0.103	0.020	–	
9. Taxonomic responses	0.645**	−0.685**	−0.044	−0.311**	0.203	0.158	0.157	−0.035	–
10. Thematic responses	−0.655**	0.682**	0.038	0.298**	−0.197	−0.176	−0.168	0.051	−0.994**

**P < 0.01, *P < 0.05.

TABLE 2 | Regression model predicting thematic performance.

		B	Std. error	β	AIC
Step 1					−245.288
	Constant	1.144	0.924		
	Identification	0.095	0.025	0.389**	
Step 2					−249.492
	Constant	3.16	1.11		
	Identification	0.091	0.024	0.373*	
	CFRS	−0.055	0.018	−0.293*	

*$R2 = 0.151$ for Step 1, $\Delta R2 = 0.085$ for Step 2 ($p = 0.014$). **$p < 0.001$, *$p < 0.05$.*

Taxonomic performance did not show any significant correlations with the predictor variables and was subsequently not included in further modeling.

The most important result was a significant negative correlation between pickiness and thematic performance ($r_s = -0.320$, $p = 0.003$, $N = 83$) and CFRS and thematic performance ($r_s = -0.247$, $p = 0.024$, $N = 83$). Whereas, correct food identification was positively correlated with thematic performance ($r_s = 0.393$, $p < 0.001$, $N = 83$). The highest quality model, as deemed by the AIC values, indicated that global food rejection (pickiness and food neophobia totalled) showed greater statistical relevancy than food neophobia or pickiness individually. Both food identification score and food rejection score (CFRS) explained a significant proportion of variance in thematic performance $R^2 = 0.237$, $F(2, 80) = 12.39$, $p < 0.001$ (see **Table 2** for model coefficients). Food identification accounts for 15.1 percent of the variability in thematic performance; as food identification increased thematic performance increased. Whereas, CFRS accounts for 8.5 percent of the variance in thematic performance; the greater the food rejection tendencies the worse the performance for thematic associations.

DISCUSSION

Leading on from the seminal work of Rioux et al. (2016, 2017b, 2018), this study aimed to investigate the development of taxonomic and thematic food knowledge in children aged 3 to 6 years. We also investigated the unexplored relationship between children's thematic knowledge and food rejection tendencies (food neophobia/picky-eating). We hypothesized that there is a significant development of food identification and both thematic and taxonomic food knowledge in children between 3 and 6 years old. We further hypothesized that food rejection tendencies (food neophobia and food pickiness) would predict poorer knowledge of thematic and taxonomic relations in the food domain.

Development of Thematic and Taxonomic Food Knowledge

Based on previous work by Thibaut et al. (2016) and Rioux et al. (2017b), we hypothesized that even 3-year-old children would be able to thematically and taxonomically associate food. However, we also expected to witness that there would be a developmental improvement in both abilities. Our results confirm that young children are indeed capable of identifying thematic and taxonomic food relations. We witnessed that children as young as 38.8 and 40.1 months were capable of performing significantly above chance in both the thematic and taxonomic conditions, respectively. Our results are consistent with previous studies evidencing that 3-year-old children succeed above chance in determining taxonomic and thematic food associations (Nguyen and Murphy, 2003; Rioux et al., 2016; Thibaut et al., 2016).

Surprisingly, age was not directly correlated with thematic and taxonomic performance, but it was positively correlated with correct food identification. Furthermore, improved food identification was a significant predictor of better knowledge of thematic relations. These findings indicate that the relationship between age and thematic categorization ability is potentially mediated by food identification. If the child is unable to identify the foods, subsequent understanding of the thematic relation is inhibited. This appears intuitive to our understanding of thematic associations, in that these pairs depend heavily on previous exposure and require familiarity with both items and/or context of occurrence more so than taxonomic pairs (Gelman and Markman, 1986; Markman, 1989; Gelman, 2003). Further studies with a larger sample size would allow mediatory analyses to delineate the specific relationship that object identification has on age and thematic categorization performance.

Food Rejection Is a Significant Predictor of Thematic Categorization Performance

The ultimate objective of this study was to establish how the previously reported negative relationship between food rejection and taxonomic categorization ability (Rioux et al., 2016, 2018) extends to thematic categorization ability in young children. We hypothesized that children with higher levels of food rejection would display poorer knowledge of taxonomic and thematic associations in the food domain. Our results are the first piece of evidence in the field to demonstrate that children with higher scores of food rejection show significantly worse thematic categorization performance.

We believe that poor thematic categorization is subsequent to a lack of exposure to different foods and associations, perhaps to a greater extent than the understanding of taxonomic relations. Thematic relations require the correct identification of the relationship between two items, whereas taxonomic understanding requires identifying the correct taxonomic belonging of an individual item. To learn taxonomic relations it is sufficient to view two objects (both belonging to the same taxon) individually and still have the capability to understand the shared relation. However, thematic relations, namely common food pairings, require concomitant exposure in that both stimuli must be presented at the same time to infer that they share a relation (Markman, 1989). For example, having viewed two different vegetables on separate occasions we may still conclude that they share a taxonomic relationship. However, we would only be able to understand the thematic relation of bread and butter after witnessing the two simultaneously served together. This line of reasoning would indicate that because foods involved in thematic relations are not always paired with their counterparts (i.e., bread may be served without butter), the exposure for thematic food relations is reduced to that of taxonomic relations.

Furthermore, a common trait of picky-eating behavior is the dislike of foods being paired or mixed (Carruth et al., 1998), hence, for a picky-eater several common thematic relations would not be considered thematic since they are less likely to have foods served or consumed together. Similarly, parents of neophobic children may be less likely to serve a variety of food to their child and may stick with "safe" foods and "safe" thematic combinations, reducing the child's possibility to develop knowledge of common food associations. This lack of exposure for children with food rejection tendencies may perpetuate the uncertainty of food associations, ultimately reinforcing their fear of novel food situations. Thus, the cycle of unfamiliarity and food rejection endures and learning opportunities remain decreased. Our interpretation would suggest that continuing to expose neophobic and picky-eaters to a variety of food associations would boost their understanding of thematic relations in the food domain and consequently foster food acceptance.

Limitations and Future Research

The findings of Rioux et al.'s previous work investigating taxonomic knowledge and food rejection in young children were not replicated in our research. As we used a forced-choice paradigm pitting thematic against taxonomic matches, children had a 50:50 chance of responding correctly, regardless of having understood the categorization. Therefore, if children with high food rejection fail to identify the thematic relation, as indicated by our results, they may default to an alternative process of selection, such as perceptual similarity. Alternatively, it might be that they chose the incorrect one because it was more attractive or preferred. Choosing an incorrect option does not necessarily mean that they have not understood the targeted relation. However, future studies should attempt to delineate the default strategies children use when unable to identify the correct association.

One may also argue that taxonomic associations were apparent in both conditions of the task, as the child could have easily reasoned that two items were paired because they both belonged to the superordinate category of "foods." Previous studies have even indicated that children may display an intermediary level of categorization between taxonomic and thematic categories, for objects that children group as the same sort, but also because of the context in a given schema or script (e.g., foods eaten at a party; Lucariello and Nelson, 1985). Literature also argues that superordinate taxonomic categories may even be considered thematic in nature based on functional/interactional relations (i.e., food gives humans energy) (Lakoff, 2008). As well as highlighting the need to decipher the nature of the relationship between thematic understanding and food rejection, our research speaks in favor of further conceptualization of thematic associations.

After reviewing previous studies on thematic associations, it appears that thematic associations are heterogeneous in nature. In the present study, we concentrated on thematically related food pairs such as "ice cream and wafer cone." However, there are diverse thematic relations involving foods, such as foods and utensils (e.g., watermelon and a knife), or foods in certain scripts (e.g., cereal for breakfast). Some thematic pairs may be of a spatial and temporal nature (i.e., sausages and mashed potato being eaten for the same meal), whilst others may be functional (ice cream goes in a wafer cone to facilitate eating). Furthermore, thematic associates appear to be culturally bound more so than taxonomic associates are (Markman, 1989). Whilst we were not able to capture the demographics of the participants, future studies should certainly include measures of cultural and social variables. Our results also underscore an important feature of thematic and taxonomic associations, in that the former may necessitate object familiarity/identification whereas the latter may not. The relationships we witnessed between age, food identification, and thematic performance were not apparent in the taxonomic performance. Previous taxonomic studies using novel stimuli have similarly demonstrated that object identification is not a necessity of taxonomic sorting, even with children as young as 3 years old (Liu et al., 2001). In contrast, researchers have previously outlined that thematic associations are heavily dependent upon previous experience (Markman, 1989). A child that correctly labels an object is more likely to have encountered that object and as such, more likely to have witnessed the object's thematic association. It appears that having a conceptual knowledge of an object aids the understanding of thematic associations. This finding paves the way for a clearer conceptualization of thematic associations and how children come to acquire thematic understanding in the food domain.

Conclusion

This study offers exploratory insight into the previously untold relationship between thematic food categorization ability and food rejection in children aged 3 to 6-years-old. Our study provides novel evidence that food rejection significantly predicts thematic knowledge in a food-based analogy task. In addition, age was found to be positively related to food identification ability, which was a significant predictor of improved thematic categorization performance. We propose that food rejection may cause a decreased exposure to thematic food associations, which subsequently restricts children's conceptual development of thematic relations. The reduced opportunity to learn and experience common thematic associates of food perpetuates unfamiliarity in food-based situations and thus drives food rejection tendencies. As the first study to detect a negative relationship between thematic food categorization and food rejection, these results suggest that enriching thematic food category knowledge in young children could be an efficient strategy to foster dietary variety. Future research should address the specific associations children with food rejection tendencies rely upon when making inferences about food categories and, most importantly, how improving children's food knowledge of the varieties of thematic associations may promote dietary variety.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://doi.org/10.5281/zenodo.3749248.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

AP, J-PT, and JL contributed to the design, implementation of the research, and to the writing of the manuscript. AP collected the data and performed the analyses. All authors contributed to the article and approved the submitted version.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX

Appendix A | List of the complete stimuli sets.

	Analogy Pair		Triad		
	A	**B**	**C**	**D:Taxonomic**	**D:Thematic**
Training Phase					
Thematic Ex.1	Notebook	Pencil			
Thematic Ex.2	Bee	Honey			
Taxonomic Ex.1	Dog	Chimpanzee			
Taxonomic Ex.2	Necklace	Ring			
			Soccer Shoe	Rain Boots	Soccer Ball
Test Phase					
Thematic Ex.1	Ice Cream	Wafer Cone			
Thematic Ex.2	Pancakes	Chocolate Sauce			
Taxonomic Ex.1	Banana	Apple			
Taxonomic Ex.2	Sardine	Salmon			
			Lemon	Cherry	Fish
			Sausage	Steak	Mashed Potatoes
			Milk	Camembert	Cereal
			Spaghetti	Couscous	Bolognaise
			Chocolate	Sweets	Bread Roll
			Cheese Dessert	Hard Cheese	Sugar
			Grated Cheese	Milk	Macaroni
			Green Beans	Beetroot	Butter
			Grapefruit	Pear	Sugar
			Beef Patty	Chicken	Burger Bun
			Gherkin	Sweetcorn	Pâté
			Strawberry	Satsuma	Pastry
			Nuggets	Steak	Ketchup
			Cheese Slice	Yogurt	Sliced Bread
			Apple	Gooseberry	Puff Pastry
			Cheese Spread	Yogurt	Breadsticks

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Longitudinal Associations Between Taste Sensitivity, Taste Liking, Dietary Intake and BMI in Adolescents

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Taste sensitivity and liking drive food choices and ingestive behaviors from childhood to adulthood, yet their longitudinal association with dietary intake and BMI is largely understudied. Here, we examined the longitudinal relationship between sugar and fat sensitivity, sugar and fat liking, habitual dietary intake, and BMI percentiles in a sample of 105 healthy-weight adolescents (baseline: BMI %tile 57.0 ± 24.3; age 14–16 years) over a 4-year period. Taste sensitivity was assessed via a triangle fat and sweet taste discrimination test. Taste liking were rated on a visual analog scale for four milkshakes that varied in sugar and fat contents (high-fat/high-sugar (HF/HS), low-fat/high-sugar (LF/HS), high-fat/low-sugar (HF/LS), low-fat/low-sugar (LF/LS) milkshakes). A modified version of the reduced Block Food Frequency Questionnaire (BFFQ) was used to assess dietary intake. All measurements were repeated annually. Repeated measures correlations and linear mixed effects models were used to model the associations between the variables. Sugar sensitivity was negatively associated with liking for the LF/HS milkshake over the 4-year period. Low sugar sensitivity at baseline predicted increases in BMI percentile over time, but this association didn't survive a correction for multiple comparisons. Percent daily intake from fat was positively associated with liking for the HF/HS milkshake and negatively associated with liking for the LF/LS milkshake over 4 years. Together, these results demonstrate that lower sensitivity to sweet taste is linked to increased hedonic response to high-sugar foods and increased energy intake from fat seems to condition adolescents to show increased liking for high-fat/high-sugar foods.

Keywords: sugar, fat, hedonic ratings, dietary intake, adolescents

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INTRODUCTION

Obesity is a complex disease state largely driven by overconsumption of energy-dense foods resulting in a positive energy balance (Mitchell et al., 2011). Taste perception and sensitivity influence consumption since they identify and evaluate foods suitable for ingestion (Loper et al., 2015). These sensory aspects of food intake shape both acute food choices and long-term ingestive behavior from childhood through adulthood providing the foundation for weight regulation (Drewnowski, 1997; Mennella et al., 2005). As such, understanding the impact of taste perception of foods on food liking and intake is a critical point for determining the development of and thus prevention of impaired body weight maintenance and obesity.

Taste sensitivity can be described as the minimum concentration at which a person is able to perceive a specific taste quality (Sørensen et al., 2003). Taste liking, on the other hand, is a measure of the affective component of attitude and is linked to the hedonic value of each taste quality (Drewnowski et al., 2012). To date, evidence linking taste sensitivity to taste liking is either limited or inconclusive (Tan and Tucker, 2019). Sensitivity to sweet taste is the construct studied most in children and adults (Hardikar et al., 2017). Studies in children report a fragile, inverse relation between sweet taste sensitivity and sweet taste liking (Fry Vennerød et al., 2018). In contrast, studies in adolescents and adults have failed to find a consistent relationship between sweet taste sensitivity and liking (Mojet et al., 2005; Coldwell et al., 2009; Garneau et al., 2018). The lack of an observed relationship among older participants could be attributed to the well-established reduction in sweet taste liking observed from childhood to adolescence and adulthood (Mennella et al., 2011; Mennella and Bobowski, 2015). Yet data suggest that sweet taste sensitivity appears to increase with age (Joseph et al., 2016). The changes observed in sweet taste sensitivity and sweet taste liking over the course of development, which support the hypothesis that taste sensitivity and preferences are dynamic, may be a function of growth. Another viable hypothesis could be that these trends are a function of repeated exposures to sweet foods via frequent intake, with the ability to discern the intensity of sweet taste increasing over time, but the hedonic pleasantness derived from sweet foods decreasing (Epstein et al., 2009). The relationship between fat taste sensitivity and fat liking has not been studied extensively, with one study reporting a negative association among adults (Bolhuis et al., 2016) and another failing to detect an association (Chamoun et al., 2019). Given the inconsistent findings across studies, longitudinal study designs across different life stages are warranted.

Taste sensitivity and its association with dietary intake have been studied to a lesser extent. Sweet taste sensitivity has been linked to food intake, with highly sweet-sensitive adults consuming more dietary protein and less carbohydrates (Han et al., 2017), and reporting lower energy intake per 7-day food diary (Martinez-Cordero et al., 2015). However, other studies found no significant link between sweet taste sensitivity and dietary intake among adults (Low et al., 2016; Jayasinghe et al., 2017). In addition, several studies reported a clear association between lower fat sensitivity and greater high-fat food intake (Costanzo et al., 2017; Heinze et al., 2018), while intake of foods rich in fiber and vitamins is lower (Heinze et al., 2018). Few studies have examined the association between fat sensitivity and food intake in adolescents. With unclear support for associations between taste sensitivity and dietary intake, further research is needed to determine the relation.

The relationship between taste liking and dietary intake has been more widely studied. Dietary intake is determined by multiple factors including biological (hunger, taste preference), psychological (perceived stress, anxiety, mood), and socioeconomic (familial environment, food availability, income, education, culture) components (Leng et al., 2017). However, taste liking and food palatability seem to be some of the key drivers of food choice (Chen and Antonelli, 2020). This is particularly true for adolescents, where hunger, food cravings and taste liking are consistently the most important determinants of food choices (Neumark-Sztainer et al., 1999; Krølner et al., 2011). Hedonic measurements of sweet taste liking have been associated with greater total energy intake (Costanzo et al., 2017), carbohydrate intake (Smith et al., 2016), and both refined and total sugar intake (Holt et al., 2000). Additionally, people classified as sweet "likers" consume more calories from sugar-sweetened beverages (Garneau et al., 2018) and have lower fiber intake (Turner-McGrievy et al., 2013). Although, this relationship has not been observed in all studies (Sartor et al., 2011; Stevenson et al., 2016). The mixed findings could be due to the smaller sample size compared to the studies with positive associations or to differences in study design. Studies have also found a positive relationship between fat liking and high-fat food intake (Ricketts, 1997; Park H. et al., 2018), with fat liking being linked to greater consumption of saturated fats and desserts, and lower consumption of fruits, vegetables, and omega-3 fatty acids (Méjean et al., 2014). Additionally, in a prospective study, higher fat liking was a risk factor for future obesity onset, with the relationship predominantly explained by greater overall dietary intake (Lampuré et al., 2016).

Taste sensitivity and taste liking have also been associated with weight status, albeit predominantly cross-sectionally (Noel et al., 2017; Tucker et al., 2017; Vignini et al., 2019; Sobek et al., 2020; Venditti et al., 2020). Higher BMI is related to lower sensitivity to sweet taste (Noel et al., 2017; Vignini et al., 2019), while a recent meta-analysis showed that fat sensitivity was not related to weight status in adults (Tucker et al., 2017). In turn, there is weak evidence that liking for fat or sweet taste separately is associated with higher BMI (Sobek et al., 2020; Venditti et al., 2020), while higher liking for fat-and-sweet sensations has been associated with an increased risk of obesity in women (Salbe et al., 2004; Lampuré et al., 2016).

Together, these studies provide some evidence about the associations between taste sensitivity, taste liking, dietary intake and BMI, but the lack of longitudinal designs limits the ability to draw inferences about the nature of these associations. Hence, the present analysis aimed to assess the relationships between sweet taste and fat sensitivity, sweet taste and fat liking, food intake and BMI percentile in a sample of lean adolescents (14–16 years old) at baseline and over a 3-year follow-up period. We hypothesized that sweet taste and fat sensitivity would be negatively associated with sweet taste and fat liking over the 4-year study period. Additionally, we expected that lower sensitivity and higher liking for sweet taste and fat would be associated with greater food intake at both baseline and during follow-up. Further we hypothesized that lower sweet taste sensitivity and higher sweet taste liking at baseline would predict increases in BMI percentiles over the 4-year study period.

MATERIALS AND METHODS

Participants

Participants were recruited as part of a longitudinal randomized controlled study investigating neurobehavioral responses to palatable food images and receipt of chocolate milkshakes at baseline and three annual follow-up visits (Stice et al., 2013;

Sadler et al., 2019). Participants were eligible for the study if they were between 14 and 16 years old and had a BMI-for-age percentile between 25th and 75th at baseline. Further details about the sample, recruitment, and complete study procedures are detailed elsewhere (Stice et al., 2013; Sadler et al., 2019). Exclusion criteria included reports of binge eating or compensatory behavior in the past 3 months, use of psychotropic medications or illicit drugs, head injury with loss of consciousness, or an axis I psychiatric disorder diagnosis in the past year (including anorexia nervosa, bulimia nervosa, or binge eating disorder), and dairy allergies. At each annual assessment, data collection for all eligible participants was completed over two separate study visits, on average 17 ± 16 days apart, with anthropometrics, taste sensitivity, and dietary intake being measured during the first visit and taste liking measured during the second visit. Parents provided written informed consent and adolescents provided written assent. This study was approved by the Oregon Research Institute's Institutional Review Board and is registered at www.clinicaltrials.gov as NCT01949636.

Anthropometrics and Demographics

Height was measured to the nearest mm using a stadiometer. Weight was assessed to the nearest 0.1 kg using a digital scale with participants wearing light clothing, without shoes. BMI values (kg/m^2) were calculated at baseline and at 1-, 2-, and 3-year follow ups. BMI percentiles were derived for participants based on the Center for Disease Control (CDC) growth charts (Kuczmarski et al., 2002).

Internal State Ratings

To standardize hunger and fullness levels, participants rated their hunger and fullness on a VAS scale from 0 ("*I am not hungry/full at all*") to 20 ("*I have never been more hungry/full*") prior to the taste sensitivity and the taste liking assessments. In the case of the taste liking test, if a hunger score $\geq$ 17 was indicated, subjects were offered a snack to bring their hunger to a neutral state (20% of subjects received a snack at year 1, 17.1% at year 2, 10.5% at year 3, and 20% at year 4). A second VAS was performed to confirm the snack was effective in normalizing their hunger/fullness.

Taste Sensitivity

At each annual assessment, taste sensitivity was assessed during the behavioral visit. Triangle taste discrimination tests (Pepino et al., 2010) assessed fat and sweet taste sensitivity respectively. For the fat sensitivity test, participants had to discriminate between six possible solutions (solutions A–F) of chocolate milk with varying fat content. For the sweet taste sensitivity test, participants had to discriminate between six possible solutions (solutions A–F) of Kool-Aid with varying sugar content. The formulation of the solutions A–F used in the triangle taste discrimination tests can be found in **Supplementary Table 2**. The administration order of the fat and sweet taste sensitivity tests was counterbalanced across participants. For each test, participants were presented with three 8 fl oz cups, two containing stimuli with identical sugar or fat concentrations and one containing a different sugar or fat concentration. For the first trial, they tasted all three and chose the one that was different. If they chose correctly two times, they moved on to a more difficult trial where the difference in concentration between the two identical and the one different stimulus was smaller. If they chose incorrectly two times, that trial was terminated and they moved on to an easier trial. This process was repeated until there were no trials left (maximum of five trials) or they failed to identify the different stimulus twice in the easiest trial. The number of times that participants correctly discriminated between the stimuli served as their taste sensitivity score for each test, with a possible range of 0 (least sensitive) to 5 (most sensitive). Detailed instructions for the triangle test can be found in **Supplementary Figure 3**. Each participant rinsed with water between each sample.

Taste Liking

Taste liking was assessed during the second visit at each annual assessment. Participants were asked to refrain from eating or drinking (except water) for at least 4 h prior to their scheduled visit. Participants rated the pleasantness ("*How pleasant is this taste?*") of four milkshakes that varied in sugar and fat contents. Detailed description of the milkshake contents can be found elsewhere (Stice et al., 2013), but in brief, each milkshake included the same ice-cream base and chocolate syrup. Fat contents of the milkshakes varied by the type of milk (half and half compared with 2% milk). The sweetness varied by the simple-syrup content. We investigated the taste liking for the following milkshakes: a high-fat/high-sugar (HF/HS) milkshake (170 kcal, 7.5g fat, and 23 g sugar/100 mL), a low-fat/high-sugar (LF/HS) milkshake (124 kcal, 1.9 g fat, 23.7 g sugar/100 mL), a high-fat/low-sugar (HF/LS) milkshake (129 kcal, 9.0g fat, and 7.3g sugar/100 mL), and a low-fat/low-sugar (LF/LS) milkshake (74 kcal, 2.4g fat, and 8.7 g sugar/100 mL). The LF/HS and HF/LS milkshakes were designed such that they had similar energy densities (1.24 kcal/mL for the LF/HS milkshake compared with 1.29 kcal/mL for the HF/LS milkshake). For the ratings, participants sampled a small amount of each milkshake (order counterbalanced) and rated the pleasantness on a visual analog scale (VAS) that ranged from 0 ("*most unpleasant sensation ever*") to 20 ("*most pleasant sensation ever*").

Dietary Intake

A modified version of the reduced Block Food Frequency Questionnaire (BFFQ) (Block et al., 1990) was used to assess average dietary intake. Across all food items, participants were given a definition of a medium portion of that food item and asked to indicate the frequency of consumption over the previous 2-week period. Response options ranged from 1 = "Never in the last 2 weeks" to 6 = "Daily or more in the last 2 weeks." Daily caloric intake, percent daily caloric intake from fat, and percent daily caloric intake from sugar were estimated from BFFQ responses.

Statistical Analysis

Statistical analyses were performed using R (version 3.6.1, The R Foundation for Statistical Computing). Descriptive statistics to summarize means, standard deviation, and percentages were generated for variables of interest. Repeated measures correlations were used to examine the within-individual longitudinal relationship between fat and sweet taste sensitivity, fat and sweet taste liking, daily caloric intake, percent daily caloric intake from fat, and percent daily caloric intake from sugar (package *rmcorr* version 0.3.0). To assess the change in BMI percentiles over time, a linear line was fit to measurements of BMI percentile at years 1, 2, 3, 4 for each participant. The slope of the line was considered the change in BMI percentile over the 4 years. BMI percentile change was also modeled using a quadratic term, but the resulting model did not significantly improve fit, as assessed by the Akaike's Information Criteria, so the linear slope was used in analyses. Linear regression was used to test whether 4-year change in BMI percentile (slope) was predicted by baseline sensitivity and liking for fat and sweet taste, controlling for sex, baseline BMI percentile, age and hunger. Results were corrected for multiple comparisons using the Benjamini–Hochberg procedure ($pFDR < 0.05$).

Post hoc Analysis

Significant and marginally significant results from the correlations were further explored using linear mixed effects models with maximum likelihood estimation (package *nlme* version 3.1-140). The baseline models included the outcomes of interest (pleasantness for HF/HS, LF/HS, and LF/LS milkshakes) and the predictors as fixed effects (sweet taste sensitivity, percent daily caloric intake from fat). To account for individual differences in the outcomes, random intercepts were included in the model at the subject level. Additional confounding variables were added as fixed effects in a stepwise manner: time, sex, BMI, age, daily caloric intake (only for the models with the percent daily caloric intake from fat), hunger, fullness. However, the addition of age, daily caloric intake, hunger, and fullness neither improved model fit nor changed the significant results, hence, the linear mixed model results presented below include only

TABLE 1 | Participant (n = 105) characteristics and behavioral measures.

	Year 1 Visit (Baseline)	Year 2 Visit	Year 3 Visit	Year 4 Visit
	Count (Percent)			
Sex				
Male	47 (44.8)			
Female	58 (55.2)			
Race				
Asian	5 (4.8)			
Black or African American	7 (6.7)			
White	83 (79.0)			
More than one race	5 (4.8)			
Other or Missing	5 (4.8)			
	Mean ± SD (Range)			
Age (years)	15 ± 1 (14–16)			
BMI (kg/m^2)	21.2 ± 2.3 (16.2–26.4)	21.5 ± 2.6 (16.8–28.3)	22.0 ± 2.8 (17.0–31.3)	22.7 ± 3.5 (16.2–40.6)
BMI percentile*	57.0 ± 24.3 (5.4–94.9)	53.8 ± 25.6 (2.4–94.7)	52.4 ± 26.5 (1.7–97.3)	52.6 ± 27.5 (0.5–99.7)
Taste Sensitivity				
Fat	2.37 ± 1.19 (0–5)	2.30 ± 1.15 (0–5)	2.43 ± 1.07 (0–5)	2.63 ± 1.25 (0–5)
Sweet	2.81 ± 1.03 (0–5)	2.77 ± 0.93 (0–5)	2.87 ± 1.08 (0–5)	2.88 ± 1.03 (0–5)
Taste Liking (pleasantness rating)				
HF/HS	14.61 ± 3.18 (7–20)	13.22 ± 4.31 (2–20)	13.74 ± 3.87 (1–20)	12.97 ± 4.53 (0–20)
LF/HS	11.94 ± 3.91 (1.5–20)	11.89 ± 4.04 (1.5–19.5)	13.09 ± 3.69 (0.5–19)	12.75 ± 3.68 (1–19.5)
HF/LS	12.87 ± 4.31 (1.5–20)	12.94 ± 4.34 (0.5–20)	12.24 ± 4.61 (1–19.5)	12.35 ± 4.07 (1–20)
LF/LS	10.10 ± 3.87 (0–19.5)	11.57 ± 3.79 (0–17.5)	11.35 ± 3.35 (2–18.5)	11.49 ± 3.67 (1–19)
Dietary Intake**				
Daily caloric intake (kcal)	1861 ± 313 (1303–3159)	1888 ± 331 (1388–3173)	1827 ± 285 (1297–2903)	1837 ± 340 (1211–2901)
% daily caloric intake from fat	35.4 ± 1.4 (32–38)	35.4 ± 1.6 (31–40)	35.2 ± 1.5 (31–38)	35.2 ± 1.5 (31–38)
% daily caloric intake from sugar	13.6 ± 1.4 (10–18)	13.6 ± 1.4 (11–18)	13.6 ± 1.6 (11–19)	13.2 ± 1.4 (11–19)
Hunger				
Prior to Taste Sensitivity test	8.82 ± 4.99 (0–20)	9.86 ± 4.55 (0–17.5)	9.90 ± 4.34 (0–18)	11.03 ± 3.82 (0–17.5)
Prior to Taste Liking test	11.21 ± 3.95 (0–19.5)	11.31 ± 4.26 (0–19)	11.46 ± 4.10 (0–20)	12.07 ± 3.60 (1–18.5)
Fullness				
Prior to Taste Sensitivity test	9.06 ± 4.35 (0–19)	8.06 ± 4.05 (0–18.5)	7.88 ± 4.28 (0–18)	7.05 ± 3.90 (0–17.5)
Prior to Taste Liking test	6.80 ± 4.39 (0–20)	6.60 ± 4.40 (0–18.5)	6.20 ± 3.97 (0–15.5)	5.99 ± 3.94 (0–17)

*n = 101; **n = 85.

HF/HS, high-fat/high-sugar milkshake; LF/HS, low-fat/high-sugar milkshake; HF/LS, high-fat/low-sugar milkshake; LF/LS, low-fat/low-sugar milkshake.

time, sex, and BMI as covariates. Statistical significance was set at $p < 0.05$.

RESULTS

Participants Characteristics

Participant demographics and summary of behavioral variables can be found in **Table 1**. Of the 125 participants that had complete anthropometric and behavioral data at baseline, 105 participants had complete taste liking and taste sensitivity data over the 4-year study period, of which 85 had complete dietary intake data. Demographics, anthropometrics and behavioral variables did not differ between the total sample (n = 105) and the subsample of 85 participants used for the dietary intake analysis, with the exception of hunger at year 3 and fullness at year 4, both being higher in the subsample. Complete demographics for the subsample (n = 85) can be found in **Supplementary Table 1**. The total sample (n = 105) consisted of 47 (44.8%) male and 58 (55.2%) female adolescents [age = 15 ± 1 (14 – 16) years at baseline]. All adolescents were healthy-weight at baseline [25th – 75th BMI-for-age percentile; BMI = 21.2 ± 2.3 (16.2 – 26.4)].

Taste Sensitivity and Taste Liking Associations

Sweet taste sensitivity and fat sensitivity were stable over time ($p > 0.05$ for the effect of time across all 4 years). Sweet taste sensitivity negatively correlated with pleasantness (r = –0.188, $p < 0.001$, pFDR = 0.021) for the LF/HS milkshake over the 4-year study period. Fat sensitivity did not correlate with pleasantness ratings for any of the four milkshakes over the 4-year period. Additionally, sweet taste sensitivity was not significantly associated with fat sensitivity over time (r = 0.029, p = 0.613). Repeated measures correlation results are displayed in **Table 2** and **Supplementary Figure 1**. The effect of sweet taste sensitivity on pleasantness for the LF/HS milkshake over time remained significant after controlling for confounding variables in the linear mixed model [β = –0.46, 95% CI = (–0.76, –0.16), p = 0.003] (**Table 3** and **Figure 1**).

TABLE 2 | Repeated measures correlations between taste sensitivity and taste liking.

		Taste Sensitivity			
		Sweet Taste		*Fat*	
		r	*p*	*r*	*p*
Taste Liking (pleasantness rating)	*HF/HS*	0.004	0.944	0.021	0.709
	LF/HS	**–0.188***	**<0.001**	0.035	0.534
	HF/LS	–0.064	0.254	–0.006	0.911
	LF/LS	–0.087	0.122	–0.024	0.672

**pFDR < 0.05.*
Degrees of freedom: 314.

TABLE 3 | Results of the linear mixed models for taste liking (pleasantness) with sweet taste sensitivity.

Outcomes	**Pleasantness for LF/HS milkshake**		
Predictors	***β estimates***	***95% CI***	***p***
(Intercept)	18.01	14.64 – 21.37	**<0.001**
Sweet Taste Sensitivity	–0.46	–0.76 – 0.16	**0.003**
Year 1	*REF*		
Year 2	0.00	–0.75 – 0.75	0.998
Year 3	1.34	0.59 – 2.10	**<0.001**
Year 4	1.13	0.35 – 1.91	**0.005**
Male	*REF*		
Female	–1.38	–2.51 – 0.25	**0.019**
BMI	–0.19	–0.34 – 0.04	**0.015**
Random Effects			
SD		2.56	
CI_{sd}		2.14 – 3.06	
N_{grp}		105	

Bold values represent findings with an uncorrected p-value < 0.05.

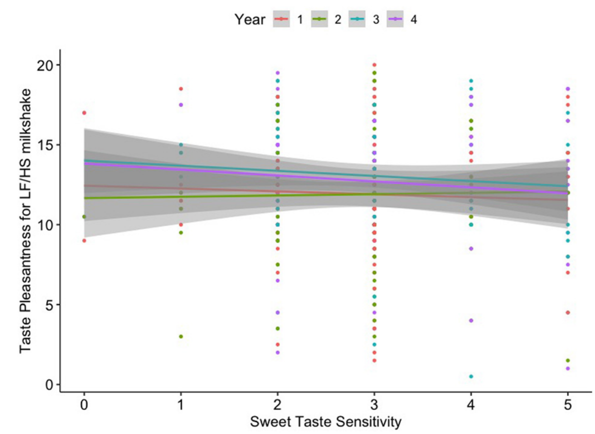

FIGURE 1 | Linear relationship between sweet taste sensitivity and taste liking (pleasantness) for the low-fat/high-sugar (LF/HS) milkshake across 4 years.

Dietary Intake and Associations With Taste Sensitivity and Liking

Percent daily caloric intake from fat was positively correlated with pleasantness for the HF/HS milkshake (r = 0.132, p = 0.035) over the 4-year study period. Although there was only weak evidence of a relationship (p = 0.051), percent daily caloric intake from fat had a small negative correlation with pleasantness for the LF/LS milkshake (r = –0.122) over the 4 years. However, these results failed to survive correction for multiple comparisons (pFDR = 0.411 for both). Neither sweet taste nor fat sensitivity was associated with dietary intake over time. Results are displayed in **Table 4** and **Supplementary Figures 2a,b**. The effect of % daily caloric fat intake on future pleasantness for the HF/HS milkshake over time remained significant after controlling for confounding variables in the linear mixed model [β = 29.53, 95% CI = (5.75, 53.31), p = 0.016]. Lastly, the effect of % daily caloric fat intake on

TABLE 4 | Repeated measures correlations between dietary intake and taste sensitivity and liking.

		Dietary Intake					
		Daily Caloric Intake		% Daily Caloric Intake from Fat		% Daily Caloric Intake from Sugar	
		r	*p*	*r*	*p*	*r*	*p*
Taste Liking (pleasantness rating)	*HF/HS*	0.003	0.959	**0.132**	**0.035**	0.011	0.867
	LF/HS	– 0.117	0.061	0.032	0.608	– 0.065	0.302
	HF/LS	0.063	0.315	0.090	0.152	– 0.021	0.734
	LF/LS	– 0.076	0.225	–0.122	0.051	0.005	0.937
Taste Sensitivity	*Sweet Taste*	0.105	0.094	0.016	0.800	– 0.015	0.806
	Fat	0.056	0.371	– 0.061	0.329	0.014	0.822

Results did not survive FDR correction. Degrees of freedom: 254. Bold values represent findings with an uncorrected p-value < 0.05.

TABLE 5 | Results of the linear mixed models for taste liking (pleasantness) with % daily caloric intake from fat.

Outcomes	Pleasantness for HF/HS milkshake			Pleasantness for LF/LS milkshake		
Predictors	***β estimates***	***95% CI***	***p***	***β estimates***	***95% CI***	***p***
(Intercept)	4.20	–4.70 – 13.10	0.358	19.69	10.33 – 29.06	**<0.001**
% daily caloric intake from fat	29.53	5.75 – 53.31	**0.016**	–27.13	–52.43 – 1.82	**0.038**
Year 1	*REF*			*REF*		
Year 2	–1.35	–2.20 – 0.49	**0.002**	1.33	0.39 – 2.28	**0.006**
Year 3	–0.83	–1.70 – 0.03	0.061	1.21	0.26 – 2.16	**0.014**
Year 4	–1.86	–2.75 – 0.97	**<0.001**	1.18	0.21 – 2.15	**0.018**
Male	*REF*			*REF*		
Female	–1.90	–3.15 – 0.66	**0.004**	–0.91	–1.96 – 0.13	0.089
BMI	0.05	–0.12– 0.22	0.558	0.02	–0.14 – 0.18	0.789
Random Effects						
SD		2.49			1.82	
CI_{sd}		2.04 – 3.05			1.39 – 2.38	
N_{grp}		85			85	

Bold values represent findings with an uncorrected p-value < 0.05.

future pleasantness for the LF/LS milkshake over time was also significant [β = −27.13, 95% CI = (−52.43, −1.82), p = 0.038] (**Table 5** and **Figures 2A,B**).

Prediction of BMI Percentile Change by Taste Sensitivity and Liking

Sweet taste sensitivity at baseline was a significant predictor of BMI percentile change [β = –1.28, 95% CI = (–2.41, –0.15), p = 0.026; **Figure 3**], although it failed to survive corrections for multiple comparisons (pFDR = 0.157). Fat sensitivity, sweet taste and fat liking were not significantly associated with changes in BMI percentile over the 4-year study period (**Table 6**).

DISCUSSION

Taste sensitivity and liking are important drivers of dietary choices particularly among adolescents who are experiencing an increase in food choice autonomy (Bassett et al., 2008). However, no study has assessed how these aspects of tastes change over time and their relation to dietary intake. Here, we observed that higher sweet taste sensitivity was associated with lower liking of a high-sugar/low-fat drink. These findings are consistent with previous studies in young adults (Chamoun et al., 2019). The negative association between sensitivity and hedonic evaluation of sweet taste supports the idea that these measures provide distinct but complementary information about taste sensations and food choices (Webb et al., 2015). Sugar has been repeatedly associated with promoting hedonically motivated eating behavior (e.g., compulsive eating), therefore, people with a high threshold for sweet taste discrimination may be insensitive to high sugar content in foods. This may place them at an increased risk for excessive sugar intake and impaired control over dietary intake (Kampov-Polevoy et al., 2006). In concert, high-sugar milkshake intake in the same group of adolescents elicited greater brain response in regions associated with food reward (e.g., putamen), oral somatosensation (e.g., Rolandic operculum), and gustatory stimulation (e.g., insula, thalamus) (Stice et al., 2013), suggesting that adolescents with lower sensitivity to high-sugar drinks have a greater reward physiological response.

The association between sweet taste sensitivity and liking did not extend to the high-sugar/high-fat milkshake. Given that texture and mouthfeel seem to also influence hedonic responses to fats (Drewnowski and Almiron-Roig, 2010), the addition

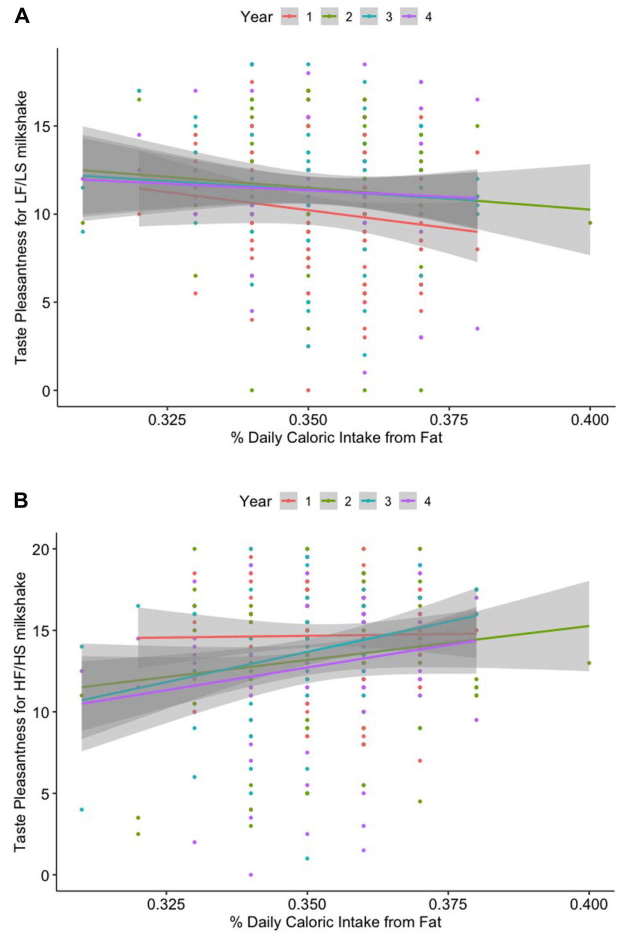

FIGURE 2 | (A) Linear relationship between percent daily caloric intake from fat and taste liking (pleasantness) for the high-fat/high-sugar (HF/HS) milkshake. **(B)** Linear relationship between percent daily caloric intake from fat and taste liking (pleasantness) for the low-fat/low-sugar (LF/LS) milkshake across 4 years.

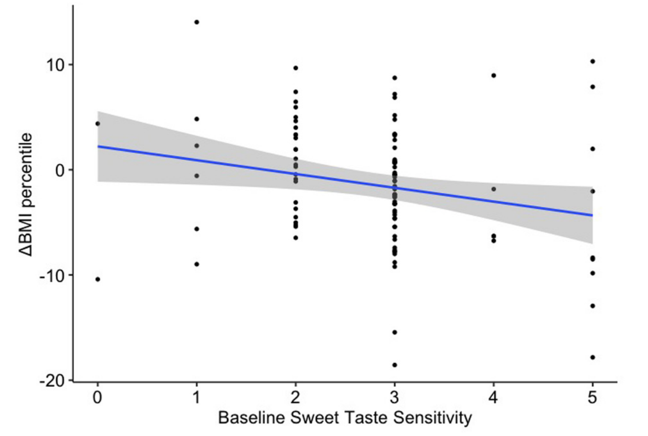

FIGURE 3 | Linear regression between baseline sweet taste sensitivity and change in BMI percentile over 4 years.

TABLE 6 | Results of the linear regression models of taste liking and taste sensitivity with change in BMI percentile over 4 years.

	ΔBMI percentile		
Predictors	***β estimates***	***95% CI***	***p***
Taste Sensitivity			
Fat	−0.21	−1.21 – 0.80	0.682
Sweet	−1.28	−2.41 – 0.15	**0.026**
Taste Liking (pleasantness rating)			
HF/HS	0.06	−0.32 – 0.45	0.750
LF/HS	0.03	−0.28 – 0.34	0.850
HF/LS	−0.01	−0.29 – 0.28	0.960
LF/LS	−0.12	−0.42 – 0.19	0.438

All models were controlled for sex, baseline BMI percentile, age, and hunger. Bold values represent findings with an uncorrected p-value < 0.05.

of fat and its viscosity/mouth feel may impact the hedonic response to sugar, dissociating it from sweet taste sensitivity. This result is specific to the high-sugar/low-fat milkshake, so adolescents with lower sensitivity to high-sugar drinks may prefer high sugar beverages with lower-fat content, where the hedonic response to sugar is not obscured by fat. However, differences in sweet sensitivity were not associated with decreased fat intake, suggesting that other factors could have a greater influence on food choices.

Dietary intake from fats was positively associated with liking for a high-sugar/high-fat drink and negatively associated with liking for a low-sugar/low-fat drink. This dovetails multiple research studies in both children and adults (Ricketts, 1997; Park H. et al., 2018), whereas increased liking for fatty foods has been associated with high fat intake as well as low fiber and vegetable intake (Drewnowski and Hann, 1999). Adolescents who prefer fat may be less likely to consume healthier foods, such as fruits and vegetables, as they find them less tasty, and instead consume foods high in fat, leading to a positive energy balance. Frequently overlooked, dislike of energy-dense foods may be protective against weight gain (Sadler et al., 2019), potentially promoting a more 'balanced' diet. Food choices are critical during adolescence, when teenagers transition from a controlled food environment toward independent food-based decision making (Bassett et al., 2008). Thus, adolescents with increased fat intake at home are more likely to be conditioned to find high-fat/high-sugar foods more pleasant and consume more of these foods later in life, possibly contributing to excess weight gain.

Several studies have shown that lower sensitivity to fatty foods is linked to higher intake of high-fat foods (Stewart et al., 2011; Liang et al., 2012), contributing to excess fat intake in the long-term. However, we did not observe this finding in our sample. This difference may be due to the methodology used in the current study, such as unique sample characteristics or the variability in the fat content of the samples used in the taste sensitivity test. Furthermore, we did not observe an association between fat taste sensitivity and fat liking, which is in line with previous observations (Chamoun et al., 2019).

Although not significant after correction for multiple comparisons, it is noteworthy that baseline sweet taste sensitivity predicted BMI percentile change of the 4-year study period. Participants with lower sensitivity had a greater increase in BMI percentile. Adolescents with a dulled sensitivity to the sweet taste could be at an increased risk of long-term weight gain, as reductions in sweet taste sensitivity may contribute to an impaired satiety response, resulting in excess high-calorie food consumption, akin to many brain based models of weight gain (Volkow et al., 2008; Yokum and Stice, 2019). Surprisingly, whereas the sweet taste sensitivity and liking for high-sugar drinks were negatively associated, BMI percentile change was not predicted by baseline liking ratings, suggesting that taste sensitivity affects future weight through a mechanism independent of food liking.

It is important to consider the limitations of this study. The effect sizes for the significant repeated measures correlations were relatively small per Cohen (2013). Indeed, in larger sample studies, smaller, yet statistically significant effects can be observed. This indicates that, while the effect is present on a larger sample as a significant trend, it may be less meaningful on an individual level. Nevertheless, the findings from this study do provide novel information in the field of taste and weight regulation that can be used to inform future studies. Few levels of sugar and fat were tested, which may have provided a less precise test of taste sensitivity. Moreover, while the stimuli were designed to mimic 'real-world' foods, sensitivity may vary with different sweeteners (e.g., fructose) and types of fat (e.g., varied fatty acids). In addition, the fat sensitivity test used in this study included solutions of milk with varying fat content instead of solutions prepared with a single type of fatty acid, thus it did not allow us to differentiate whether participants made decisions based on basic taste (fatty acid) or other textural properties of these solutions. The validity of self-reported dietary intake is continually being debated, as it is susceptible to many biases (Park Y. et al., 2018). Also, the present study did not use one of the measures that are considered more valid (e.g., 7-day diet diary); as such, the diet data results need replication. Additionally, the current sample is quite homogeneous, while recent studies suggest there could be differences in taste sensitivity among racial and ethnic groups (Williams et al., 2016). Further research is needed to replicate these findings in more diverse samples. Despite these weaknesses, the large sample and the prospective collection of behavioral measures are meaningful strengths.

CONCLUSION

In sum, these results point toward the notion that lower sensitivity to sweet taste is linked to increased hedonic response to high-sugar foods, with potential contributions to overeating. Further, increased energy from fat may act to 'condition' adolescents to show increased liking for high-fat/high-sugar foods. These data are supported by many brain-based models of obesity and provide a nuanced examination of sensitivity and liking. The consistency of the findings with previous literature point to the importance of aspects of taste intensity underlying food intake and possibly weight regulation.

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 Oregon Research Institute's Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AP was responsible for data analysis and drafting the manuscript. GS contributed to data analysis. ES and KB were responsible for study design, data collection, and data curation. All the authors were responsible for reviewing and editing the manuscript, and read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

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Can Parental Body Dissatisfaction Predict That of Children? A Study on Body Dissatisfaction, Body Mass Index, and Desire to Diet in Children Aged 9–11 and Their Families

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Body image has been associated with self-care and the assumption of either healthy habits or poor diets and eating disorders. As a vital element in the formation of a positive body image, the role of the family in childhood has been highlighted by a few studies. This study aimed to assess whether children's body dissatisfaction could be predicted by their parents' body dissatisfaction, body mass index (BMI), and approach to change. The sample consisted of 581 participants (366 parents and 215 children). The following instruments were used: anthropometric data, the Brief Scale of Body Dissatisfaction for Children, the IMAGE questionnaire (approach to change and drive for muscularity subscales), and the Eating Disorder Inventory-2 (body dissatisfaction and drive for thinness subscales). The results indicated that 19% of children, 22.8% of mothers, and 70.2% of fathers were overweight or obese. The multiple regression models developed for boys and girls explained 60 and 57% of the variance in body dissatisfaction, respectively. Several variables attributable to the mother (higher approach to change, higher drive for thinness, and higher BMI) and to the boys themselves (drive for muscularity, approach to change, and having a high BMI percentile) predicted a higher level of body dissatisfaction. For girls, only variables regarding themselves (approach to change, age, and BMI percentile) explained their body dissatisfaction. Relationships with the traits of the father were not detected for both models. The influence of sociocultural factors on the construction of gender and the negative consequences of mothers' dieting for aesthetic purposes, on the development of children's body image, are discussed.

Keywords: body dissatisfaction, childhood, family, drive for thinness, drive for muscularity

INTRODUCTION

Body image is developed mainly in childhood and adolescence and is formed by the experiential representation of one's appearance and body shape (Smolak and Thompson, 2009). This representation may not match the objective and physical reality of the body because various biopsychosocial factors interact in the formation of the body image (Rodríguez and Alvis, 2015). From the cognitive-behavioral perspective, most previous studies agree that body image is the experience of one's body and is a multifactorial construct where cognitive, emotional, perceptive, and behavioral aspects interact (Alleva et al., 2015; Longo, 2016). Cognitive-emotional issues are framed in an attitudinal dimension that includes thoughts and emotions related to focusing attention on the areas of the body that tend to be farther from the ideal (e.g., abdomen, hips), a drive for thinness and/or muscles, planned dieting and compulsive activity to change one's figure, comparisons with slender bodies, fear of gaining weight, and emotional states, such as anger, sadness, and anxiety generated by dissatisfaction with one's body (Trejger et al., 2015; Thompson and Schaefer, 2019).

Due to the mental representation of the body, individuals may feel satisfaction or dissatisfaction with their body. Dissatisfaction is associated with low self-esteem, anxiety, depression, and the risk of developing eating disorders and suicide in adolescence (Brausch and Gutierrez, 2009; Nayir et al., 2016). The obsessive internalization of a certain body and weight generates negative consequences for health. In this sense, a negative attitude toward the body promotes inappropriate behaviors—such as nutritionally incorrect behaviors, compulsive physical activity, and compensatory behaviors—to modify the body in both men and women (de Oliveira da Silva et al., 2018; Burnettea and Mazzeo, 2020) and is also a predictor of long-term weight gain (Lowe et al., 2019). As such, the prevention of body image disturbance has become a relevant issue in public health agendas (Kahan and Puhl, 2017).

The desire to have a certain figure is supported by the canons of beauty that, in Western society, have been associated with personal, social, and professional success. Among women, the socially transmitted canon has generated an image of an ideal body and has been pursued by many, including mothers who, in turn, are the reference points for their children. The sociocultural pressure on women has been so intense that many professionals postulate that body dissatisfaction is the "normative discontent" of the female sex, thus, unfortunately, normalizing the dissatisfaction women experience with their body; considering this normal for women, no measures are taken to decrease body dissatisfaction in this population (Carrard et al., 2018). Moreover, there is a tendency to incorporate the concept of being fit, and the importance of the musculature associated with a healthy body. In this sense, some authors find that incorporating muscular ideal in the ideal of a healthy body in women has negative consequences and leads to unhealthy behaviors (Uhlmann et al., 2018). These negative consequences extend past the woman's own health. The woman as a mother is a key educational reference for her daughter in the development of a positive body image, and her attitudes toward her body affect the body dissatisfaction and eating behaviors of her daughter, as has been reported in the literature (Bauer et al., 2013; Arroyo et al., 2017; Zarychta et al., 2019). It has also been reported (Dahill et al., 2021) that adolescent children declared themselves to be affected by critical comments on their body and eating habits, or "fat-talk," from their mothers.

Among males, there seems to be an increase in pressure toward a muscular and toned body that is associated with success (Karazsia et al., 2017; Arellano-Perez et al., 2019). Research shows that there is less body dissatisfaction among males, perhaps as a result of the influence of different reference models related to the male beauty canon, which reflects more heterogeneity than that of women. This is evident by how the results of different scales evaluating bodybuilding differed according to the social characteristics of the men evaluated (Cheng et al., 2016). In this respect, strategies to prevent body image disturbance are not oriented to young men, and there is scarce research on this subject (Doley et al., 2020). Nonetheless, fathers remain a significant role model for their children. Communication with both parents and affective closeness have implications on the development of body image and health in general (Hitti et al., 2020). However, the influence of the parents on children's body image has been scarcely studied.

Pre-adolescence and adolescence are an evolutionary stage of vulnerability. Vulnerability regarding the body is not only due to neuropsychological and biopsychosocial changes, but also because body image acquires a significant role in the development of one's identity (Rodríguez and Alvis, 2015; Vartanian and Hayward, 2020). In this sense, Wang et al. (2018) found that 72.8% of young female adolescents experienced body dissatisfaction and a drive for thinness versus 46.2% of males. Conversely, 14.6% of females and 40% of males strived for muscularity. Although this kind of study in childhood and pre-adolescence is sparse, the literature review reveals that approximately 50% of children aged 7–12 years want to be thinner (Vaquero et al., 2013). Similarly, Heidelberger and Smith (2018) found that among 10-year-olds, 60% of girls desired to be thinner versus 48% of boys; meanwhile, 62 and 50% of boys and girls, respectively, expressed a drive for muscles (Sánchez-Castillo et al., 2018). Although there are differences between boys and girls regarding body dissatisfaction, there has recently been a trend toward increasing dissatisfaction among young men (Holland and Tiggemann, 2016). Despite this, most research on body dissatisfaction focuses on young or adolescent girls and women (Dion et al., 2016; Paxton and Damiano, 2017).

One of the main issues studied in the field of body dissatisfaction has been the possible relationship between weight and body dissatisfaction. Additionally, obesity has traditionally been identified as a risk factor in the development of body dissatisfaction, primarily due to the social rejection of obesity and being overweight (Puhl and Heuer, 2010); this contributes to an obsessive desire for a particular physical figure (O'Brien et al., 2016). In this regard, a relationship was found between body satisfaction and body mass index (BMI) in a sample of more than 1000 adolescents (Kantanista et al., 2017), wherein male youths with low and normal weight experienced more satisfaction than those who were overweight; however, female youths with low weight experienced more satisfaction than those who were normal weight or overweight. Nonetheless, specific relationships between weight and body dissatisfaction have not always been found. For instance, Krch (2004) points out that being overweight and obese was not related to body dissatisfaction, thus emphasizing the greater importance of body perception relative to the BMI (Yan et al., 2015) and value attributed to the body (Shuanglong and Guangye, 2018). Regardless, the desire to modify one's body is usually addressed by dieting to control weight; this gives rise to the prevalence of restrictive and compulsive behaviors in Western society (Puhl et al., 2015). Therefore, authors claim that a cognitive intervention based on facilitating the acceptance of one's own body not only favors the development of a positive body image but also promotes the implementation of a balanced diet (Wilson et al., 2020).

One widely studied aspect is the role of the family in the formation of body image. The role of the family, along with the influence of peers and sociocultural factors, is incorporated in the tripartite model of body dissatisfaction as one of the main predictors (Thompson et al., 1999; Keery et al., 2004). They influence not only the development of body dissatisfaction but also that of eating disorders. The family influences the development of body image, like other forms of social learning, directly and indirectly (Bauer et al., 2017). Examples of direct influence are parents' comments about the body shape and/or the need for weight control by children (Francis and Birch, 2005), while an example of indirect influence is the parents' behaviors toward their own body (Cooley et al., 2008; Rodgers et al., 2009). Both types of influence may convey several factors, including the importance of the functionality of the body; care through a healthy, active, and shared lifestyle in the family; messages of affection and respect (Carbonneau et al., 2020) or, in contrast, body dissatisfaction (Arroyo et al., 2018).

Although many studies on family context and body dissatisfaction have focused on the mother–daughter relationship, several recent studies suggest the importance of the influence of both parents, specifically through critical comments on children's bodies (Chng and Fassnacht, 2016; Wansink et al., 2017). Similarly, Biolcati et al. (2020) emphasizes that the influence of parents' critical comments on the development of body dissatisfaction affects daughters in different life stages, such that mothers and fathers influence adolescence and young adulthood, respectively. Through qualitative and quantitative methods, McLaughlin et al. (2015) also studied dyads of 145 mothers and 145 daughters and concluded that there was an agreement between young women aged 8–12 years and their mothers on the negative influence of comments and teasing toward the body on the development of body dissatisfaction.

Studies carried out with children have evidenced the possible influence of parental body dissatisfaction on that of their children. As such, many studies have focused on linking eating behaviors and parental physical activity to the risk of being overweight in children (Matthews-Ewald et al., 2015). The authors found that, in a sample of children aged 3–7 years, parental dissatisfaction as assessed by a silhouette scale correlated with child dissatisfaction (Kościcka et al., 2016). Similarly, Webb and Haycraft (2019) highlight the link between body dissatisfaction and disadaptative eating habits of parents and the body dissatisfaction of children aged 6–9 years.

Although several studies have examined body dissatisfaction among children, most of the literature is focused on adolescent or adult women (Dion et al., 2016; Paxton and Damiano, 2017). The sociocultural pressure to achieve a thin body is present in Western society and, according to several authors, in most parts of the world (Izydorczyk and Sitnik-Warchulska, 2018). However, the sociocultural presence or influence of a drive for muscularity remains unclear. Moreover, the literature reveals that body dissatisfaction, behaviors to control weight, and maternal obsession with thinness influences the development of body dissatisfaction among daughters (Kluck, 2010; Neumark-Sztainerç et al., 2010; Bauer et al., 2013; Arroyo et al., 2017; Zarychta et al., 2019). Despite the rise in body dissatisfaction among boys, to the best of our knowledge, there are no studies analyzing mother–son dyads. Although the father's role is crucial in the healthy development of children (Hitti et al., 2020), studies about paternal body dissatisfaction and its relationship with those of the children are scarce (Matthews-Ewald et al., 2015; Chng and Fassnacht, 2016; Kościcka et al., 2016; Wansink et al., 2017; Webb and Haycraft, 2019; Biolcati et al., 2020).

Given the crucial role of dissatisfaction in the health of young people and the role of the family as a major factor in the development of such dissatisfaction, this study examined whether a child's body dissatisfaction was associated with and could be predicted by parents' concerns about their weight and shape. Therefore, child–father and child–mother dyads were evaluated in the following variables: percentile of BMI, BMI, body dissatisfaction, drive for thinness, drive for muscularity, and beliefs about approach of modifying the body through diet. Specifically, the following hypotheses are proposed:

Hypothesis 1: The percentile of BMI, drive for muscularity, and approach to change are predictors of body dissatisfaction in boys and girls.

Hypothesis 2: Body dissatisfaction, drive for thinness, drive for muscularity, approach to change, and the BMI of the mothers and fathers are predictors of body dissatisfaction in boys.

Hypothesis 3: Body dissatisfaction, drive for thinness, drive for muscularity, approach to change, and the BMI of the mother and father are predictors of body dissatisfaction in girls.

MATERIALS AND METHODS

Participants

This study was a cross-sectional study of children aged 8–11 years and their parents who were invited to participate in body satisfaction and healthy habits studies at the University of Castilla-La Mancha (Spain). Two hundred ninety children (8–11 years old) and their parents were invited to participate. From these, 215 (73.79%) child–father and/or child–mother dyads returned completed questionnaires. Thus, the final sample size was 581 participants (215 families, including 366 parents and 215 children). The inclusion criteria were: being enrolled in a primary school in Toledo (Spain) and willingness to participate in our study voluntarily and anonymously. All families (including both children and parents) completed a survey that assessed socioeconomic data; the measures are described below.

Procedure

The school was informed about the research objectives and the requirement of voluntary and anonymous participation. Once the school agreed to participate, the families were asked to provide informed consent, and the anonymity of the data and voluntary participation was guaranteed. Through the school's usual channels of communication, informed consent forms were sent to the families to be signed. Finally, the objectives of the research were explained to the children whose parents had given consent, and they were also informed about voluntary participation, and that participation could be terminated at any point.

Children were assigned a code that was also used for their families. The questionnaires for fathers and mothers were delivered through the children using an envelope. The parents returned the questionnaires in the sealed envelope and left them at the school office. The evaluation of the children was carried out collectively using the evaluation booklet where the socio-demographic data and the EDI-2 and IMAGE questionnaire appeared. Meanwhile, anthropometric measurements were taken individually, without informing the children. All data were collected anonymously, in such a way that the participants could not be identified. In turn, the database was safeguarded by researchers. The study was developed in compliance with the Helsinki Declaration regarding privacy, confidentiality, and informed consent, as well as the Data Protection Act enforced in Spain. The study also complied with the ethical requirements of the University of Castilla-La Mancha regarding research with humans.

Measures

The Child's Body Dissatisfaction

This was measured with the Brief Scale of Body Dissatisfaction for Children (EBICI; Baile et al., 2012). The psychometric properties of the instrument were provided by the referenced authors, who reported a reasonable internal consistency for Spanish participants (Cronbach's $\alpha = 0.738$). This scale consists of three items that measure body image. Each item has several options for the answer [e.g., Item 1: Regarding your physical appearance: (a) I think I have an adequate weight and image; (b) I would like to lose some kilograms; (c) I would like to lose many kilograms]. The participant is required to choose the one that best represents them; items 1, 2, and 3 range from 0–2, –1 – –2, and 0–3, respectively. The final score ranges from –1 to 7 and is the sum of the responses to all the questions, with a higher score associated with worse body satisfaction. The scale showed adequate internal consistency in our study (Cronbach's $\alpha = 0.67$).

Parent's Body Dissatisfaction and Drive for Thinness

This was measured using the Spanish version (Garner, 1998) of the Eating Disorder Inventory (EDI-2; Garner, 1991). This questionnaire consists of 91 items that measure drive for thinness, bulimia, body dissatisfaction, ineffectiveness, perfectionism, interpersonal distrust, interoceptive awareness, maturity fears, asceticism, impulse regulation, and social insecurity. For this study, we used the subscales driven for thinness (e.g., I am worried because I would like to be a thinner person) and body dissatisfaction (e.g., I think my thighs are too thick). Both 6–points scales were rated from 0, meaning "never," to 5, meaning "always." For this study, the subscales driven for thinness and body dissatisfaction showed good internal consistency (Cronbach's $\alpha = 0.87$ for mothers and 0.71 for fathers, respectively). The final scores for the drive for thinness (nine items) and body dissatisfaction (seven items) subscales—ranging from 0–45 and 0–35, respectively—were the sum of responses to all the questions, where higher scores were associated with worse body satisfaction.

Parent's and Children's Parents and Children's Drive for Muscularity and Approach to Change

This was measured with the Body Dissatisfaction Image questionnaire (IMAGEN; Solano-Pinto and Cano-Vindel, 2010; Solano-Pinto et al., 2017), which consists of 38 and 25 items in the original and abbreviated IMAGEN questionnaires, respectively (Solano-Pinto et al., 2017). For this study, we used approach to change of the cognitive-emotional subscale from the abbreviated version (three items, e.g., I should work on my diet). To measure drive for muscularity, three items evaluating concerns for the body were used (e.g., "I would like to have more muscle;" "I feel guilty when I cannot work out;" and "If I had more muscle, I would be more self-confident"). Each item was rated using a scale ranging from 0–4 scale, wherein 0 and 4 meant "never or almost never" and "always or almost always," respectively. These subscales showed acceptable internal consistency in our study (Cronbach's $\alpha = 0.74$, 0.71, and 0.78 for children, mothers, and fathers, respectively).

Data Analyses

First, because we were interested in whether body dissatisfaction differs between boys and girls, we tested both models separately. Second, we conducted descriptive statistics. Third, to investigate the relationship between a child's body dissatisfaction and parents' concerns about their own weight and shape (i.e., body dissatisfaction, drive for thinness, drive for muscularity, and approach to change), we computed bivariate Pearson correlations. Finally, to determine the unique influence of each predictor, we conducted multiple regression analyses using SPSS (Windows version 25), including the child's demographics (age and BMI percentile) and parental BMI as control variables. For significant predictors, f^2 was included as a measure of effect size. We considered an f^2 of 0.02, 0.15, and 0.35 as small, medium, and large effects, respectively (Cohen et al., 2003).

To avoid multicollinearity and given that some of the measures could be interrelated, only significant correlates of a child's body dissatisfaction were included as predictors in the subsequent multiple regression analysis. Moreover, to ensure that there was no multicollinearity among these predictor variables, we used the variance inflation factor (VIF). VIF values between and 1–10 are typically used to indicate the absence of multicollinearity (Cohen et al., 2003). Additionally, due to some missing data, we were concerned about potential variables that could be associated with these missing data and could bias our findings. To examine whether the missing at random assumption was satisfied (Little and Rubin, 2002), we conducted binary logistic regression to find additional potential predictors related to missingness.

RESULTS

Descriptive statistics are presented in **Tables 1**, **2**.

Children's Characteristics

From the sample, 49.3% ($n = 106$) were male, with a mean age of 9.78 years (range: 8–11 years). The majority of children (70.7%) were between the 10th and 85th percentile for BMI, considering the normal range. Only 41 (19.1%) had a percentile above the 85th, indicating that they were overweight or obese.

For both gender ($M_{daughters} = 9.74$, $M_{sons} = 9.81$; $p = 0.60$) and BMI percentile ($M_{daughters} = 57.45$, $M_{sons} = 50.47$; $p = 0.10$), results were not significantly different between daughters and sons.

Mothers' Characteristics

The mothers were 43.21 years old on average (range: 24–53 years). Most mothers were of normal weight; 69.8% showed a BMI under 25, and 3.1% a BMI under 18.5. Only 41 (19.1%) participants were overweight, while 8 (3.7%) were obese. The vast majority were Caucasian, married, had a high education level, and were employed.

Fathers' Characteristics

The fathers showed a mean age of 45.45 years (range: 28–63 years). Most of them ($n = 123$, 57.2%) were overweight, and 28 (13.0%) were obese. The vast majority were Caucasian, married, had a high education level, and were employed.

Before conducting the analyses, we tested for multicollinearity. No multicollinearity was evident among the tested predictors; this was evidenced by the VIF for the predictors, which ranged between 1.04 and 2.05, with tolerance values ranging between 0.45 and 0.90 (Cohen et al., 2003). Additionally, potential predictors of the missing data from those variables that correlated with a child's body dissatisfaction were examined using binary logistic regression. The following results did not show any potential predictors among those evaluated: mother's drive for thinness ($p = 0.25$), father's approach to change ($p = 0.83$), mothers' BMI ($p = 0.70$), and father's BMI ($p = 0.05$).

Body Dissatisfaction in Sons

Bivariate Pearson correlations analyzing the body dissatisfaction scores of the boys in the sample are presented in **Table 3**. Body dissatisfaction in the son was related to a higher son's approach to change, son's drive for muscularity, higher body dissatisfaction of the mother, higher drive for thinness of the mother, and approach to change of the mother.

TABLE 1 | Demographic and clinical characteristics of our families (categorical variables).

	Number	Percentage
Mothers		
Education		
Low (no or primary education)	3	2
Medium (secondary education)	15	7
High (tertiary education)	135	63
Home Country		
Spain	196	91
Morocco	3	1
Other	7	3
Race		
Caucasian	90	95
African American	3	1
Other	2	1
Occupation		
Employed	163	76
Housewife	38	18
Student	1	0.5
Marital status		
Single	7	3
Married	175	81
Separated	18	8
Widowed	1	0.5
Socio-economic level		
Upper	23	11
Middle	90	42
Lower	29	13
Fathers		
Education		
Low (no or primary education)	56	26
Medium (secondary education)	13	6
High (tertiary education)	114	53
Home Country		
Spain	180	84
Morocco	3	1
Other	3	1
Race		
Caucasian	85	40
African American	3	1
Other	1	1
Occupation		
Employed	172	80
Housework	8	4
Retirement	1	0.5
Marital status		
Single	4	2
Married	174	81
Separated	10	5
Socio-economic level		
Upper	44	20
Middle	90	42
Lower	14	7

TABLE 2 | Descriptive statistics for our families (continuous variables).

	Mean	*SD*	Min-max	Range	Missing (%)
Sons (*N* = 106)					
BMI percentile	50.47	30.64	1–99	–	1 (1)
Body dissatisfaction	1.03	1.88	−1 to 6	−1 to 7	0 (0)
Drive for muscularly	4.38	3.24	0–12	0–12	6 (6)
Approach to change	4.00	4.10	0–12	0–12	8 (8)
Daughters (*N* = 109)					
BMI percentile	57.45	31.38	1–99	–	0 (0)
Body dissatisfaction	0.85	1.73	−1 to 7	−1 to 7	0 (0)
Drive for muscularly	2.24	2.71	0–12	0–12	6 (6)
Approach to change	3.09	3.32	0–12	0–12	5 (5)
Mothers (*N* = 191)					
BMI (kg/m^2)	23.25	3.52	17.65–40.35	–	24 (11)
Body dissatisfaction	16.76	8.08	0–38	0–45	16 (7)
Drive for muscularly	2.69	2.41	0–12	0–12	32 (15)
Drive for thinness	10.65	7.75	0–35	0–35	36 (17)
Approach to change	5.56	3.75	0–12	0–12	8 (4)
Fathers (*N* = 182)					
BMI (kg/m^2)	26.65	3.17	20.06–38.09	–	33 (15)
Body dissatisfaction	14.23	6.41	0–40	0–45	39 (18)
Drive for muscularly	2.71	2.84	0–12	0–12	35 (16)
Drive for thinness	7.83	5.42	0–26	0–35	34 (16)
Approach to change	4.92	3.79	0–12	0–12	16 (9)

For our main analysis, we conducted a multiple linear regression analysis with the sons' body dissatisfaction as the outcome variable. The rest of the variables (i.e., son's approach to change, son's drive for muscularity, mother's body satisfaction, mother's drive for thinness, and mother's approach to change) were included as predictors. The child's demographics (age and BMI percentile) and parental BMI were included as controls in this analysis.

The results of the regression analysis are presented in **Table 4** and **Figure 1**, including the standardized regression coefficients (βs) and the change in R^2 for each predictor. The model accounted for 60% of the total variance in son's body dissatisfaction ($F[8,61] = 11.572$, $p < 0.001$). Drive for muscularity, approach to change, mother's approach to change, mother's drive for thinness, BMI percentile of the son, and mother's BMI, accounted for 14, 35, 4, 18, 24, and 11%, respectively, of the variability, wherein higher drive for muscularity, approach to change, mother's drive for thinness, son's BMI percentile, and mother's BMI and lower mother's approach to change, were related to worse body satisfaction of the son. The other predictors were not significant ($p > 0.05$). All predictors showed a medium effect size (mother's drive for thinness: $f^2 = 0.22$, son's BMI percentile: $f^2 = 0.32$, son's drive for muscularity: $f^2 = 0.16$, and mother's BMI: $f^2 = 0.12$), except for the mother's approach to change ($f^2 = 0.04$) and son's approach to change ($f^2 = 0.54$) which showed small and large effect sizes, respectively.

Daughter's Body Dissatisfaction

Bivariate Pearson correlations of the daughter's body dissatisfaction scores are presented in **Table 5**. Worse body satisfaction in the daughter was related to higher drive for muscularity, higher approach to change, worse mother's body satisfaction, and higher mother's drive for thinness.

For our main analysis, we conducted a multiple linear regression analysis with the daughter's body dissatisfaction as the outcome variable. The rest of the variables (i.e., daughter's drive for muscularity, daughter's approach to change, mother's body satisfaction, and mother's drive for thinness) were included as predictors. The daughters' demographics (age and BMI percentile) and parental BMI were included as controls in this analysis.

The results of the regression analysis are presented in **Table 6** and **Figure 2**, including the standardized regression coefficients (βs) and the change in R^2 for each predictor. The model accounted for 57% of the total variance in the daughter's body dissatisfaction ($F[7,67] = 12.555$, $p < 0.001$). The approach to change, age, and BMI percentile of the daughter accounted for 43, 2, and 10%, respectively, of the variability, whereby a higher approach to change, higher BMI percentile, and being older were related to worse body satisfaction in the daughter. The other predictors were not significant ($p > 0.05$). All predictors showed

TABLE 3 | Pearson correlations between son's body dissatisfaction with the other variables of interest.

		1	2	3	4	5	6	7	8	9	10	11
Son's variables	(1) Body dissatisfaction	–										
	(2) Drive for muscularly	0.37*	–									
	(3) Approach to change	0.59*	0.47*	–								
Mother's variables	(4) Body dissatisfaction	0.34*	0.09	0.23*	–							
	(5) Drive for muscularly	−0.01	−0.01	0.06	0.42*	–						
	(6) Drive for thinness	0.42*	0.18	0.30*	0.67*	0.58*	–					
	(7) Approach to change	0.20*	0.04	0.04	0.46*	0.41*	0.66*	–				
Father's variables	(8) Body dissatisfaction	0.05	−0.06	−0.06	0.11	0.01	−0.03	0.14	–			
	(9) Drive for muscularly	−0.02	−0.20	−0.04	0.23*	0.26*	0.26*	0.14	0.06	–		
	(10) Drive for thinness	0.13	−0.07	−0.01	0.10	0.16	0.10	0.10	0.31*	0.50*	–	
	(11) Approach to change	0.17	0.07	0.04	0.20	0.17	0.22*	0.36*	0.32*	0.30*	0.59*	–

*$p < 0.05$.

TABLE 4 | Linear regression analyses to determine the influence of each predictor on son's body dissatisfaction.

	Son's body dissatisfaction					
	B	*SE*	*P*	R^2	95% CIs	
					Lower bound	Upper bound
Son's approach to change	0.146	0.045	0.002	0.35	0.056	0.236
Son's drive for muscularity	0.120	0.055	0.032	0.14	0.011	0.230
Mother's body satisfaction	0.021	0.025	0.386	0.11	–0.028	0.070
Mother's approach to change	–0.166	0.060	0.007	0.04	–0.286	–0.047
Mother's drive for thinness	0.059	0.029	0.044	0.18	0.002	0.117
Son's age	–0.258	0.160	0.112	0.00	–0.578	0.062
Son's BMI percentile	0.012	0.006	0.029	0.24	0.001	0.024
Mother's BMI	0.186	0.049	<0.001	0.11	0.088	0.283

a small effect size (daughter's BMI: $f^2 = 0.10$, daughter's age: $f^2 = 0.00$), except for the daughter's approach to change, which showed a large effect size ($f^2 = 0.75$).

DISCUSSION

Different authors have emphasized the importance of body image in childhood and adolescent health (Kahan and Puhl, 2017); this was the motivation for this study. The general objective was to discover if parents' body dissatisfaction can predict body dissatisfaction in their children in childhood: specifically, whether body dissatisfaction in girls and/or boys could be explained by their own approach to change and drive for muscularity and the body dissatisfaction, drive for thinness, drive for muscularity, and approach to change of their parents. For this, 215 (73.79%) child-father and/or child–mother dyads returned completed questionnaires, forming a final sample size of 581 participants with 215 families: 366 parents and 215 children. Anthropometric variables of the participants were analyzed using BMI.

For the body dissatisfaction of boys, 60% of the variance was determined by the model. The boys' own significant variables were the BMI percentile, approach to change, and drive for muscularity. Among the parental variables, the maternal variables drive for thinness, body dissatisfaction, and approach to change significantly explained the body dissatisfaction of their sons, while no paternal variables were found to be statistically significant.

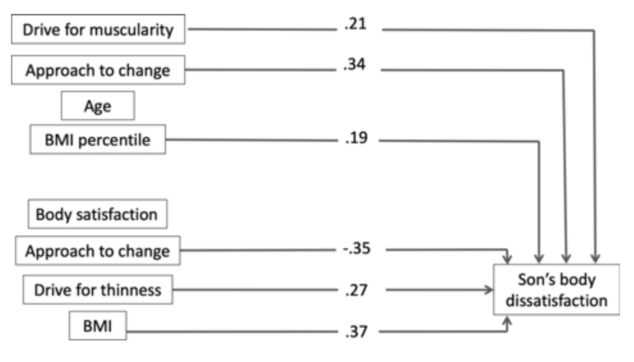

FIGURE 1 | Results from multiple regression analysis for son's body dissatisfaction. Only significant paths are displayed ($p < 0.05$) as β coefficients.

The model proposed to explain body dissatisfaction in girls accounted for 57% of the total variance in their body dissatisfaction. Among the variables of the girls, their BMI percentile, approach to change, and age were significant, while the drive for muscularity had a residual significance. Regarding the maternal variables evaluated, only drive for thinness had a residually significant explanatory character. None of the paternal variables explained their daughters' body dissatisfaction.

Consequently, Hypothesis 1, which stated that the percentile for BMI, drive for muscularity, and approach to change are predictors of body dissatisfaction in boys and girls, is proven to a great extent. There were significant correlations between the dependent variable—body dissatisfaction—and BMI percentile, drive for muscularity, and approach to change for both girls and boys. In the model used to examine body dissatisfaction in boys, the BMI percentile, approach to change, and drive for muscularity were significant predictors; in the model for girls, drive for muscularity had only a residual significance and was not a remarkable predictor. These results confirm other studies' findings; the relationship between weight and body dissatisfaction was emphasized along with being overweight as a risk factor for the development of body dissatisfaction (Puhl and Heuer, 2010; O'Brien et al., 2016), which takes place in both males and females (Kantanista et al., 2017) and may be confirmed in childhood. These data also reflect the existence of bodily dissatisfaction in children, confirming the increase in mean body dissatisfaction scores in men (Holland and Tiggemann, 2016; Karazsia et al., 2017).

The variable approach to change refers to the modification of weight through dieting. Therefore, we may state that thinking about dieting to change weight explains body dissatisfaction in both boys and girls. This may be in line with the increasing prevalence of restrictive and compulsive behaviors in Western society (Puhl et al., 2015). For future research, it would be appropriate to evaluate whether children with body dissatisfaction who are figuring out an approach to change also engage in restrictive and/or compulsive behaviors to modify the body, either with the desire to lose weight or become muscular.

The Western canon of beauty is characterized by a slim body for women (Carrard et al., 2018) and muscularity for men (Karazsia et al., 2017). However, the canon is not static and has evolved to promote bodybuilding, as part of the concept of fitness, among women (Uhlmann et al., 2018). As such, in this study, both issues—the obsession with thinness and bodybuilding—were evaluated. One of the highlights of this study is that drive for muscularity explains body dissatisfaction significantly in boys and residually in girls. This is in line with studies highlighting that body dissatisfaction in children is linked to the desire for a different body, either slim or more muscular; this desire is present in adolescents—primarily in males, but also in females (Wang et al., 2018)—and in children (Heidelberger and Smith, 2018; Sánchez-Castillo et al., 2018). It should also be noted that the EBICI instrument used to assess body dissatisfaction evaluates, among others, the desire to lose weight, which would imply the desire for a thinner body. This data highlights that the children evaluated desire to have a muscular and slender body. Therefore, one may think that a slender body and a muscular body may be part of the ideal body internalized by children. This study cannot corroborate this hypothesis, but this may be considered in future research, along with an in-depth study of the canon of beauty and gender roles offered to boys and girls through different educational agents. These results should also be taken into account while formulating campaigns for obesity prevention and health promotion, to prevent body image disturbance and the approach of modifying the body through diet or physical activity, mainly in children who are overweight and obese. As some authors emphasize, the prevention of body image disturbance should be considered significant in public health (Kahan and Puhl, 2017), emphasizing a cognitive intervention that deepens the acceptance of one's own body (Wilson et al., 2020).

Meanwhile, Hypothesis 2, which stated that body dissatisfaction, drive for thinness, drive for muscularity, approach to change, and the BMI of the parents are predictors of body dissatisfaction in boys, has been partially confirmed. Among the maternal variables evaluated, the variable with the greatest effect on the child's body dissatisfaction was the mother's BMI. These data would again confirm that being overweight and obese are predictive factors in the development of body dissatisfaction (Puhl and Heuer, 2010). However, both being overweight and having an overweight mother seem to be risk factors to be considered in the development of body dissatisfaction in children. This result should be interpreted in addition to the other significant variables. This may confirm the sociocultural pressure directed toward women, who aside from being female and overweight, and having an obsession with thinness, have no plan for weight change, which partly explains the child's body dissatisfaction. Perhaps this may be interpreted

TABLE 5 | Pearson correlations between daughter's body dissatisfaction with the other variables of interest.

		1	2	3	4	5	6	7	8	9	10	11
Daughter's variables	(1) Body dissatisfaction	–										
	(2) Drive for muscularly	0.50*	–									
	(3) Approach to change	0.65*	0.43*	–								
Mother's variables	(4) Body dissatisfaction	0.20*	0.00	0.11	–							
	(5) Drive for muscularly	0.06	– 0.52	0.09	0.17	–						
	(6) Drive for thinness	0.31*	0.14	0.18	0.55*	0.40*	–					
	(7) Approach to change	0.07	– 0.03	0.04	0.54*	0.27*	0.46*	–				
Father's variables	(8) Body dissatisfaction	0.15	– 0.12	– 0.01	0.13	– 0.03	0.13	0.17	–			
	(9) Drive for muscularly	0.19	0.21	0.13	0.14	0.30*	0.41*	0.30*	0.06	–		
	(10) Drive for thinness	0.17	0.05	0.02	0.20	0.18	0.43*	0.28*	0.31*	0.55*	–	
	(11) Approach to change	0.02	0.07	– 0.10	0.16	0.15	0.25*	0.38*	0.24*	0.37*	0.60*	–

*$p < 0.05$.

TABLE 6 | Linear regression analyses to determine the influence of each predictor on daughter's body dissatisfaction.

	Daughter's body dissatisfaction					
	B	*SE*	*P*	R^2	95% CIs	
					Lower bound	Upper bound
Daughter's drive for muscularity	0.128	0.068	0.063	0.25	–0.007	0.264
Daughter's approach to change	0.224	0.053	<0.001	0.43	0.1117	0.330
Mother's body dissatisfaction	0.014	0.022	0.527	0.04	–0.030	0.058
Mother's drive for thinness	0.048	0.025	0.063	0.09	–0.003	0.098
Daughter's age	0.327	0.155	0.038	0.02	0.018	0.636
Daughter's BMI percentile	0.012	0.005	0.014	0.10	0.002	0.021
Mother's BMI	–0.042	0.041	0.311	0.01	–0.124	0.040

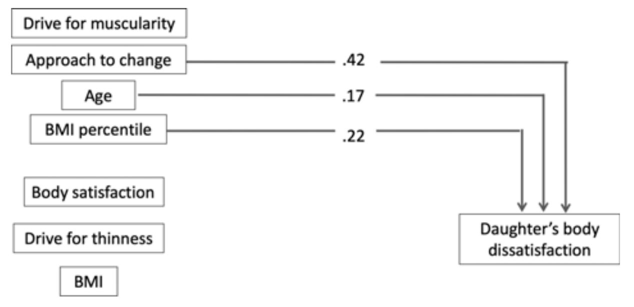

FIGURE 2 | Results from multiple regression analysis for daughter's body dissatisfaction. Only significant paths are displayed ($p < 0.05$) as β coefficients.

by the desire for a socially accepted body contrary to that of their mother, who does not plan to change her body and is, in turn, socially rejected. It could be that the child internalizes these aspects and rejects the overweight status of their mother, who, although concerned about thinness, does nothing to alter her appearance; this rejection becomes tangible in the development of the daughter's body dissatisfaction.

Some studies highlight an increase in mean body dissatisfaction scores in men (Holland and Tiggemann, 2016; Karazsia et al., 2017). This increase could be reflected by the prediction of children's body dissatisfaction (Kościcka et al., 2016). However, in part, this was not verified in this study. In the evaluated sample, the mother's dissatisfaction predicted the children's dissatisfaction, as indicated in the literature (Bauer et al., 2013; Arroyo et al., 2017; Zarychta et al., 2019). Fundamentally, this prediction was made for sons, which is a novel finding of this study, and may be related to the above-mentioned increase in male scores in previous research.

Finally, Hypothesis 3, which stated that body dissatisfaction, drive for thinness, drive for muscularity, approach to change, and the BMI of the parents are predictors of body dissatisfaction in girls, was not confirmed, achieving a residual role in explaining body dissatisfaction in girls for the drive for thinness of the mother. This can be interpreted by the increased sociocultural pressure on the woman, causing the need to have a particular body associated with success to be internalized from an early age. This would explain why the variables evaluated in the girls, percentile of BMI, approach to change, and age, explained girls' body dissatisfaction and not the variables evaluated in both parents.

The reviewed literature indicates that body dissatisfaction is common among women. It is worth focusing on its severity, despite its frequency, due to its negative health consequences (Carrard et al., 2018). Body dissatisfaction is related to the performance of nutritionally incorrect behaviors and compulsive physical activity, as well as unstable mental health (de Oliveira da Silva et al., 2018; Lowe et al., 2019; Burnettea and Mazzeo, 2020); additionally, as evidenced in this study, it has negative consequences for the sons. However, the variables evaluated in men have not been found to be predictive of body dissatisfaction in children. This has various interpretations. The traditional social role assigned to women makes them responsible for certain home tasks, such as those related to food, clothes, and health. Thus, mothers tend to spend more time with their children than fathers. Therefore, there is a higher prevalence of women as educational agents inside the family. In the evolutionary stage of childhood, the child may also have a greater bond with the mother, due in part to the greater time spent with her, while in other stages, such as in emerging adulthood, the father may have more influence (Biolcati et al., 2020). This result should be further explored in future studies since, as Doley et al. (2020) claimed, there are scarce studies that include males. In this sense, it would also be interesting to consider other variables in the family environment that may explain children's body dissatisfaction, such as critical comments and teasing by parents (Dahill et al., 2021), communication style (Hitti et al., 2020), eating habits (de Oliveira da Silva et al., 2018; Webb and Haycraft, 2019; Burnettea and Mazzeo, 2020), and physical activity (Matthews-Ewald et al., 2015).

This study has several limitations that should be noted. The convenience sample and lack of control of the strange variables are highlighted. Future studies should include health indicators for both men and women that indicate whether the need for dieting could be due to health reasons. The performance of, type of, and reasons for diet may also be of interest. Additionally, a longitudinal design will allow the evolution of the predictors of body dissatisfaction in childhood and adolescence to be studied.

The suitability of the evaluation instruments used should be studied in depth since the EDI was created to evaluate aspects related to eating disorders, mainly in women. As such, it is necessary to research adequate instruments for the evaluation of body dissatisfaction in adults and children that take into account the multifactorial characteristics of the construct, rethinking the peculiarities of the canon of beauty that is currently transmitted to children. In contrast, an evaluation of the different types of values attributed to the body and their relationship to the construction of a positive body image may also be of interest. Finally, although the models presented do not fully explain children's body dissatisfaction, they assert that other educational agents should be considered. Following the tripartite model of body dissatisfaction, the influence of peers and sociocultural factors should be examined (Thompson et al., 1999; Keery et al., 2004).

Despite these limitations, the study is novel since it includes the evaluation of the father and the assessment of the desire for bodybuilding in both sexes. Despite these limitations, the study is novel since it includes the evaluation of the father and the assessment of the drive for muscularity in both sexes. This enables the establishing of dyads of fathers, mothers, and children. Among the results, the predictive character of the mother's body dissatisfaction on boys is notable.

The implications of these results should be considered when formulating education and health programs and administering them, not only for the prevention of dissatisfaction in childhood but also in adulthood. Sociocultural pressure on the body can contribute to the development of unhealthy behaviors, therefore attempts should be made to modify sociocultural models of the body. The normalization of corporal dissatisfaction as something expected for women must be removed from the collective imaginary, with actions carried out in different vital stages directed at the entire population. The influence of society as educational agents should be considered, where women and men should actively participate in the communication and education of their children (Hitti et al., 2020). This would increase health care and promote and encourage the positive development of their children's body image. Additionally, women have different experiences—such as pregnancy, menopause, other unavoidable events, and the aging process—all of which produce changes in their physical appearance that must be socially valued and perceived positively to guarantee a positive construction of the body's experience.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because individualized data from the project cannot be publically shared on a data repository due to the conditions of non-disclosure described in the consent form signed by the participants and their families. Requests to access the datasets should be directed to NS-P, natalia.solano@uclm.es.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the clinical drug research ethics committee "Complejo hospitalario de Toledo" (ref. 636). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NS, YS-V, and RF-C conceived the study and prepared the study materials. NS and YS-V collected the data. DG managed the data and conducted the analyses together with NS and RF-C. All the authors contributed to the interpretation of the results, provided critical revisions of the first draft, and approved the final version of the manuscript.

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Delay of Gratification Predicts Eating in the Absence of Hunger in Preschool-Aged Children

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Poor ability to regulate one's own food intake based on hunger cues may encourage children to eat beyond satiety, leading to increased risk of diet-related diseases. Self-regulation has multiple forms, yet no one has directly measured the degree to which different domains of self-regulation predict overeating in young children. The present study investigated how three domains of self-regulation (i.e., appetitive self-regulation, inhibitory control, and attentional control) predicted eating in the absence of hunger (EAH) in a community sample of 47 preschool-aged children (M age = 4.93, SD = 0.86). Appetitive self-regulation, as measured using a delay of gratification task, was significantly and negatively associated with EAH 1 year later ($p < 0.5$). Measures of inhibitory and attentional control did not significantly predict EAH. These results suggest that food-related self-regulation may be a better predictor of overeating behaviors than general measures of self-regulation.

Keywords: self-regulation, eating in the absence of hunger, preschool, taste test, inhibitory control, delay of gratification

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INTRODUCTION

Developing healthy eating habits early in life is critical to establishing a healthy lifestyle and preventing the onset of diet-related diseases. Diet-related diseases once thought to be applicable only to adults (e.g., metabolic syndrome, type 2 diabetes, non-alcoholic fatty liver disease) are now being seen in children with increasing frequency (Daniels, 2006; Lucan, 2015). In the same way that individuals with a high body mass index (BMI) in childhood are more likely to continue to have a high BMI in adulthood (Guo et al., 2002), eating habits and food preferences established in childhood track into and through adulthood (Devine et al., 1998; Skinner et al., 2002; Nicklaus et al., 2004). As such, a better understanding of individual differences in eating behaviors related to high BMI and associated diseases is necessary to advance interventions aimed at improving health outcomes across the lifespan.

Many people eat not only in response to satiety, but also in response to external cues and emotions; these behaviors can lead to patterns of intake that go beyond energy needs (Dallman, 2010), increasing risk for diet-related diseases (Bleich et al., 2015). While often thought of in the context of adulthood, this phenomenon is also reliably seen in children and families (Blissett et al., 2010; Pieper and Laugero, 2013). The gold standard for measuring such eating behaviors in the laboratory is use of an "eating in the absence of hunger" paradigm (EAH; Birch et al., 2003), which measures the degree to which an individual continues consuming palatable foods beyond satiety. In children, EAH is associated with decreased satiety responsiveness (Carnell and Wardle, 2007) and greater adiposity (Cutting et al., 1999; Fisher and Birch, 2002; Hill et al., 2008; Zocca et al., 2011), both of which are related to an increased risk for elevated adult BMI and associated chronic diseases (Freedman et al., 2001; Juonala et al., 2011). Importantly, EAH has been successfully measured in children as young as 21 months (Asta et al., 2016), and has been used as a laboratory measurement of overeating in people of all ages (Fisher and Birch, 2002; Hill et al., 2008; Appelhans et al., 2011).

Extant data suggest that difficulties with self-regulation (Johnson and Birch, 1994; Disantis et al., 2011), may increase risk for children's tendency eat beyond satiety (McPhie et al., 2014). Self-regulation (SR) is defined as the ability to regulate one's own arousal, emotion, and behavior (Kopp, 1982; Bridgett et al., 2013). SR capacity relies on executive function (EF; Hofmann et al., 2012), a set of higher-level cognitive processes that support an individual's ability to regulate their behavior and emotion (Bridgett et al., 2013). Indeed, preschool-aged children with lower teacher-rated cognitive development scores have been shown to engage in more emotional-based EAH (Pieper and Laugero, 2013). While this study investigated and did not find an association between experimental tasks assessing EF and EAH, the authors acknowledged that their sample ($N = 29$) may have been too small to find such effects (Pieper and Laugero, 2013). Indeed, a broader literature on EF abilities has shown that it is meaningfully related to eating behaviors in preschool- (Allom and Mullan, 2014; Levitan et al., 2015; Reimann et al., 2020) and school-aged (Riggs et al., 2010a,b; Nederkoorn et al., 2015; Kelly et al., 2020) children (but see Hughes et al., 2015; Tan and Lumeng, 2018). A few studies have compared subdomains of EF (e.g., inhibitory control, updating), and suggest that they may be uniquely related to eating behavior (Allom and Mullan, 2014; Gettens and Gorin, 2017).

Like EF, SR is not a single construct. While work on SR and related constructs often conceptualizes them as unitary processes (e.g., Wiebe et al., 2011; Deater-Deckard, 2014), many models divide SR into different domains based on the degree of emotion involved (e.g., Metcalfe and Mischel, 1999; Willoughby et al., 2011; Bridgett et al., 2015). This multifaceted perspective on SR has been employed in the eating field, with most models separating out cool (i.e., solely behavioral) SR tasks from hot (i.e., emotional) SR tasks (e.g., Pieper and Laugero, 2013). One of the tasks used to assess hot SR is the classic delay of gratification paradigm (Willoughby et al., 2011), which requires individuals to control their desire to consume a single snack in order to gain a second snack. It may be that this process, which we refer to as "appetitive SR," is conceptually more similar to self-regulating the desire to consume a tempting food in the absence of hunger as compared to more classic EF tasks or other forms of behavioral SR. However, no studies have directly compared appetitive and behavior SR with regard to eating in young children. Individual differences in SR abilities appear around age 3 (Carlson et al., 2004), and show dramatic growth through age 5 (Diamond, 2002). As such, the preschool period (defined here as aged 3 through 5) may be the ideal time to investigate the precise associations between SR and EAH in order to identify potential targets of intervention to alter developmental trajectories related to eating behaviors and the risk for associated diet-related diseases.

TABLE 1 | Demographic information.

Demographics	*M* (SD)		%
Child Demographics	**Session 1**	**Session 2**	
Age (years)	4.00 (0.77)	4.93 (0.86)	
Female Race			49%
Caucasian			87.23%
Asian			2.13%
Hispanic			0%
Multiracial			8.51%
Native American/Indian			2.13%
Preschool attendance			61.7%
Household/parent demographics			
Mother highest level of education (years)	15.36 (2.46)		
Mother body mass index (kg/m^2)	30.07 (8.01)		
Gross family income	$71,406.38 ($46,531.57)		

Therefore, in the present study we sought to investigate the associations between three separate forms of SR and EAH in a community sample of preschoolers. Appetitive SR was measured using a delay of gratification task, and two separate forms of behavioral SR were measured via attentional and inhibitory control tasks. We hypothesized that (1) all measured domains of SR would be inversely associated with EAH, such that greater SR ability would predict lower EAH, and (2) this association would be the strongest with regard to delay of gratification as compared to both forms of behavioral SR. Given past research suggesting that both delay of gratification and inhibitory control are associated with EAH, we ran additional exploratory analyses to examine whether interactions between appetitive and behavioral SR significantly predicted EAH.

METHODS

Participants

The sample for the present study consisted of 47 preschoolers (*M* age at Session 2 = 4.93, SD = 0.86, range = 3.78–6.83 years) who participated in a follow-up session (hereby referred to as Session 2) following engagement in a larger study on SR in parents and children (hereby referred to as Session 1). Of the 89 families who participated in the larger study, 75 signed a consent form allowing the research team to recontact them for additional research opportunities. The subsample who returned ∼1 year later for Session 2 did not differ from the full sample with regard to child age, sex, gross family income, maternal education, or maternal BMI (p-values > 0.28). Demographics for the present sample are detailed in **Table 1**.

Families were recruited via physical and online flyers; criteria for participation were biological mothers over age 18 with children ages 3 through 5 who had not yet entered kindergarten at the time of Session 1. Exclusion criteria were if mothers had less than half-time custody of the child, had a history of significant neurological disorder, or were taking medication that affects cognitive function; if the child had a developmental delay, sensory impairment, or the mother believed the child could not participate in the study successfully; or if the family was involved with child welfare services or reported that their primary language was not English. There were no additional eligibility criteria to participate in Session 2. All study procedures were approved by the University's Committee for the Protection of Human Subjects.

Protocol

In Session 1, mothers and children came into the laboratory for a roughly 3-h visit consisting of video-recorded parent-child interactions, mother-completed surveys, and child assessments of self-regulation, emotion identification, and school readiness. Measures relevant to the present analyses are described below. In Session 2, dyads returned to the same laboratory roughly 1 year later ($M = 364.17$ days, SD = 56.29) for a 2-h session scheduled around the time of day when mothers identified that the child usually ate lunch (all sessions began between 11 a.m. and 2 p.m., with 80.9% beginning at 11 a.m.). At the beginning of this session, mothers provided informed consent, after which both mother and child were weighed and measured for height in triplicate. Then, the child was presented with a 10,000 calorie test meal food array. Mothers were instructed to help their child eat lunch from the food array, but not eat anything themselves. These meals were video recorded. After lunch, mothers were asked to complete surveys while the child performed an EAH paradigm framed as a taste test in another room with the experimenter. Children were reunited with their mothers after 15 min. Families were then debriefed, thanked, and compensated $40 for their time.

Measures

Family Demographics (Session 1)

At Session 1, mothers were asked to report the birth date, sex, and the race/ethnicity of their child. From that, age was calculated as the number of days between the child's birth and the session date, divided by 365.25. Mothers also reported the gross family income and her highest level of educational attainment by degree.

Anthropomorphic Measurements (Session 2)

Mother and child BMI were assessed using laboratory measurements of height (inches) and weight (pounds) at the beginning of Session 2. Individuals were asked to remove shoes and heavy clothing, and stand with their shoulders and heels against a wall. They were asked to take a breath in and out, and their height was measured using a stadiometer mounted on a flat wall at the exhale. This was done three times, and height (in inches) was calculated as the average of all measurements. Similarly, weight (in pounds) was measured three times using a digital scale and averaged. BMI was then calculated using the following equation: weight/height^2 x 703. We converted BMI to z-score relative to same-age, same-sex peers (Mei et al., 2002) using Baylor College of Medicine's online BMI-percentile-for-age calculator (https://www.bcm.edu/cnrc-apps/bodycomp/bmiz2.html) for use in analyses.

Self-Regulation Tasks (Session 1)

Delay of Gratification Task

As detailed in Murray and Kochanska (2002), children were first asked to choose a preferred snack from an array of fruit snacks, M&Ms, and goldfish crackers. The experimenter placed the snack on a napkin in front of the children and asked them to wait until they rang a bell before retrieving it. The child was then told that they would receive a second snack if they were able to wait until the bell was rung. Four trials were conducted, where the child had to wait 30, 60, 120, and 180 s for the bell to ring. Halfway through each trial, the experimenter picked up the bell as if they were about to ring it. For each trial, the child was given a score representing waiting behavior: 0 (eats the snack before the bell is lifted), 1 (eats the snack after the bell is lifted), 2 (touches the bell or snack before the bell is lifted), 3 (touches the bell or snack after the bell is lifted), or 4 (waits for bell to ring before touching snack or bell). The final score was the average score over four trials, such that a child with an average score of 0 ate the snack before the bell was lifted for all trials, and a child with an average score of 4 waited until the bell was rung for all trials.

Flanker Task

The Flanker Task was administered via the NIH Toolbox Cognition Battery, which was adapted from the Attention Network Task (Rueda et al., 2004) and is normed for administration for children as young as 3 years old (Zelazo et al., 2014). Children were presented with a stimulus on the center of a tablet screen and were required to indicate the left-right orientation while inhibiting attention to the stimuli flanking it. On some trials the orientation of the flankers was congruent with the orientation of the central stimulus and on the other trials the flankers were incongruent. The test consisted of a block of 20 fish trials (designed to be more engaging and easier to see, and to make the task easier for children) and a block of 20 arrow trials, shown only if the participant scores >90% on the fish stimuli. The NIH Toolbox uses a two-vector method to score performance, which incorporated both accuracy and reaction time (RT) for participants who maintained a high level of accuracy (>80% correct), and accuracy only for those who did not meet this criterion. While age-referenced standardized scores are available for this task, we used raw scores in the present analyses in order to match the other SR tasks, for which age-referenced scores were not available.

Go/NoGo Task

Two GNG tasks were administered to children in the present study. First, children performed the Zoo Game (detailed in Grammer et al., 2014). Briefly, the task asked children to help a zookeeper put animals back in their cages by pressing a button as quickly as they can (Go [G] trials), unless they see Fred, a monkey who is helping the zookeeper (NoGo [NG] trials). The task began with three practice blocks in which children can practice (1) pressing the button on the laptop when they see an animal, (2) pressing the button within a certain time limit, and (3) practice inhibiting their response when they see the monkey. To increase the salience of the task, feedback was added at the end of each trial, such that children saw a smiling face if they correctly withheld their response on NG trials and a mad face if they either pressed the button on NG trials or did not press the button on G trials. Timing of this task was modified for the age range of the children in the present study by increasing the duration of the stimulus presentation and decreasing the number of trials. As such, each trial began with a 500–700 ms jittered fixation cross, 1,200 ms stimulus presentation, 500 ms black screen, and 1,000 ms feedback. Responses could be made while the stimulus was on the screen or at any point during the following 500 ms. A total of 90 trials were completed, 25% of which were NG. Percent correct was calculated across both types of trials.

We also asked children to complete the Fish GNG Task from the Early Years Toolbox (detailed in Howard and Okely, 2015). Briefly, the task asks children to respond to G trials ("catch fish," 80% of trials) and withhold responding on NG trials ("avoid sharks," 20% of trials). The task begins with go instructions followed by 5 practice go trials, no-go instructions followed by 5 practice no-go trials, combined GNG instructions followed by a mixed block of 10 practice trials (80% go trials), and a recap of instructions prior to the task commencing. Feedback in the form of auditory tones was provided on all practice trials. The task itself did not contain feedback, and was comprised of 75 test stimuli divided evenly into three test blocks (each separated by a short break and a reiteration of instructions). Stimuli were presented in pseudo-random order, such that a block never began with a no-go stimulus and no more than two successive trials were no-go stimuli, separated by a 1,000 ms interval between stimuli. Percent correct was calculated across both types of trials. Due to computer error, data from 15 participants were not recorded. Given the similarities in performance for the two GNG tasks ($r = 0.439$, $p < 0.001$), a composite score was created by z-scoring and averaging performance.

Test Meal (Session 2)

After anthropomorphic measurements were collected, mother-child dyads were escorted to a private room for lunch. They were instructed that the lunch was only for the child, but the mother was to help the child eat until they were no longer hungry. They were told that they had as much time as they needed, then granted access to a frequently used (Mirch et al., 2006; Tanofsky-Kraff et al., 2009; Shomaker et al., 2010a,b) *ad libitum* test meal varied in macronutrients (>10,000 kcal, **Figure 1**) and consisting of items most children like (e.g., bread, cheese, meat, chips, candy, cookies, fruit, chicken nuggets, water, milk, lemonade, apple juice). Mothers indicated before the session if there were any foods that should be omitted from the array due to allergies or vegetarian preferences (total $N = 3$; remove red food dye = 1, remove meat items = 2). All food items were weighed in grams (g) to the nearest single decimal before families entered the lunch room. When families completed lunch, experimenters ensured that they had not saved any food for later, and then weighed the remaining test meal food items when families were no longer able to see the lunch room. Energy content and macronutrient composition for each item were determined according to data from the USDA National Nutrient Database for Standard Reference, Release 24, and from the manufacturer labels on packaged food items. Total energy intake in kilocalories (kcal) was determined by subtracting the food weights after the participant's meal from premeal weights.

Eating in the Absence of Hunger (Session 2)

Immediately after the completion of lunch, mothers were asked to complete a set of surveys in the waiting room, and children were escorted to a room containing the following foods displayed in separate bowls (**Figure 2**): potato chips (28g; Kettle brand Sea

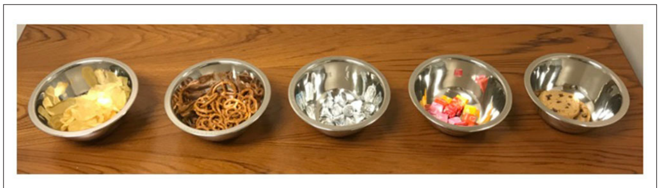

FIGURE 2 | Taste test food array (from left to right: chips, pretzels, Hershey's kisses, Starburst, cookies).

FIGURE 1 | Test meal food array.

Salt), pretzel twists (28g; Rold Gold brand Tiny Twists), chocolate drops (90g, Hershey brand kisses, individual-wrapped), fruit chew candies (150g; Starbursts brand, individually-wrapped), and chocolate chip cookies (70g; Grandma's brand). Mothers had indicated which foods their child should not eat due to allergies beforehand; children performed their taste test using only the foods that were permitted by their mothers (total N = 1; removed red/pink Starburst containing red food dye). Consistent with the original paradigm used in the proposed age range (Cutting et al., 1999; Fisher and Birch, 1999), children were instructed to taste each of the foods and provide a rating from 1 to 5 using a smiling-face scale where 1 = "very tasty" and 5 = "not very tasty" validated for use in the assessment of taste in pediatric populations (Mistry et al., 2018). Children were encouraged to complete the taste test within 5 minutes, and were then told that they had to remain in the room while their mother completed her surveys. They were told that they could eat as much of the remaining food as they wanted, as well as play with a bin of toys in the room opened by the experimenter. The experimenter remained in the room with the child for the full duration of the taste test and subsequent play period, and was instructed to minimize interactions with the child. After 15 minutes, the child was escorted to their mother. EAH was measured by calculating the difference in weight (g) of each snack before and after the eating period and summing across all snacks. Energy intake was calculated using the same methods as for the test meal.

Analyses

Study variables were assessed for skew and kurtosis; variables with a skewness or kurtosis over ±1 were transformed to improve distributions and re-assessed. Total calories consumed during lunch was identified as non-normally distributed. The distribution of this variable was greatly improved by transformation using the transform Tukey function in the R package *rcompanion* (Mangiafico, 2019), which follows the Tukey's Ladder of Powers principle to improve the distribution of skewed variables. This transformed variable was used for all subsequent analyses. A missing data analysis revealed that 7 participants were missing data from the Flanker task, and 2 were missing data from the GNG tasks. The majority of the data points lost were due to a computer error, which is considered to be missing completely at random. Therefore, we imputed all the missing data using multiple imputation implemented using the *mice* package in R (van Buuren and Groothuis-Oudshoorn, 2011).

All analyses were run using R (R Core Team, 2019). Zero-order associations between scores on the three SR tasks were first run using Pearson's correlations, adjusted for multiple tests using the Benjamini-Hochberg correction (Benjamini and Hochberg, 1995); adjusted *p*-values are presented. Associations between SR and EAH were tested using three separate linear regression models, one for each form of SR. To explore the interactions between the different forms of SR on EAH, we entered all three forms of SR in the same model and tested two- and three-way interactions between SR tasks. Interactions were interrogated and plotted using the R package *interactions* (Long, 2019). Covariates in all models included child BMI z-score (Session 2) and total calories consumed (kcal) during the test meal (Session 2). Confirmatory analyses were also analyzed using % estimated energy requirements (calculated according to the Institute of Medicine guidelines; Institute of Medicine of the National Academies, 2005); the pattern of results did not change.

RESULTS

Confirmatory Results

As shown in **Table 2**, zero-order correlations between SR tasks revealed that delay of gratification (as measured by Snack Delay score) was not significantly associated with either attentional control (as measured by the Flanker Task), $r_{(45)} = 0.22$, $p = 0.16$, or inhibitory control (as measured by the Go/NoGo composite), $r_{(45)} = 0.13$, $p = 0.48$. Attentional and inhibitory control were significantly positively associated, $r_{(45)} = 0.43$, $p = 0.01$.

Delay of gratification at Session 1 was negatively associated with total calories consumed (kcal) during the EAH paradigm 1 year later at Session 2, $b = -12.46$, 95% CI [−23.95, −0.97], SE = 5.86, $t_{(41.13)} = -2.13$, $p = 0.040$ (**Table 3A**). Attentional control at Session 1 was not associated with EAH at Session 2,

TABLE 2 | Descriptive data of self-regulation, test meal, and EAH variables, and correlations with confidence intervals.

Variable	*M*	*SD*	Range	1	2	3	4
1. Snack Delay Task	1.80	1.71	0–4				
2. Flanker Task (raw score)	20.43	12.07	4–40	0.22 [−0.09, 0.48]			
3. Go/NoGo Task composite	0.04	0.76	−2.12–1.62	0.11 [−0.19, 0.40]	0.44** [0.13, 0.67]		
4. Test meal (total kcal consumed)	492.57	300.14	128.54–1351.30	−0.03 [−0.32, 0.26]	0.37* [0.09, 0.60]	0.11 [−0.19, 0.39]	
5. EAH (total kcal consumed)	120.90	72.11	27.64–319.99	−0.27 [−0.52, 0.01]	0.15 [−0.16, 0.44]	0.18 [−0.11, 0.45]	0.37** [0.10, 0.60]

*M and SD are used to represent mean and standard deviation, respectively. Correlations were run on the pooled estimates from multiply imputed data sets. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). EAH, eating in the absence of hunger. * Indicates p < 0.05. ** Indicates p < 0.01.*

TABLE 3 | Results of the multiple regression analyses by self-regulation domain.

Predictor	*t*	*p*	*b*	R^2
(A) Appetitive self-regulation				0.185
Intercept	−2.195	0.034	−1493.736*	
Snack Delay	−2.126	0.040	−12.462*	
Child BMIz	−0.670	0.507	−8.224	
Kcal consumed at lunch‡	2.405	0.021	1410.550*	
(B) Attentional control				0.105
Intercept	−1.808	0.078	−1350.670	
Flanker Task	0.375	0.710	0.376	
Child BMIz	−0.442	0.661	−5.675	
Kcal consumed at lunch‡	1.945	0.059	1261.262	
(C) Inhibitory control				0.120
Intercept	−1.852	0.071	−1324.944	
Go/NoGo Task composite	0.986	0.330	13.502	
Child BMIz	−0.193	0.848	−2.499	
Kcal consumed at lunch‡	2.019	0.050	1244.224	

*The dependent variable for all regressions was EAH, defined as total calories (kcal) consumed during the taste test. BMIz = z-scored body mass index. All parameters were calculated using pooled estimates from multiply imputed data sets. ‡Variable transformed. *p < 0.05.*

$b = 0.38$, 95% CI [−1.59, 2.34], SE = 1.03, $t_{(33.38)} = 0.37$, $p = 0.71$ (**Table 3B**), nor was inhibitory control, $b = 13.50$, 95% CI [−13.33, 40.34], SE = 13.69, $t_{(40.94)} = 0.99$, $p = 0.33$ (**Table 3C**). Visualization of these results for total calories consumed are shown in **Figure 3**.

A direct comparison of the confidence intervals for the effects of SR on EAH by domain revealed that, while the confidence intervals overlapped (**Figure 4**), the 95% confidence interval for delay of gratification did not include the estimated associations of attentional and inhibitory control with EAH. We compared standardized regression coefficients using Eid et al.'s (2011) formulas implemented in the Psychometrica online calculator (Lenhard and Lenhard, 2014), which revealed that the effect of delay of gratification on EAH was indeed significantly higher than the effect of inhibitory control, $z = -2.15$, $p = 0.016$, but not attentional control, $z = -1.35$, $p = 0.089$. An exploratory direct comparison of the tasks assessing all three SR domains in the same model revealed that no one SR domain was significantly associated with EAH when controlling for the other two SR domains as well as child BMI z-score and total calories consumed during lunch (p-values > 0.11). Full models, data, and R scripts are available online – https://osf.io/wbntq/.

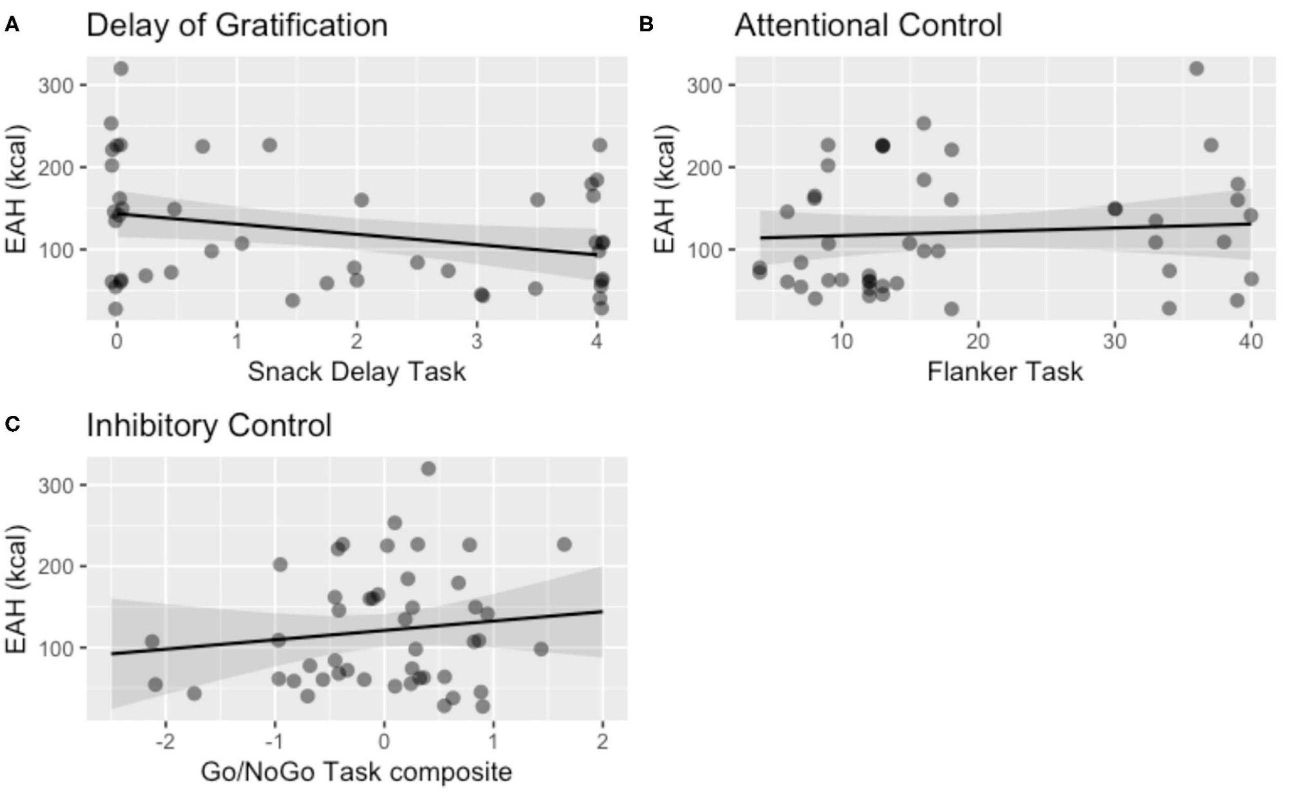

FIGURE 3 | Visualization of the main effect of child self-regulation on eating in the absence of hunger (EAH) controlling for child age, child sex, child BMI, and the number of calories (kcal) consumed during the lunch test meal, in the domains of **(A)** delay of gratification ($b = -12.46$, $p = 0.04$), **(B)** attentional control ($p = 0.67$), and **(C)** inhibitory control ($p = 0.34$). One of the multiply imputed data sets was chosen at random for plotting purposes.

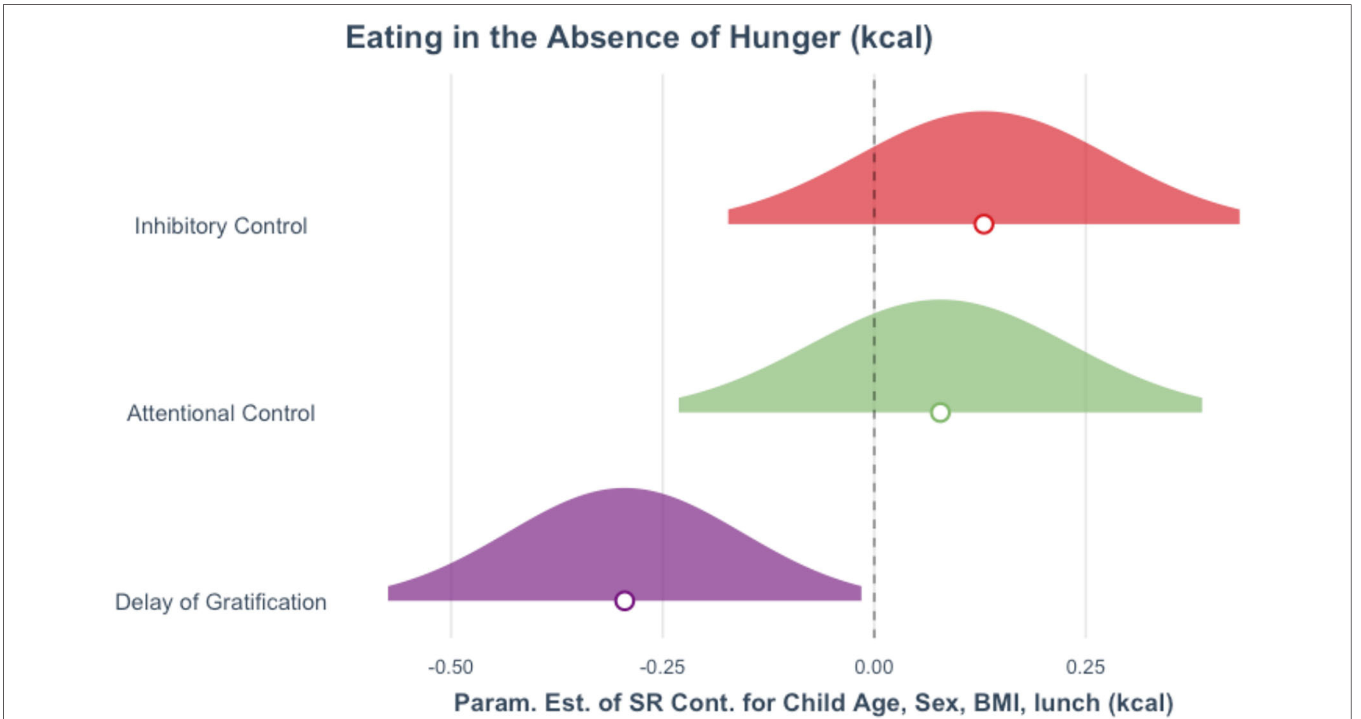

FIGURE 4 | Visualization of the effects of self-regulation on eating in the absence of hunger (EAH) by self-regulation (SR) domain, controlling for child age, child sex, child BMI, and the number of calories (kcal) consumed during the lunch test meal. Each curve represents the 95% confidence interval, circles represent the standardized parameter estimates for inhibitory control ($\beta = 0.130$), attentional control ($\beta = 0.078$), and delay of gratification ($\beta = -0.295$). One of the multiply imputed data sets was chosen at random for plotting purposes.

Exploratory Results

As shown in **Table 4**, there was a significant interaction between delay of gratification and inhibitory control at Session 1 on EAH at Session 2, $b = 42.22$, 95% CI [3.85, 80.58], SE = 19.57, $t_{(27.18)} = 2.16, p = 0.04$. Simple slopes analyses performed on one of the multiply imputed data sets revealed that the slope of the association between delay of gratification and calories consumed was significant for individuals who performed worse than −1 SD below or at the mean on inhibitory control (−1 SD: $b = -57.46$, SE = 21.62, $t = -2.66$, $p = 0.01$; mean: $b = -32.03$, SE = 12.44, $t = -2.57$, $p = 0.01$). In other words, children who were at or below the mean on both the Snack Delay and Go/NoGo Tasks consumed the most calories (**Figure 5**). All other interactions were non-significant (p-values > 0.11).

TABLE 4 | Results of the multiple regression analyses examining interactions between self-regulation domains.

Predictor	t	p	b	R^2
				0.325
Intercept	−2.198	0.037	−1796.711	
Snack Delay (z-scored)	−2.241	0.033	−32.180*	
Flanker (z-scored)	1.561	0.130	24.877	
GNG (z-scored)	−1.366	0.183	−27.139	
Child BMIz	−1.243	0.225	−18.717	
Kcal consumed at lunch‡	2.366	0.025	1663.941*	
Snack*Flanker	−1.680	0.105	−25.787	
Snack*GNG	2.157	0.040	42.217*	
Flanker*GNG	−0.811	0.425	−14.911	
Snack*Flanker*GNG	0.414	0.682	7.483	

*The dependent variable for all regressions was the total calories (kcal) consumed during the taste test. Snack, Snack Delay Task score; GNG, Go/NoGo Task composite variable; BMIz, z-scored body mass index. All parameters were calculated using pooled estimates from multiply imputed data sets. ‡Variable transformed. *p < 0.05.*

DISCUSSION

In this study, we first hypothesized that SR would inversely predict EAH ∼1 year later in a community population of preschool-aged children. In partial support of this hypothesis, we found that there was a significant negative association between Snack Delay Task score in Session 1 and total calories consumed during the taste test at Session 2. Children who were able to wait until the end of all delay periods on the Snack Delay Task consumed, on average, approximately 50 calories fewer than children who were unable to wait during any of the delay periods. There was no significant association between SR and EAH in the domains of attentional or inhibitory control (p-values > 0.33).

Our second hypothesis was that the association between SR and EAH would be strongest in the domain of appetitive SR, such that delay of gratification be a better predictor of EAH as compared to inhibitory and attentional control. In support of this

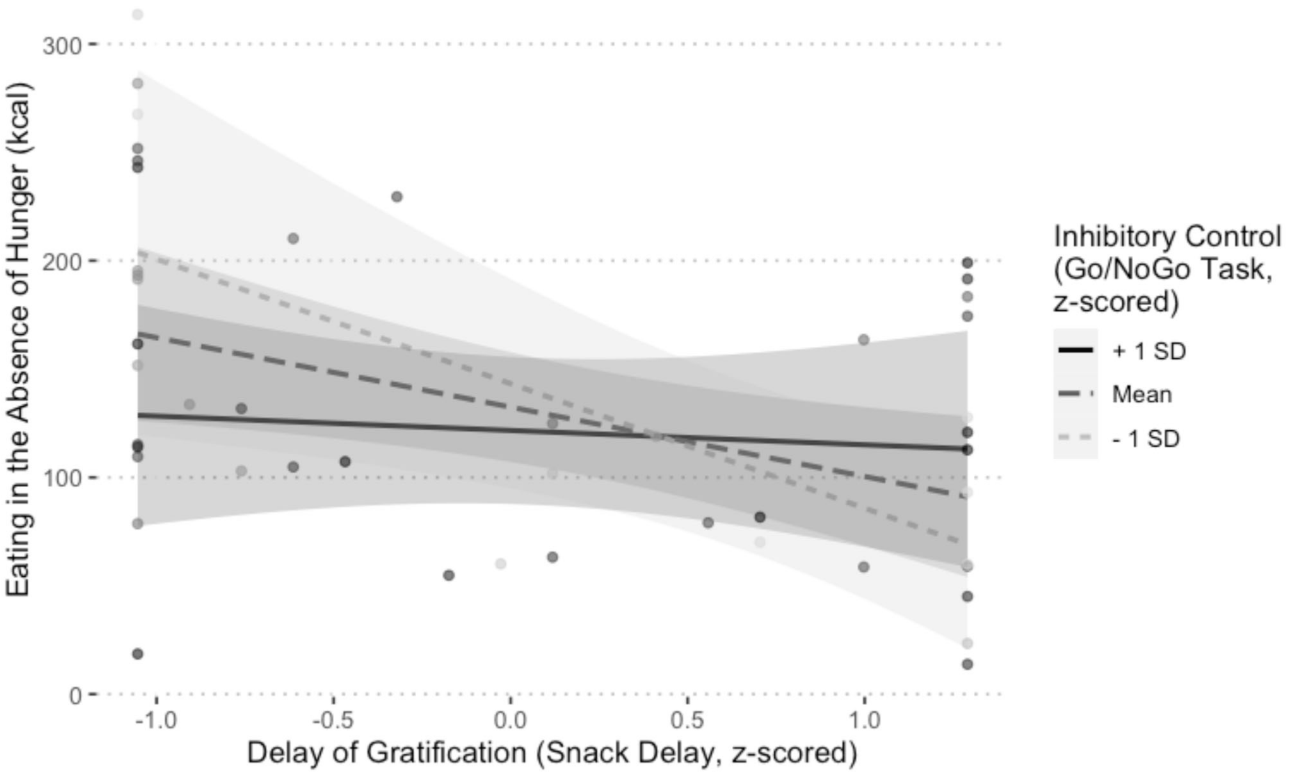

FIGURE 5 | Visualization of the interaction between inhibitory control (Go/NoGo Task) and delay of gratification (Snack Delay Task) on eating in the absence of hunger (EAH), controlling for child age, child sex, child BMI, and the number of calories (kcal) consumed during the lunch test meal, $b = 42.22$, $p = 0.04$. One of the multiply imputed data sets was chosen at random for plotting purposes.

hypothesis, we found that the only significant effect of SR on later EAH was in the domain of appetitive SR, and a direct comparison of the standardized regression coefficients revealed that the effect of delay of gratification on EAH was indeed significantly higher than the effect of inhibitory control (the comparison with attentional control was at the trend level). However, the effect of delay of gratification on EAH was not significant when controlling for attentional and inhibitory control. This is most likely due to a combination of reduce degrees of freedom with an already moderate sample size, as well as the shared variance between the three SR tasks (see **Table 2**). Therefore, while delay of gratification performance on the Snack Delay Task is a significant predictor of later EAH, we are unable to use these data to definitively conclude that it is a better predictor compared to other measures of SR.

Taken in context with the literature on SR and eating behavior, future research should examine how the link between SR and EAH changes over time. SR-related skills are some of the last neurocognitive skills to fully develop and each domain appears to grow at a different pace (Brocki and Bohlin, 2004; Casey et al., 2005; Huizinga et al., 2006). However, most of these studies do not include children as young as those in the current study. A recent review of the SR literature separating food and non-food SR in early childhood concluded that, while there are suggestions of common underpinnings of both forms of SR, each domain develops somewhat independently with increasing integration across childhood (Russell and Russell, 2020). The present findings that delay of gratification was not significantly associated with either attentional or inhibitory control in children aged 3–6 fits within this framework. As such, longitudinal studies of associations with pediatric EAH are warranted. Interventions aimed at improving eating habits should be developed in age-appropriate ways, including the relative SR domain development of the target population.

This study had some limitations. First, only 47 of the 75 families we contacted participated in Session 2. While these families did not meaningfully differ from the full set of families with regard to demographics, there may be other differences that we did not capture. Second, because these were secondary analyses, we did not run *a priori* power analyses to determine the necessary sample size to achieve appropriate statistical power to test our hypotheses. A *post hoc* sensitivity analysis in G*Power (Faul et al., 2009) revealed that the present sample size of 47 was powered ($\alpha = 0.05$, power $= 0.8$) to detect small-to-medium effect sizes ($f^2 = 0.18$). The present findings found a small effect of delay of gratification on EAH ($f^2 = 0.12$), and thus should be interpreted with caution. Third, the composition of the participants in this study was relatively homogeneous with regard to race and ethnicity; as such these results may not be generalizable to other racial/ethnic groups. These families were not recruited based on obesity risk, and were limited with regard to child BMI. We also limited our sample to biological mothers to reduce caregiving variance, which additionally reduces the generalizability of these findings. Fourth, families were told that their meals were being video recorded. While the cameras were unobtrusively placed in the room, this may have affected how much the child ate or how the mother fed the child. Fifth, while we asked families to join us during their typical lunch time, we do not have information as to what the children ate prior to the laboratory session. Lastly, as they were done in controlled laboratory settings, the test meal and taste test protocols may not fully approximate eating behavior in the real world.

The purpose of this study was to quantify the degree to which SR in preschool-aged children predicted EAH across three different domains of SR. While previous studies have documented a link between EF and eating behaviors associated with increased weight and risk of diet-related diseases (e.g., Allom and Mullan, 2014; Levitan et al., 2015; Reimann et al., 2020), this is the first time that different domains of SR have been directly compared in the same sample of preschool-aged children. We found that appetitive SR, as measured by performance on a delay of gratification task, was significantly negatively associated with EAH about 1 year later. Performance on inhibitory and attentional control tasks was not. There was also a significant interaction between appetitive SR and inhibitory control, such that children who evinced poor performance on the tasks assessing both forms of SR ate a greater number of calories during the EAH session than other children. These results support previous findings that self-regulation is meaningfully associated with eating behavior, but suggest that these effects may be strongest in the domain of appetitive self-regulation.

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 University of Oregon Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

NG and NK designed the study, edited drafts, and approved the final version. NG collected and analyzed the data and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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Strength or Nausea? Children's Reasoning About the Health Consequences of Food Consumption

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Children's reasoning on food properties and health relationships can contribute to healthier food choices. Food properties can either be positive ("gives strength") or negative ("gives nausea"). One of the main challenges in public health is to foster children's dietary variety, which contributes to a normal and healthy development. To face this challenge, it is essential to investigate how children generalize these positive and negative properties to other foods, including familiar and unfamiliar ones. In the present experiment, we hypothesized that children might rely on cues of food processing (e.g., signs of human intervention such as slicing) to convey information about item edibility. Furthermore, capitalizing on previous results showing that food rejections (i.e., food neophobia and picky eating) are a significant source of inter-individual variability to children's inferences in the food domain, we followed an individual approach. We expected that children would generalize the positive properties to familiar foods and, in contrast, that they would generalize more often the negative properties to unfamiliar foods. However, we expected that children would generalize more positive and less negative properties to unfamiliar sliced foods than to whole unfamiliar foods. Finally, we expected that children displaying higher levels of food rejections would generalize more negative properties than children displaying lower levels of food rejections. One-hundred and twenty-six children, aged 3–6 years, performed an induction task in which they had to generalize positive or negative health-related properties to familiar or unfamiliar foods, whole or sliced. We measured children's probability of generalization for positive and negative properties. The children's food rejection score was assessed on a standardized scale. Results indicated that children evaluated positively familiar foods (regardless of processing), whereas they tend to view unfamiliar food negatively. In contrast, children were at chance for processed unfamiliar foods. Furthermore, children displaying higher levels of food rejections were more likely to generalize the negative properties to all kinds of foods than children displaying lower levels of food rejections. These findings entitle us to hypothesize that knowledge-based food education programs should take into account the valence of the properties taught to children, as well as the state of processing of the food presented. Furthermore, one should take children's interindividual differences into account because they influence how the knowledge gained through these programs may be generalized.

Keywords: food familiarity, food processing, food rejection, cognition, inductive reasoning, neophobia

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INTRODUCTION

Dietary variety is needed for normal and healthy child development (Nicklaus, 2009; Nyaradi et al., 2013). However, in many Western countries, there is a lack of dietary variety due to the low consumption of fruits and vegetables (DeCosta et al., 2017). As a consequence, childhood nutrient deficiencies and obesity are becoming increasingly common (Birch and Fisher, 1998; Falciglia et al., 2000; Centers for Disease Control and Prevention, 2015; World Health Organization, 2015a,b). Nutrient deficiency is of particular concern as dietary variety may protect against long-term chronic diseases (Power and Parsons, 2000; Tucker et al., 2006; Zappalla, 2010). The rise in risk factors for diseases emphasizes the importance of understanding how children learn and reason about food and nutrition.

From a cognitive perspective, extending children's food repertoire can be seen as a generalization problem, in which children have to rely on their prior knowledge about familiar foods to extend it to other foods, either familiar or unfamiliar. Knowing that a familiar food has positive (or negative) effects on health, both children and adults can extend this information to other foods and choose foods (acceptance or rejection) accordingly. Inductive reasoning is a fundamental capacity that allows us to generalize a property from a familiar to an unfamiliar instance of a given category (see Murphy, 2002; Hayes, 2007; Gelman and Davidson, 2013, for reviews). For example, understanding that a tomato is a source of vitamins, or gives strength, could allow children to extend this property to other tomatoes (even if those tomatoes vary slightly in size, color, or shape; Murphy, 2002). Beyond other exemplars of the tomato category, children might also generalize these properties to other unfamiliar vegetables because tomato belongs to the vegetable category. To date, there is an extensive body of research demonstrating children's early abilities to reason inductively (Gelman and Markman, 1986; Welder and Graham, 2001; Gelman, 2003; Sloutsky and Fisher, 2004a,b).

The present paper's aim is to focus on children's inductive reasoning (i.e., generalization) of health-related food properties that were either positive/beneficial (e.g., "gives strength") or negative/detrimental (e.g., "results in nausea"). More precisely, the present study explored conditions under which children would generalize both types of properties from familiar foods to other familiar and unfamiliar foods belonging to the same taxonomic categories (e.g., vegetable). We focused on vegetables and fruits as it has been reported that children are less willing to try novel instances of these categories compared to other kinds of foods (Dovey et al., 2008). We also contrasted two types of food presentations, raw (whole) vs. processed (sliced) to test the idea that food transformation might act as a cue for food quality/safety in children (Foroni et al., 2013; Coricelli et al., 2019; Lafraire et al., 2020). Indeed, evidence suggests that children are sensitive to unfamiliar perceptual features to generalize food edibility (Rioux et al., 2018a). Therefore, for unfamiliar foods their processing states might convey the information that they have been prepared to be eaten and, thus, are edible. Therefore, the types of food presentations could influence the way children reason about foods and their properties. We also addressed these questions from an individual difference perspective by exploring the possible role of food rejection dispositions in children's induction within the domain of food categories. Indeed, recent studies have reported a relationship between inductive reasoning and the intensity of food neophobia and pickiness in preschoolers (Rioux et al., 2018a,b).

Generalization inferences with meaningful properties critically depend on determining which known characteristics of the categories are causally related to or predictive of the property to be generalized (Heit and Rubinstein, 1994; Hayes and Lim, 2013; Bright and Feeney, 2014; Hayes and Heit, 2018). For instance, children use taxonomic food categories to make inferences about biological properties (i.e., generalizing biological properties to other foods in the same taxonomic category) but use script food categories to make inferences about contexts or situations (such as milk and cereals as breakfast foods) in which foods are usually eaten (Nguyen, 2012; Thibaut et al., 2016). Children can also attend to external information (a category based on a value-laden assessment such as "healthy" or "unhealthy") to make inferences about the effects of eating (Nguyen, 2008). Therefore, children can selectively and productively cross-generalize the properties of familiar foods based on the appropriate knowledge required. In the case of foods children are unfamiliar with, recent evidence reveals that children attend to the perceptual features of these foods to guide their inductions (Rioux et al., 2018b; Lafraire et al., 2020). In the present study, familiar and unfamiliar foods have been compared to isolate the characteristics perceived as central by children when they have to generalize positive or negative food properties. Among these characteristics, we hypothesized that the perceived level of food processing could guide children's inductions of positive and negative properties to unfamiliar food stimuli.

Food processing is a unique and universal behavior aiming at increasing food eatability and edibility (Carmody et al., 2011; Wrangham, 2013; Zink and Lieberman, 2016). Adults interpret food processing features as edibility cues. For example, Foroni et al. (2013) showed that participants rated non-processed foods as less immediately edible than processed foods, which were perceived as ready to be consumed. Processed foods were also categorized as food quicker than non-processed foods (Coricelli et al., 2019). Thus, adults seem to use transformation features as edibility cues. Children also understand that processed foods are the outcome of a purposeful transformation (Girgis and Nguyen, 2020). This distinction between unprocessed and processed foods also influences children's inductive strategies. For instance, Lafraire et al. (2020) showed that children did not generalize properties in the same way to processed and raw unfamiliar foods. The authors contrasted three states of food processing: whole, sliced, and pureed. They observed that children's generalization patterns were different when the foods were raw (whole) as compared to processed. They suggested that children might interpret food processing as a social cue to edibility. Indeed, starting during the weaning period, solid food pieces are gradually introduced from fine pureed to sliced child-size bites to ensure minimal risk for ingestion. Despite the fact that slicing is a simple type of food processing (compared to the culinary transformation manipulated by Foroni et al., 2013; Coricelli et al., 2019), children nevertheless favor raw sliced fruits and vegetables over raw unprocessed alternatives (Swanson, et al., 2009; Olsen, et al., 2012; Baker et al., 2015). Furthermore, cutting and slicing are often the starting point of more elaborated food preparation processes. However, whether or not children would use slicing as a cue associated with food safety remains an entirely open issue.

Former studies revealed adults' tendency to sort foods and food properties as positive or negative for health (Rozin et al., 1996). Recent research has shown that children as young as 3 years of age already understand this distinction (Nguyen and Murphy, 2003; Nguyen, 2007) and use it productively to make inferences about the human body (Nguyen, 2008). They can accurately distinguish between healthy and unhealthy foods, and provide explanations as to why a specific food has positive (e.g., "makes you strong") or negative properties (e.g., "you get sick"; Nguyen, 2007). When reasoning on health consequences of food consumption, children can disregard other categorical relationships in favor of an evaluative criterion. For instance, in a related issue, Nguyen (2008) showed that by the age of 4, children can disregard taxonomic relationships in favor of evaluative categories (i.e., healthy and unhealthy). In Nguyen (2008), children were told that a healthy food (such as milk) "makes a body 'daxy.'" Then, children were asked which of two alternative foods, one healthy (e.g., apple) and one unhealthy (e.g., potato chip), would also make a body "daxy." Results revealed that children were able to extend the property taught for a healthy food to another healthy food (i.e., from milk to apple), even when it belonged to another taxonomic/script category (e.g., healthy foods may include particular fruits, beverages, and so on). Actually, with evaluative primes (e.g., line drawing of a smiling face), children systematically disregard stronger taxonomical relationships (e.g., between two foods) in favor of a non-taxonomically-related evaluative choice (e.g., an animal; Nguyen, 2020). Furthermore, when the evaluative criterion is made central with a positive or a negative prime, children spontaneously sort foods with positive properties from foods with negative properties (DeJesus et al., 2020). However, to the best of our knowledge, no study has investigated how children generalize health-related properties from a familiar food to other foods (both familiar and unfamiliar foods).

For familiar foods, adults and children can rely on their background knowledge (Aldridge et al., 2009). For instance, 3-to-4-year-old children tend to associate familiar fruits and vegetables such as apples or spinach with positive bodily effects (Nguyen, 2007; Thibaut et al., 2020). On the contrary, children are uncomfortable eating food when they cannot anticipate the consequences of their ingestion (Pliner and Hobden, 1992) since unfamiliar substances might be toxic. According to Rozin (1979), food neophobia is an adaptive strategy for children to avoid the risk of ingesting new (and potentially poisonous) items. More precisely, food neophobia is defined as the reluctance to eat, or the fear of, new foods (Pliner and Hobden, 1992). It is now well-established that a proportion of 3-year-old children and beyond exhibit food neophobia and pickiness (i.e., the two main dimensions of food rejection dispositions, see Dovey et al., 2008; Lafraire et al., 2016, for reviews). Interestingly, the intensity of food rejections represents a significant source of inter-individual variability with respect to children's inferences in the food domain (Rioux et al., 2018a,b). Rioux et al. (2017) have demonstrated that children with high rejection scores on a relevant scale, tended to have poorer categorization and induction performances compared to children with lower scores on the same scale. For example, Rioux et al. (2018b) showed, in a property induction task, that children with higher food rejection scores rely on superficial color-similarity to drive their inductive strategies, whereas children with lower food rejections scores rely on category membership. However, to date, no studies have investigated the influence of food rejections on the generalization of health-related food properties. Potential differences between high and low rejection children regarding health issues as a function of familiarity is an important issue, since food rejection is associated with low consumption of fruit and vegetables (Dovey et al., 2008) and with a less diverse diet (Birch and Fisher, 1998; Falciglia et al., 2000). Therefore, investigating neophobic and picky children's reasoning on food properties for inferences about the negative health-related effects of eating is of both theoretical and practical importance. Indeed, if these children are more sensitive to food's risks, they might generalize this information to more foods than their neophobic, or less fussy, counterparts.

In this paper, we assessed children's reasoning on the positive-negative distinction and its interaction with individual differences in food rejections. Most of the previous studies focused on children's inductive reasoning on foods with familiar or unfamiliar foods and did not directly compare them. In addition, they did not manipulate food processing states (whole, sliced, or cooked), which has been shown to influence edibility judgments and food preferences, at least in adults. Here, we will compare food familiarity and food processing states and their interaction with food rejection tendencies. More precisely, we asked children to generalize a positive or negative property associated with a training familiar fruit or vegetable, to other foods from the same taxonomic category as the training, familiar or unfamiliar, and whole or sliced.

H1. We expect that children would generalize more positive than negative properties to familiar foods compared to unfamiliar foods. The reason is that other familiar healthy foods are known to be safe. A related hypothesis is that children should generalize less positive properties and more negative properties to unfamiliar foods because they are more cautious about unfamiliar foods.
H2. If food processing acts as a cue for food safety/quality, children will generalize more positive than negative properties to sliced than to whole unfamiliar foods.
H3. Food neophobia is defined as the fear of novel foods. We thus expect that neophobic children will generalize more negative properties to unfamiliar foods compared to their neophilic counterparts.

MATERIALS AND METHODS

Participants

Participants were 126 children (60 girls and 66 boys; age range = 3.44–6.42 years; mean age = 5.30 years; *SD* = 0.714). They were preschoolers from eastern France predominantly Caucasian and came from middle-class urban areas. Informed consent was obtained from their school and their parents. The procedure was in accordance with the Declaration of Helsinki and followed institutional ethics board guidelines for research on humans. This study was reviewed and approved by an official agreement between the Academia Inspection of the French National Education Ministry and the University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Materials

In order to assess each child's food rejection dispositions, caregivers filled out the Child Food Rejection Scale (CFRS; Rioux et al., 2017). The CFRS was developed to assess, by hetero-evaluation, 2-to-7-year-old children's food rejection on two subscales: one is measuring children's food neophobia (six items) and one is measuring their pickiness (five items). On a 5-point Likert-like (*Strongly disagree*, *Disagree*, *Neither agree nor disagree*, *Agree*, and *Strongly agree*), caregivers were asked to rate to what extent they agree with statements regarding their child's neophobia (e.g., "*My child rejects a novel food before even tasting it*") and pickiness ("*My child rejects certain foods after tasting them*"). Each answer was then numerically coded with high scores indicating higher food neophobia and pickiness (scores could range from 6 to 30 for neophobia, mean = 16.2, *SD* = 4.89; from 5 to 25 for pickiness, mean = 16.6, *SD* = 3.84; and global food rejections from 11 to 55, mean = 32.8, *SD* = 7.70).

We constructed four biological properties that a food was said to have for a fictional character called "Feppy." The properties were chosen so that they could be understood by young children (see Thibaut et al., 2016 for other examples). There were two positive and two negative properties. Pictures depicting "Feppy" going through the four properties related changes caused by food ingestion were generated (see **Figure 1**). We provided these pictures to help children interpreting the properties. Since food neophobia is mainly targeting vegetables and fruits (Dovey et al., 2008), we chose the stimuli in these categories. We constructed four sets of stimuli (*n* = 36), two sets made up of vegetables (*n* = 18, 2 training pictures + 16 test pictures), and the two sets made up of fruits (*n* = 18, 2 training pictures + 16 test pictures). Each set was composed of a familiar training and eight test food items, that is, four familiar and four unfamiliar stimuli. Moreover, in order to avoid that children would generalize on the basis of taxonomic categories (i.e., fruits or vegetables) when reasoning about the properties, each experimental set was homogeneous (e.g., only fruits or only vegetables).

We selected slicing, with sharp edges to not look accidental (like crushing), because slicing is a common food transformation and also, in the case of familiar foods, does not make the food unrecognizable. Transformations such as crushing or puree most often result in something which is no longer recognizable. Trainings and tests were evenly divided into whole and sliced.

For familiar stimuli, we first selected 48 common foods that are often served in school canteens, from a variety of internet sites and picture databases (e.g., FoodCast database; Foroni et al., 2013). Since food processing of a familiar food item might impact its recognizability and familiarity which, in turn, may impact induction, all familiar foods were controlled for recognition prior to the study by 12 3-to-7-year-old children using a picture identification task. None of these children participated in the actual study. Stimuli pictures that were not successfully named by at least 70% of the children were removed from the final set.

Secondly, to generate the unfamiliar subset of pictures, 95 adults rated 25 *a priori* unfamiliar foods on a 7-point Likert-like scale (ranging from *Not familiar at all* to *Very familiar*). Following common practice (Rioux et al., 2018a,b,c; Lafraire et al., 2020), we assumed that children would not know foods that would be unknown to most adults. Pictures for which the rating was beyond 2.5 (out of 7) were removed.

To avoid any similarity confound in a food pair between trainings (e.g., sliced orange) and tests (e.g., a whole banana, whole Buddha fingers, a sliced star fruit, or a sliced strawberry), in each set, we selected training items that were dissimilar to the tests of their set in shape, type of slicing (e.g., chopped in cubes, quarters, or slices), and color (see **Figure 2** for a set of stimuli used in the property generalization task). An online test was conducted to control for global perceptual similarity. Eighty adults were instructed to assess the similarity between trainings and tests on a 7-point Likert-like scale (ranging from *Not similar at all* to *Extremely similar*). Participants were presented with 32 food pairs, eight Whole-Whole pairs, eight Whole-Sliced pairs, eight Sliced-Whole pairs, and eight Sliced-Sliced pairs. The presentation order of the pairs was fully randomized across participants. **Table 1** provides the perceptual similarity ratings. They were significantly below 4 (out of 7, i.e., neither similar nor dissimilar) for each food pair type. This control was important to avoid as much as possible any color or shape similarities between training and test pictures of a set because these similarities have an impact on children's performances of food category-based induction tasks (Rioux et al., 2018a,b).

TABLE 1 | Similarity rating for each food pair type.

Food pair type	Mean	*SD*
Whole-Whole	2.56***	1.05
Whole-Sliced	2.26***	1.04
Sliced-Whole	2.24***	1.00
Sliced-Sliced	3.21***	1.13

Wilcoxon tests compared food pair type similarity ratings against 4. ***$p < 0.001$.

Design

Children participated in a within-subject design where health-property Valence (Positive and Negative), Training State (Whole familiar and Sliced familiar), and Test (Whole familiar, Sliced familiar, Whole unfamiliar, and Sliced unfamiliar) were crossed (see **Table 2**).

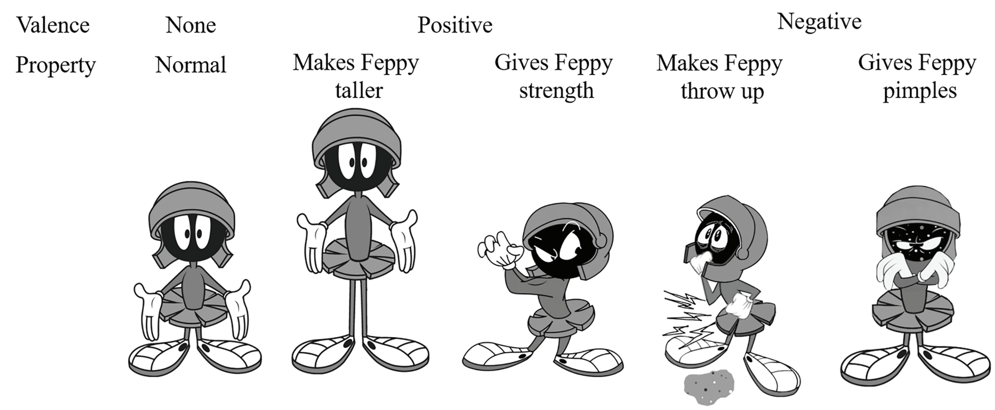

FIGURE 1 | Pictures of Feppy used in the property generalization task.

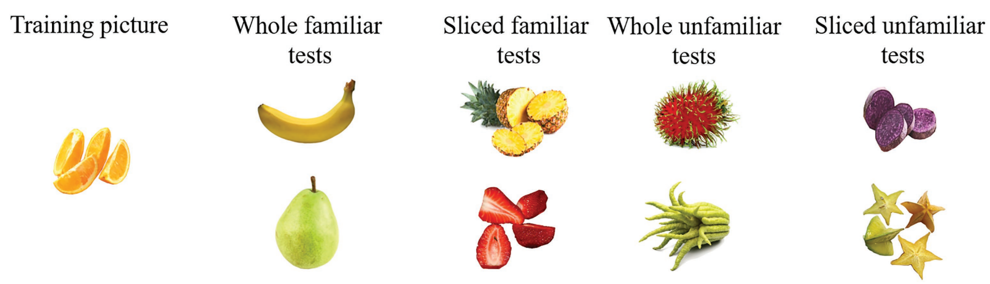

FIGURE 2 | Example of a set of fruit stimuli used in the property generalization task.

Procedure

Children were tested individually in a quiet room at their school. The experiment consisted of two parts run successively and in a constant order for all the children.

Induction Task

Children sat at a table with two mailboxes. The experimenter told the children that they would play a game and, then, showed two images of Feppy, each on top of one of the mailboxes. One image displayed Feppy in a neutral condition (i.e., neither in a positive or negative condition). The other image of Feppy illustrated the targeted verbal property (e.g., "Feppy is throwing up," see **Figure 1**). For each set (e.g., Set #3; **Table 2**), children learned that a stimulus (e.g., a sliced orange), displayed on the training picture, and had an effect on Feppy after he ate it (e.g., "Makes Feppy throw up"). Then, they were asked whether the eight test pictures would also have the same effect on Feppy if he ingested them. Opaque mailboxes were used to prevent children from comparing each test item with the others, which might influence their answer (see Thibaut and Witt, 2015, for a discussion of conceptual comparison strategies). In contrast, the training items were kept in view during the entire experiment (see **Figure 3**). For each set, the instructions were as follows (translated from French): "This is Feppy (pointing to Feppy in a neutral condition). Doctors who observed Feppy discovered how his body could be affected by what he eats. The doctors told me that this food (showing a training picture without naming it) makes Feppy throw up (example when the property was negative). Do you see Feppy? He looks like he just

TABLE 2 | Experimental design.

Set #	Property Valence	Training State	Test
1	Positive (e.g., "Makes Feppy taller")	Whole familiar (e.g., lettuce)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)
2	Positive (e.g., "Gives Feppy strength")	Sliced familiar (e.g., orange)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)
3	Negative (e.g., "Makes Feppy throw up")	Whole familiar (e.g., lemon)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)
4	Negative (e.g., "Gives Feppy pimples")	Sliced familiar (e.g., broccoli)	Whole familiar (x2) Sliced familiar (x2) Whole unfamiliar (x2) Sliced unfamiliar (x2)

36 stimuli, 2 sets of 9 fruits (1 training picture and 8 test pictures) and 2 sets of 9 vegetables (1 training pictures and 8 test pictures).

FIGURE 3 | Apparatus of the property generalization task.

threw up and has a tummy ache, you see?" We then place the training picture in front of the mailbox that contains foods that make Feppy throw up. "Now, I will show you more pictures (without naming the pictures) and I want you to tell me if we should put it in the mailbox of foods that make Feppy throw up. If not, you will have to put it in the other mailbox. Do you think this (pointing to the first test picture without naming it) goes in the mailbox of foods that make Feppy throw up or in the other mailbox?" The same question was then asked for the next seven test pictures, shown successively. Each child carried out this sorting task for all food sets, one after the other, without any feedback. For each set, the experimenter changed the picture of Feppy to illustrate another property (e.g., the "makes Feppy throw up" picture was replaced by the "gives Feppy strength" picture). Then, the experimenter asked the child: "Do you see Feppy now? He looks really strong, he is showing his muscles, you see?" The order in which both sets and within each set the test pictures were presented was pseudo-randomized and counterbalanced across children.

Identification Task

Following the induction task, children were asked to name the 16 familiar test pictures they encountered during the experimental task. For each item, a score of 1 was given for the correct name and 0 for an error (i.e., not being able to give the name or incorrect name). We then assigned for each child a global percentage of identification (mean = 86.9%, *SD* = 15.0), a percentage of identification of whole tests (mean = 88.2%, *SD* = 20.3) and a percentage of identification of sliced tests (mean = 85.6%, *SD* = 20.2).

RESULTS

Induction Task

For each trial, a score of 1 was given when children generalized the property to the test and placed it into the corresponding mailbox, and a score of 0 was given when the child did not generalize the property to the test. We tested our predictions with a generalized linear mixed-effects model (Baayen et al., 2008), using a *Binomial* distribution, to analyze the probability of generalizing the property, using the lme4 package, function glmer, in the R environment (Bates et al., 2015). As shown in **Table 3**, the models were constructed by iteratively adding predictive variables to the null model (M0, the intercept and no predictor). Based on the procedure of decreasing the Akaike Information Criterion (AIC; Hu, 2007), we constructed the model that was the best fit to the data with the probability of generalization as the outcome measure. Our best fit model (M8) contained random effects (participants), and within-subjects fixed-effects: Test (Whole familiar, Sliced familiar, Whole unfamiliar, and Sliced unfamiliar), Valence (Positive and Negative), Neophobia (continuous factor), and the two-way interactions, Test × Valence and Neophobia × Valence. This model explained 14.3% of the variation across our sample, as demonstrated by the adjusted R^2. We report the ANOVA output results for the models throughout. **Table 4** shows the descriptive statistics for the probability of generalizing the positive and negative properties to the tests. We also conducted Wilcoxon tests to determine whether the probability to generalize the properties to the different tests was significantly different from chance (0.5).

TABLE 3 | The goodness of fit of the generalized linear mixed models.

	Model	*Df*	AIC	Pseudo R^2	*p*
M0	1		2788.8	0	
M1	… + Test	3	2782.7	0.007	0.008
M2	… + Test + Valence	4	2779.5	0.010	0.024
M3	… + Test + Valence + Premise state	5	2781.5	0.010	0.920
M4	… + Test + Valence + Neophobia	5	2777.5	0.013	0.045
M5	… + Test + Valence + Neophobia + Pickiness	6	2779.3	0.013	0.676
M6	… + Test * Valence + Neophobia	8	2562.8	0.140	<0.001
M8	… + Test * Valence + Neophobia * Valence	9	2560.7	0.143	0.043
M9	… + Test * Valence * Neophobia	15	2566.6	0.145	0.415

M8 was the best model given the data because it had the lower AIC.

First, the results revealed a significant effect of Test [χ^2 (3) = 9.50, $p = 0.023$, $\Delta R^2 = 0.007$].[1] *Post-hoc* Tukey comparisons revealed that children generalized the properties to the Sliced unfamiliar tests (*M* = 0.482, *SD* = 0.280) significantly less often than they did to Whole familiar (mean = 0.577, *SD* = 0.277, $p = 0.013$) and Sliced familiar tests (mean = 0.563, *SD* = 0.297, $p = 0.05$). There was also an effect of Valence [χ^2 (1) = 5.11, $p = 0.024$, $\Delta R^2 = 0.003$]. Children generalized the positive properties (mean = 0.564, *SD* = 0.162) significantly more often than they did for the negative properties (mean = 0.510, *SD* = 0.151). As shown in **Figure 4**, there was a significant interaction effect between Test and Valence [χ^2 (3) = 198.03, $p < 0.001$, $\Delta R^2 = 0.127$]. A Tukey a *posteriori* test revealed

[1]Delta R^2 are reported in lieu of η^2 for the mixed models in this paper, since no satisfactory method is currently available to estimate effect sizes on mixed models (Westfall et al., 2014).

that children generalized significantly more the positive properties to familiar tests than they did for negative properties (all $p < 0.001$). A reverse pattern was found for Whole unfamiliar tests, children generalizing significantly less often the positive properties (mean = 0.318, SD = 0.369) than they did for the negative properties (mean = 0.737, SD = 0.329, $p < 0.001$). Interestingly, children generalized significantly more the positive properties (mean = 0.480, SD = 0.364) and less the negative properties (mean = 0.482, SD = 0.341) to Sliced unfamiliar tests than they did to Whole unfamiliar tests (all $p < 0.01$).

Second, a significant effect of Neophobia was found [χ^2 (1) = 4.02, p = 0.045, ΔR^2 = 0.003]. Food neophobia scores and the probability to generalize the properties were significantly positively correlated (as attested by Spearman's correlation coefficient, r = 0.195, p = 0.029). As shown in **Figure 5**, there was a significant interaction effect between Neophobia and Valence [χ^2 (1) = 4.09, p = 0.043, ΔR^2 = 0.003]. Food neophobia scores were positively correlated with the probability to generalize the negative properties (r = 0.282, p = 0.005, see the red line in **Figure 5**).

TABLE 4 | Mean probability to generalize positive and negative properties (SD in brackets).

Test	Positive	Negative
Whole familiar	0.750 (0.271)**	0.411 (0.366)*
Sliced familiar	0.710 (0.325)**	0.409 (0.339)**
Whole unfamiliar	0.318 (0.369)**	0.737 (0.329)**
Sliced unfamiliar	0.480 (0.364)	0.482 (0.341)

Wilcoxon tests compared children's probability to generalize the properties against chance (0.5).
$^*p < 0.025$; $^{**}p < 0.001$.

Identification

Children' global percentage of identification was significantly above the arbitrarily fixed 70% accuracy threshold that served to select the familiar stimuli (as attested by a Wilcoxon test, mean = 86.9%, SD = 15.0; W = 2,188, $p < 0.001$, d = 0.97). The same pattern was found for whole (mean = 88.2%, SD = 20.3; W = 2,198, $p < 0.001$, d = 0.92) and sliced familiar foods (mean = 85.6%, SD = 20.2; W = 2,158, $p < 0.001$, d = 0.78). Paired-samples t-test did not reveal any difference in identification performances between food processing states (W = 220, p = 0.236).

Finally, children's percentage of identification was only significantly positively correlated with their Age (r = 0.320, $p < 0.001$). Since no effect of Food Rejections was found in the identification task, these results suggest that the previous

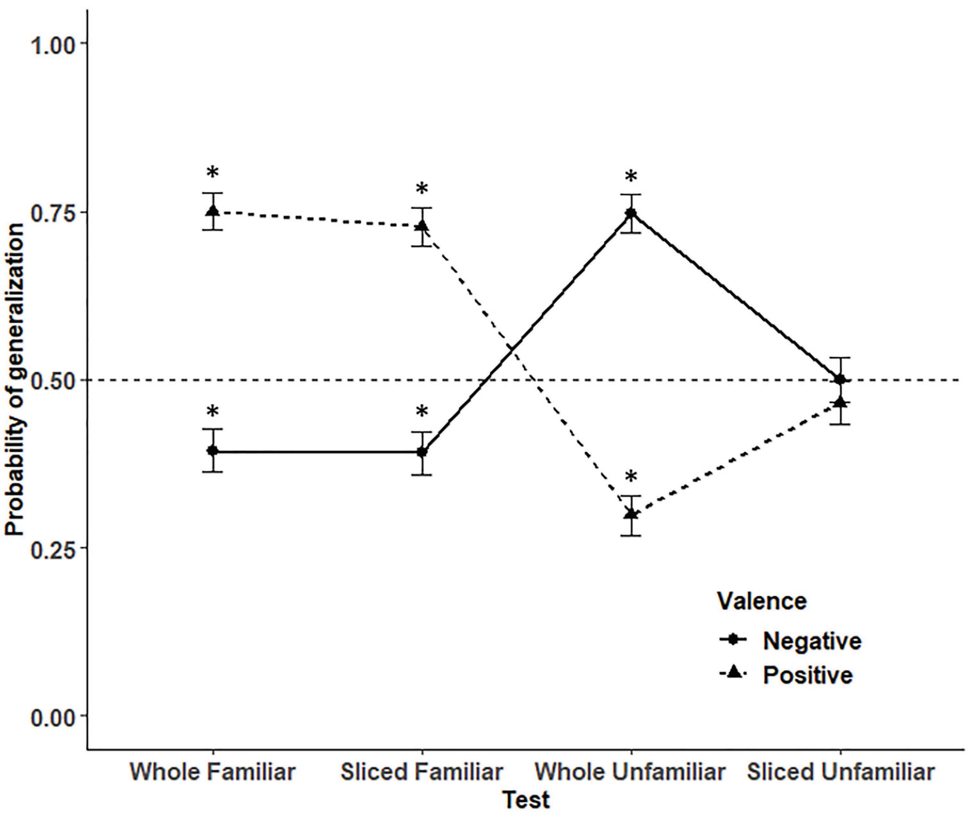

FIGURE 4 | The probability to generalize the properties as a function of Test and Valence. Stars represent significant differences against 0.5. Vertical bars represent MSEs.

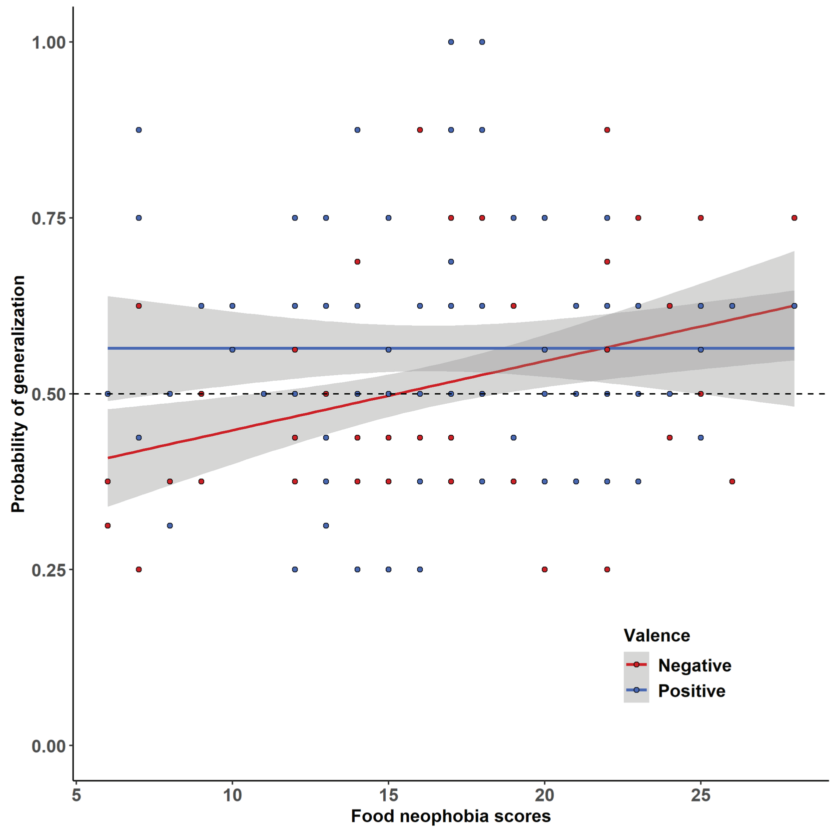

FIGURE 5 | The probability of properties generalization as a function of Food Neophobia scores [as attested by the Child Food Rejection Scale (CFRS)] and Valence.

result found in inductive reasoning did not arise from differences in children's ability to recognize the foods given.

DISCUSSION

This paper studied children's generalization of positive and negative food properties, as a function of their food rejection dispositions. We contrasted familiar and unfamiliar foods and their processing states, whole and sliced. To the best of our knowledge, this experiment is the first to manipulate food familiarity and processing states, and to assess their interaction with food rejection tendencies. Our data revealed clear dissociations between the generalization patterns for positive and negative properties as a function of food familiarity.

Our results confirmed former findings showing that children reason on a positive-negative distinction in that they associate familiar foods with positive properties (i.e., above chance) and not with negative properties (i.e., below chance; H1). These results expand previous findings of Nguyen et al.' studies (Nguyen and Murphy, 2003; Nguyen, 2007, 2008; Thibaut et al., 2016) as our training items were also fruits and vegetables known to be healthy, which were associated with a negative property. This result not only highlights that children effectively use their previous knowledge of foods, but also that they are capable to adapt to new contrasting information (i.e., a supposed healthy food having negative properties).

Unfamiliar foods revealed a contrasting pattern of results. Children were cautious in the case of unfamiliar test stimuli. Indeed, for whole unfamiliar foods, they generalized positive properties under chance but generalized negative properties above chance. Without any knowledge (positive or negative) of these foods, children seem to have conjectured that whole unfamiliar foods might be threatening. Yet, regarding the sliced unfamiliar tests, children generalized more positive and less negative properties to these foods than they did to the whole unfamiliar tests. Thus, children used food processing as a relevant dimension when reasoning about unfamiliar foods (Lafraire et al., 2020). Here, even as subtle transformations not affecting food's organoleptic properties directly (Foroni et al., 2013; Coricelli et al., 2019), food processing might have decreased children's apprehension regarding unfamiliar foods. Children showed that they were sensitive to the state of the food as regard to its edibility (Foroni et al., 2013; Coricelli et al., 2019; H2). Nonetheless, children's pattern of generalization for both positive and negative properties was at chance level for sliced unfamiliar test foods. Therefore, we cannot firmly conclude that the food processing state totally removed children's cautiousness regarding unfamiliar foods. Using advanced culinary food transformations might help to disambiguate the perceived edibility of unfamiliar foods as a function of the degree of food processing.

In addition, our study adds important information to previous studies such as the one by Rioux et al. (2018a), which showed that neophobic children face generalization problems. Indeed, as hypothesized neophobic children generalized the negative properties more often than their less neophobic counterparts (H3), whereas we did not find any effect of food neophobia on positive property generalization. Interestingly, contrary to our expectations, this generalization of the negative properties was not specific to the unfamiliar tests. This suggests that when facing threatening risks, neophobic children face a generalization problem and can extend negative experiences to other foods, even familiar ones. This interpretation is in line with Crane et al.'s (2020) recent claim that neophobic individuals are cautious decision-makers who favor safe decisions (i.e., generalizing the negative properties more broadly) to prevent more costly errors (i.e., not generalizing the negative properties to potentially harmful substances). Finally, similarly to Rioux et al. (2018a), we did not find any significant effect of food pickiness. Considering that a high score on the neophobia subscale (Rioux et al., 2017) means that parents *Strongly agreed* that their child shows cautiousness or even distress toward foods, it is not surprising that these children strongly generalized negative properties. However, only the notions of liking and acceptance are considered in the pickiness subscale, which, contrary to neophobia, are not directly related to the perceived risk of foods.

CONCLUSION

In conclusion, our results provide evidence in favor of our hypotheses and have potential implications for knowledge-based food education interventions. Indeed, it appears that children have conceptions about the health consequences of familiar foods. They are also very cautious when dealing with unfamiliar whole foods. Whereas children do not extend the positive properties to the unfamiliar foods, they would for the negative properties. Furthermore, it appears that children are also sensitive to the processing state of foods. While being categorical for whole unfamiliar foods, with sliced unfamiliar foods children did not know whether or not they should generalize the positive and negative properties. Finally, our results contribute to the growing evidence associating food rejection dispositions with food domain generalization problems. Here, neophobic children generalized more the negative properties than their less neophobic counterparts. This finding suggests that there is a need to be aware of children's interindividual differences when providing information on food effects.

Nonetheless, our study had several limitations. First, our sets were generated on a single taxonomic category (e.g., fruits), including the unfamiliar foods. It would be of interest to investigate children's generalization of health-related properties with other food categories that are less prone to rejections (such as starchy foods). Second, one limitation of the present study is the fairly low number of properties illustrating the positive and negative conditions. Increasing the number of properties to generalize is important if we want to better understand whether children's reasoning of positive and negative properties is general or specific to the kind of food health-related properties provided. Another limit is the low number of trials per each experimental condition. Indeed, we had to comply with the limited repertoire of foods children are familiar with, while reducing the perceptual similarities between trainings and tests as much as possible. Third, we did not control for children's liking of the presented foods. Some children may have generalized the negative properties on the basis of aversive memories related to previous experiences with familiar foods. Finally, the design was complex which might affect the interaction between variables.

Despite these limitations, we believe that the present experiment opens up promising new research avenues, and sheds light on the relationships between children's food reasoning and food rejections. Future research might then assess the potential developmental effect to determine when and to what extent children might be sensitive to food processing as an edibility cue. In the present experiment, foods were either whole or cue, with minimal human transformations. However, a strategy worth investigating would be to manipulate the degree of food processing in a broader sense, including cooking for instance. Another promising line of research would be to explore the effect of stressing the intention of the chef who prepares food, or why preparing food is an important process. Indeed recent studies revealed that children who took part in culinary activities showed increases in their food acceptance (Chu et al., 2014; Allirot et al., 2016; DeJesus et al., 2019). By exposing children to food transformation processes of a raw product by interaction with a chef or parents, children's food risk perception may decrease which could lead to increased acceptance of the given food.

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 official agreement between the Academia Inspection of the French National Education Ministry and the University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

DF, JL, and J-PT conceived the hypotheses and the design of the study. DF collected the data and performed the statistical analyses. All the authors contributed to the manuscript writing, read and approved the submitted version.

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The Prevalence of Hyperpalatable Baby Foods and Exposure During Infancy: A Preliminary Investigation

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Objective: To characterize the prevalence of hyperpalatable foods (HPF) among baby foods in the U.S. and examine the prevalence of HPF exposure and consumption from both baby food and adult food sources among infants aged 9–15 months.

Methods: A U.S. baby food database as well as baby foods from three 24-h dietary recalls of 147 infants were used to identify baby foods as HPF per previous publication. HPF exposure was defined as intake of any HPF during the 3-day measurement period. To determine the extent of HFP consumption, % kilocalorie (kcal) intake from HPF was characterized.

Results: Only 12% of baby foods were HPF; however, nearly all participants (>90%) consumed HPF, primarily through exposure to adult foods. Younger infants (<12 months) consumed 38% [standard deviation (SD) = 23.6%] of their daily food kcal from HPF and older infants (≥12 months) consumed 52% (SD = 16.4%) of daily food kilocalorie from HPF. Most younger infants (68%) and older infants (88%) had repeated exposure to the same HPF across the measurement period.

Conclusions: The prevalence of HPF among baby foods in the U.S. is low. However, almost all infants were exposed to HPF, and HPF comprised a substantial percentage of daily food kilocalorie in infants' diets. Findings highlight the transition to solid food consumption during complimentary feeding period is a critical time for early HPF exposure.

Keywords: baby food, hyperpalatable, obesity, reward pathway, ingestive behaviors, infant dietary intakes

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INTRODUCTION

Infancy is a sensitive developmental period and the most formative time for developing eating habits and food preferences that support growth needs. To this end, several investigations have shown that during the first year of life, food preferences are learned through repeated exposure to new foods (Schwartz et al., 2011; Nicklaus and Remy, 2013; Birch and Doub, 2014; Nicklaus, 2016). In a classic study by Sullivan and Birch, for example, feeding peas or green beans to 4-to-6-month-olds on 10 occasions, over approximately one month, led to significant increases in consumption of the vegetable over time (Sullivan and Birch, 1994). Relatedly, Maier et al. found that repeated exposure to a disliked vegetable (8 times in 16 days) early in the complementary feeding period resulted in intakes that were four-fold greater than the amounts the infants initially consumed (Maier et al., 2007). Thus, early exposure to healthy foods during the early feeding period may strongly influence infant feeding behavior.

In contrast to the evidence regarding healthy food exposure in infancy, early and repeated exposure to unhealthy foods among infants has not been well documented. Early exposure may adversely affect the establishment of food preferences and dietary intake patterns, which may have downstream consequences for obesity risk. For example, in the Melbourne Infant Feeding Activity and Nutrition Trial (InFANT) Program, consumption of nutrient-poor (sweetened beverages and cereals, sweet, and salty snacks) items at 9 months was strongly correlated with consumption of the same foods at 18 months (Lioret et al., 2013). Infants are highly sensitive to their nutritional environments; thus, early and repeated exposure to certain foods may dysregulate food reinforcement mechanisms and ingestive processes (Epstein et al., 2007). For example, hyperpalatable foods (HPF) contain combinations of palatability-inducing ingredients that can activate brain reward neurocircuitry and bypass physiological satiety mechanisms, leading to overeating despite feeling satiated (Fazzino et al., 2019). Early and repeated exposure to HPF during infancy may result in excessive activation of brain reward circuitry and reduced engagement of satiety mechanisms (Olszewski et al., 2019). With time, exposure to HPF may adversely affect the establishment of food preferences and drive infants to consume HPF, thereby heightening the risk of later obesity (Poti et al., 2017).

The availability of HPF among baby foods is unknown; thus, characterization of the prevalence of HPF among baby foods available in the U.S. food system is needed to understand the potential risk of exposure to HPF during infancy. Furthermore, no study has examined the degree to which infants in the U.S. may consume HPF during the complementary feeding period, a critical window in which food preferences may be most strongly established (Skinner et al., 2002). Specifically, while newborns start with a milk-based diet, they transition to complementary foods at ∼6 months of age (this is accompanied by their discovery of foods with a variety of different smells, tastes, and textures), and finally to primarily table foods by the end of the second year of life. Exposure to HPF at any point within the first 2 years, but particularly during the early complementary feeding phases, may skew the development of food preferences and eating behaviors toward HPF. Therefore, limiting or avoiding exposure to HPF during infancy is likely ideal.

The objectives of our study were to: (1) examine the prevalence of HPF among baby foods available in the U.S. using the Nutrition Data System for Research, a database that is representative of the U.S. food system for the infant population, and (2) examine the prevalence of HPF exposure and consumption patterns among infants during the complementary feeding phase of 9–15 months of age. HPF were defined according to Fazzino et al. (2019).

Abbreviations: Kcal, kilocalorie; HPF, hyperpalatable food.

METHODS

Participants

The current study was a secondary analysis of data accrued from an ongoing longitudinal intervention (NCT02936284). Data used in the current study were obtained at the baseline measurement period. The sample consisted of 147 families with infants between 9 and 15 months of age. All families were recruited between 2017 and 2019. Due to the requirements of the intervention study, this sample excluded infants if: they were born preterm (< 37 weeks' gestation), born with a low birth weight (<2,500 g), on any special diets, born with known medical problems, showed signs of developmental delays or disabilities, born to a mother who was < 18 years at time of birth, born to a mother who smoked, used controlled substances, or consumed excessive alcohol during pregnancy, born in a high-risk pregnancy, and/or not a singleton.

Procedures

Interested parents were screened via a telephone interview, and eligible parent-infant dyads were scheduled for a laboratory appointment. Parents were also sent links to study questionnaires before their appointment. The University's Institutional Review Board approved the study protocol and all participants provided written informed consent upon arrival to the laboratory. After parental consent was obtained, a packet of information regarding dietary data collection procedures (which included tips and frequently asked questions to guide the estimation of a child's food intakes) was given to the parents.

Infant Dietary Collection

Parents of infants were contacted *via* a telephone call on three separate occasions (2 weekdays and 1 weekend), to collect three, 24-h dietary recalls for the infants; the procedure was a modified version from the Feeding Infants and Toddlers Study (FITS) (Anater et al., 2018). The telephone calls took place at a time deemed preferable by the participating parent. The recalls inquired about foods and beverages given by the parent, and if applicable, other caregivers (i.e., daycare providers). If the infant was still breastfeeding, the parent was instructed to keep track of their duration at the breast. Upon calling the parent, the research member asked if the infant had had a normal/healthy eating day 24 h prior; if not, then a new day to complete the recall was established. The research staff utilized a script to maintain protocol integrity. All research staff completed dietary recalls using the United States Department of Agriculture (USDA) Automated Multiple-Pass Method (Raper et al., 2004) and were extensively trained by a registered dietitian (MS/RD).

Once the telephone call for the dietary recall began, parents would be instructed to first give a quick list of everything their infant had consumed, involving no interruption from the research member. After receiving the quick list, the research member would look for any major eating gaps and inquire about possible beverages at those times. Following this, the research member would read back what they had written down and asked the parent to let them know if they wanted to modify anything. Upon completion of the first run-through, the research member would continue with more detailed questions about the infant's daily consumption, beginning with the first food on the list and asking open-ended questions to obtain further details when needed. If the parent struggled to estimate the amount of a food or beverage, the research member would refer them to the serving size guide in the handout packet. If something was unusual or unclear, the research member would seek clarity. At this point, the research member would ask about major eating gaps throughout the day again, and probe to see if anything was consumed. Before ending the call, information on supplements, medications, and the typicality of the days' eating were gathered.

Data Processing: Baby Food Database and Intake Data

Baby Food Database

Data on baby foods available in the U.S. were obtained from Nutrition Data System for Research (NDSR; version 2019; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN). The NDSR software obtains information on the composition of foods and ingredients, which has been collected from the USDA National Nutrient Database for Standard Reference. In cases when information is missing, the developers of NDSR pull from other existing nutritional databases and scientific publications and employ necessary methodology in order to enhance validity of the values listed in the database. The baby food dataset is considered representative of the U.S. food system for babies and is one of the most comprehensive databases for infant food analysis. The dataset contained $n = 1,084$ total items as baby foods. Data were processed according to the definition for HPF (Fazzino et al., 2019). Specifically, liquids (i.e., infant formulas, juice, etc.) were removed from the dataset n (= 167) since the HPF definition only applies to solid foods. A total of $n = 917$ items was included in the analysis. For the majority of the food items ($n = 853$), a standard serving size was considered as the serving size indicated by the manufacturer (i.e., the portion of food used on the food's nutrition label), consistent with Fazzino et al. (2019). For a small minority of items, the total kcal per serving was listed as 0, which corresponded with a very small serving size (i.e., 1 puff had 0 kcal). To obtain a positive (greater than zero) kcal estimate, that was necessary for determination of hyper-palatability, the servings sizes of foods with less than 5 kcal per serving were increased to ¼ cup ($n = 64$). Increasing the serving size retained the original composition of the foods, while yielding a positive kcal count for analysis. The serving size adjustment did not alter the categorization of foods that met HPF criteria before vs. after the adjustment.

Intake Data

A total of $n = 441$ dietary recalls were available for $n = 147$ participants. All participants had 3 days of recalls in the final analysis. Across the recalls, infants consumed a total of $n = 3,624$ foods and $n = 1,539$ beverages, for a total of $n = 5,163$ items. Recalls were combined at the participant level for analysis. Of the foods consumed, $n = 860$ were baby foods and the remaining were foods typically consumed by adults (referred to herein as adult foods). Six foods were not included analyses, because a participant reported the infant consumed zero kcal. The HPF definition was applied to the $n = 3,618$ foods (non-liquids) available for analysis. The US Centers for Disease Control and Prevention (CDC) recommends breastfeeding or formula-feeding for a year before fully transitioning to table foods; thus, the sample was separated by younger infants (<12 months) and older infants (≥12 months) for analyses.

Application of HPF Criteria

Data were processed according to the HPF definition (Fazzino et al., 2019). For all food items in both the baby food and intake databases, variables for percent kilocalories (kcal) from fat, sugar, and carbohydrates (after removing sugar and fiber) were calculated. Percent sodium was calculated as percent sodium in grams per serving. HPF criteria were applied using the following metrics: (1) fat and sodium (> 25% kcal from fat, ≥ 0.30% sodium), (2) fat and simple sugars (> 20% kcal from fat, > 20% kcal from sugar), and (3) carbohydrate and sodium (> 40% kcal from carbohydrates, ≥ 0.20% sodium).

Data Analysis

Baby Food Database

The prevalence of HPF overall in the baby food database was calculated by determining the number of food items that met HPF criteria divided by the total number of food items in the dataset. In addition, the prevalence of HPF among meal-based items and snacks were calculated separately for each category. Finally, the prevalence of HPF was calculated in light of the standardized Nutrition Data System for Research food category. Baby foods classified as miscellaneous or assigned to more than one food category ($n = 241$) were distributed into one of six final food categories by two co-authors, Morris, a registered dietitian, and Rohde, independently. Discrepancies between the two were resolved by Kong, the first author. The final outcomes were: fruits ($n = 158$), vegetables ($n = 83$), fruit and vegetable mixtures ($n = 147$), grain-based ($n = 360$), dairy and non-dairy alternatives ($n = 69$), and proteins (meat, fish, and other proteins) ($n = 100$).

Intake Data

Outcomes of interest were HPF exposure and pattern of HPF consumption. More specifically, the percentage of infants exposed to HPF was calculated as the total number of participants who consumed HPF (at least one HPF in their 3-day dietary recalls) divided by the total number of participants. To determine the source of exposure, the percentage of participants who consumed HPF as baby foods or adult foods was calculated. In addition, considering that repeated exposure to the same food may be strongly influential in the development of preferences for HPF, we determined the percentage of infants who consumed the same HPF on more than one day (in more than one diet recall). To examine the pattern of HPF intake among infants, percent kcal from HPF overall, and from each HPF group (fat and sodium, fat and simple sugars, and carbohydrate and sodium) was calculated.

Outcomes were reported for younger infants (<12 months) and older infants (≥12 months) separately. In line with the

TABLE 1 | Percentage of hyperpalatable foods (HPF) among all baby food items in the Nutrition Data System for Research (*n* = 917).

Category	HPF items identified (*n* = 105)	% HPF items as FSOD[a]	% HPF items as FS[a]	% HPF items as CSOD[a]
Grain-based	74	21.0	31.4	34.3
Dairy and non-dairy alternatives	17	0.0	16.2	0.0
Proteins (i.e., meat, fish, etc.)	10	1.9	3.8	3.8
Vegetables	3	2.9	0.0	1.9
Fruits and vegetables mixtures	1	0.0	1.0	0.0
Fruits	0	0.0	0.0	0.0

[a]*Included food items that met the criteria for more than one hyperpalatable food group.*
FSOD, fat and sodium; FS, fat and simple sugars; CSOD, carbohydrate and sodium.

main focus of the study on solid food intake, primary analyses determined the percentage of daily HPF energy intake by calculating the total daily energy intake from HPF, divided by total daily energy intake from solid foods. However, because energy intake from milk may represent a substantial percentage of younger and older infants' intake, analyses were also conducted by calculating the percentage of daily energy intake from HPF out of total daily energy intake (milk + solid foods).

RESULTS

Prevalence of HPF Among Baby Foods in the U.S. Food System

HPF comprised 12% (105/917) of total baby foods in the NDSR database. Of the HPF items, 26% (27/105) met criteria for the fat and sodium group, 52% (55/105) met criteria for the fat and simple sugars group, and 40% (42/105) met criteria for the carbohydrate and sodium group. Items were largely distinct, with 82% (86/105) of foods meeting criteria for a single food group (fat and sodium, fat and simple sugars, or carbohydrate and sodium).

The vast majority of items in the dataset (85%, 778/917) were meal-based items for breakfast, lunch, or dinner, such as purees and mixed dishes (e.g., chicken and vegetables). The remaining 15% (139/917) of items were snacks. HPF prevalence differed dramatically across meal and snack items. Specifically, 6% (47/778) of meal-based items were HPF. In contrast, 42% (58/139) of snack items were HPF. HPF snack items fell primarily into carbohydrate and sodium (47%, 27/58) and fat and simple sugars (43%, 25/58) groups. The snack items were primarily crackers (e.g., Earth's Best Organic Crunchin' Crackers–Cheddar) and snack bars (e.g., Plum Organics Jammy Sammy Snack Size Sandwich Bar–Peanut Butter and Grape).

Analyses of HPF prevalence by Nutrition Data System for Research food category revealed that HPF were differentially prevalent across categories (**Table 1**). Specifically, 25% (17/69) of foods in the dairy and non-dairy alternatives category met HPF criteria, with foods largely consisting of yogurt blends, and puddings. Similarly, the grain-based category had 21% (74/360) HPF prevalence and was comprised mainly of snacks such as crackers, biscuits/cookies, and snack bars. The proteins category had 10% (10/100) HPF prevalence, and consisted primarily of breaded proteins (e.g., fish nuggets) and protein-mixed dishes (e.g., Pasta Pick-Ups Beef and Tomato Ravioli). In contrast, no fruits met HPF criteria. One fruit and vegetable mixture (< 1%, 1/147) met HPF criteria (Happy Tot Super Smart Organic Bananas, Mangos and Spinach + Coconut Milk) due to the elevated fat and sugar contents. Four percent (3/83) of vegetables category met criteria for HPF, all of which were breaded vegetable nuggets with elevated fat and sodium (e.g., Earth's Best Organic Gluten Free Baked Sweet Potato Nuggets).

HPF Exposure and Consumption Patterns Among Younger Infants (<12 Months) and Older Infants (≥12 Months) of Age

Descriptive Statistics

Characteristics of the infants and their mothers are presented in **Table 2**. Overall, the sample consisted of primarily highly educated families (≥ college graduates = 87.4%) of Caucasian race (77.6%). The mean and standard deviation (SD) for weight-for-length of the infants was 0.6 (0.9) z-score. Younger infants consumed a mean of 848.0 (SD = 214.0) kcal of total energy per day (milk + solid foods), of which 45% (SD = 13.7%) was energy from solid foods. Older infants consumed a mean of 985.1 (SD = 235.9) kcal of total energy per day (milk + solid foods), of which 67% (SD= 16.5%) was energy from solid foods. Both younger and older infants consumed the majority (≥60%) of their daily solid food energy intake from adult foods (younger infants: M = 60%, SD = 31.6%; older infants: M = 87%, SD = 15.3%) instead of baby foods.

Exposure to HPF

The vast majority of younger infants (91%; 68/75) and older infants (100%; 72/72) consumed HPF. Most younger infants (85% 64/75) and older infants (100%; 72/72) were exposed to HPF through adult foods. In contrast, 5% of younger infants (4/75) and 0% of older infants (0/72) were exposed to HPF solely through consuming baby foods. Exposure to HPF as a proportion of solid foods consumed per day is presented in **Figure 1**. The majority of both younger and older infants consumed between 20 and 60% of their daily foods from HPF (**Figure 1**). Regarding repeated HPF exposure, 68% of younger infants and 88% of older infants consumed the same HPF on more than one day.

Pattern of HPF Consumption

On average, younger infants consumed 38% (SD = 23.6%) of their daily solid food energy from HPF and older infants consumed 52% (SD = 16.4%) of daily solid food energy from HPF. Younger and older infants consumed the greatest

TABLE 2 | Participant characteristics (*n* = 147).

	Mean (SD)	*N* (%)	Range
Child			
Sex, male		68 (46)	
Age, month	11.9 (1.9)		9.1–15.8
Race, Caucasian		114 (77.6)	
Refuse to answer		0 (0)	
Gestational age, weeks	39.4 (1.2)		37–43
Birth weight, kg	3.5 (0.5)		2.5–5.2
Weight-for-length z-score[a]	0.6 (0.9)		−1.7–3.1
Breastfeeding duration	8.1 (4.6)		0.5–15.8
< 6 month		45 (30.8)	
≥ 6 month		101 (69.2)	
First introduction to solid foods	5.3 (1.0)		2.0–9.0
< 4 month		5 (3.4)	
4–5 month		65 (43.6)	
≥ 6 month		76 (51.0)	
Mother			
Age, year	32.2 (4.3)		22.8–46.3
Education level			
Some college or below		22 (15.3)	
College graduate or higher		122 (87.4)	
Refuse to answer		0 (0)	
Parity			
Nulliparous		79 (54.1)	
Parous ≥ 1		67 (45.9)	
Current BMI, kg/m²	30.0 (7.7)		18.9–51.3
Normal weight		48 (33.3)	
Overweight/obese (≥ 25 BMI)		96 (64.4)	
Household total income			
< $30,000		13 (8.9)	
$30,000–$69,999		37 (25.2)	
$70,000–$109,999		55 (337.4)	
≥ $110,000		34 (23.1)	
Refuse to answer		8 (5.4)	

[a] *Calculated using the WHO growth charts.*

percentage of HPF energy from fat and sodium foods, followed by carbohydrate and sodium foods, and fat and sugar foods (presented in **Table 3**). Examples of commonly consumed HPF from baby foods consisted of various crackers and puffs, yogurts, and cookies. Commonly consumed HPF from adult foods consisted of various cheeses (e.g., cheddar), breakfast foods (e.g., waffles, pancakes), and snacks (e.g., animal crackers, chips, and cereal). When considering total daily energy intake (milk + solid foods), younger infants consumed 19% (SD = 13.6%) of their total daily energy from HPF and older infants consumed 35% (SD = 14.5%) of their total daily energy from HPF.

DISCUSSION

The study sought to characterize the prevalence of hyperpalatable foods (HPF) among baby foods available in the U.S. food system, and to determine the degree to which infants are exposed to HPF within the first 15 months of life, a critical period for the development of food preferences and eating habits. Findings indicated that a minority (12%) of available baby foods in the U.S. met criteria for hyper-palatability, suggesting that for the most part, foods available to infants in the U.S. may not contain ingredients that are designed to artificially enhance palatability. However, analysis of infants' dietary intakes revealed that the vast majority (>90%) of younger infants (<12 months) and older infants (≥12 months) consumed HPF, primarily through exposure to adult foods. Furthermore, dietary energy intake from HPF was high and comprised over one third of daily solid food energy consumed among younger infants and over half of daily solid food energy consumed among older infants.

Our findings indicate that overall, infants may have a low risk for exposure to HPF when consuming available baby foods in the U.S. food system. This is encouraging since the recently published 2020–2025 Dietary Guidelines for Americans below 2 years of age recommends completely avoiding foods with added sugars and excessive salt, while opting for a variety of multicolored vegetables, legumes, fruit, whole grains, full-fat dairy, meat, eggs, seafood, nuts, seeds, soy products, and oils (exact quantities differ between 0 and 11 and 12 and 23 months). Here, the majority of baby foods available were meal-based items such as purees, which largely did not appear to be altered in a way that artificially enhances palatability. However, analyses did reveal substantial differences in HPF prevalence across types of baby foods, with almost half (42%) of snack items meeting criteria for HPF, vs. a small minority of meal-based items meeting HPF criteria (6%). Thus, a potential point of risk for HPF exposure may be when infants are fed baby snack foods, such as crackers and biscuits. However, in general, at the food system-level, the potential for exposure to HPF when consuming baby foods alone appears to be low. This finding is encouraging and suggests that when consuming *only* baby foods, infants may be able to avoid the intake of foods that can strongly influence their taste preferences and excessively activate brain reward neurocircuitry.

Despite the low prevalence of HPF among baby foods in the U.S., our findings indicate that almost all infants in the sample were exposed to HPF. Notably, the vast majority of infants were exposed to HPF when consuming adult foods, indicating that the transition from a milk-based diet to complementary feeding with solid foods may be a key point for HPF exposure. While the risk of exposure to HPF through adult foods is concerning, it is not entirely surprising within the context of the current food environment in the US. Our prior work has indicated that >60% of adult foods available in the US were HPF (Fazzino et al., 2019); thus, the early exposure risk in infancy is likely the result of living in an obesogenic food environment replete with HPF. However, despite the challenges in limiting HPF exposure, it is likely that preventing exposure to HPF among infants is likely ideal for facilitating healthy neural, physical, and psychological development. In this regard, evidence from imaging studies conducted primarily among adults is accumulating to suggest that consuming a food high in multiple palatability-inducing ingredients, such as an HPF,

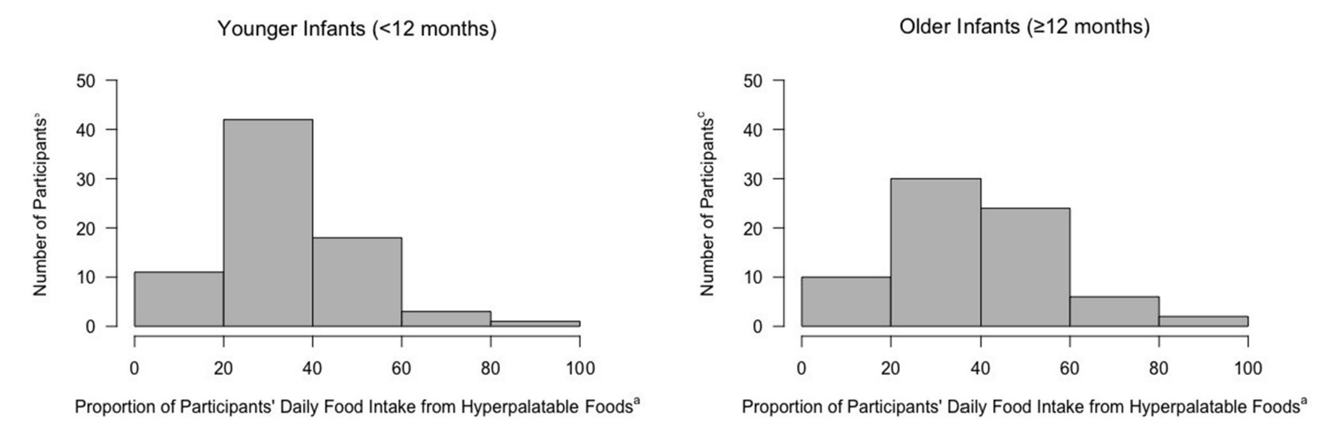

FIGURE 1 | Proportion of daily food intake (kcal) from hyperpalatable foods among infants. [a]Calculated as number of hyperpalatable foods consumed/total solid foods consumed per day. [b]$n = 75$, Younger Infants. [c]$n = 72$, Older Infants.

TABLE 3 | Percentage of daily caloric intake from hyperpalatable foods (HPF) among infants.

HPF category	Younger infants (<12 months) M (SD) (%)	Older infants (≥12 months) M (SD) (%)
Energy intake from FSOD[a]	19 (19)	34 (15.1)
Energy intake from FS[a]	10 (11)	9 (8.5)
Energy intake from CSOD[a]	15 (15.5)	20 (12.4)

[a]Calculated as energy intake of HPF/total energy intake from solid foods.
FSOD, food and sodium; FS, fat and simple sugars; CSOD, carbohydrate and sodium.

strongly activates brain regions involved in reward processing, motivation, and executive functioning (Gordon et al., 2020). Importantly, these same brain regions are activated during consumption of other highly rewarding stimuli, including drugs (Gordon et al., 2020). While it is unknown whether the findings of imaging studies conducted among adults translates to infants, it is likely that infants' brains are more sensitive to external stimuli (including food) than adults, given their rapid neurodevelopment. Thus, limiting exposure to HPF is likely ideal for healthy development.

Early exposure to HPF may have early negative effects on reward processing, food preferences, and eating behavior. Studies in utero, noteworthily, demonstrate that flavors from the mother's diet are capable of entering the amniotic sac and influencing an infant's food preferences, for better and for worse. Furthermore, during the complementary feeding period, individuals prenatally exposed to garlic, anise, and carrots showed greater liking and/or intakes of foods with those tastes (Mennella et al., 1995, 2001; Schaal et al., 2000). From experimental research in rats, however, consumption of highly palatable foods throughout pregnancy has led to offspring with increased preferences for fat, sugar, and salt (Bayol et al., 2007). Despite the inability to examine prenatal HPF exposure in our cohort of infants, regular, repeated exposure to HPF postnatally, in infancy, equally presents a major cause for concern. Thus, our finding that most infants in our sample already had repeated exposure to HPF through daily dietary intake is disturbing. Notably, HPF comprised 38 and 52% of daily food energy intake among younger and older infants, respectively, suggesting that daily exposure was substantial. Overall, the results highlight the transition to solid foods, particularly adult foods, as a key potential point for early exposure to HPF, as well as the development of regular HPF intake patterns. Our findings further highlight the need for the Dietary Guidelines for Americans below age 2 to focus on delaying the introduction of HPF, which may lead to overconsumption.

Early and habitual exposure to HPF, coupled with a genetic predisposition, may greatly increase the risk of developing obesity in childhood and later adulthood (Berthoud et al., 2011). Food is a primary reinforcer, and infants are innately motivated to eat for survival purposes. However, in today's obesogenic environment, HPF are readily available, and their overconsumption during infancy may set the stage for infants to develop childhood obesity (Gearhardt et al., 2011a,b). Infants have trivial room for nutrient-poor foods; therefore, every calorie counts and caregivers should strive to meet the nutritional needs of their infants without providing excess energy. Furthermore, the types of food offered by caregivers are important for forming early food preferences that can influence later health (Nicklaus and Remy, 2013). An advantage of the infancy period is that caregivers have full control over the home food environment and can be empowered to feed their infants in a way that supports energy balance. Thus, infants' dietary intakes should be aligned with their growth and developmental needs, which can be achieved by minimizing the introduction of and exposure to HPF at a young age.

This study had several limitations. First, infant intake data were reported by caregivers and thus may be susceptible to overestimation (Fisher et al., 2008). However, dietary recalls are still the best available method to date for measuring infant dietary intakes in free-living conditions. Second, the study sample was comprised of infants who were primarily from high socioeconomic status families, and thus our findings may not be generalizable to more diverse cohorts. This study should be replicated in low-income populations because they are more likely to struggle with adhering to healthful lifestyles due to limited resources. Finally, the definition for HPF was developed based on food data from studies conducted in adults. Thus, HPF criteria might only represent nutrient thresholds to enhance food palatability for adults and not infants. However, it is possible that the threshold needed to enhance food palatability for infants is likely lower than for adults; infants have limited exposure to solid foods and they have substantially more taste buds than adults, which may intensify a food's taste. Thus, further work is needed to determine whether other foods may be hyperpalatable for infants at a threshold that is lower than the threshold for HPF that has been identified for adults.

Despite the limitations, this study had many strengths, including assessment during a critical and narrow window of development (the complementary feeding period), the use of a quantitative definition of HPF to identify target foods for analysis, and the use of three, 24-h dietary recalls, which is the best available measure to estimate infant nutrient intakes (Ma et al., 2009). For the dietary recalls, parents were given thorough instructions and physical copies of dietary recall guides, and registered dietitians were trained to conduct nutrition analyses. Lastly, we performed our nutrition analysis using the research graded program, Nutrition Data System for Research software. This database is supremely comprehensive, consisting of over 18,000 foods (1,000 specifically being baby foods) and is continuously updated to maximize accuracy in data collections.

In conclusion, this study was the first to examine the prevalence of HPF among infant foods, and the extent to which infants are exposed to HPF during the complementary feeding period. Our findings highlight the complementary feeding period as a key period of risk for HPF exposure and the development of regular HPF consumption patterns. Larger, longer term observational studies on HPF consumption among infants and toddlers are needed to advance the field's understanding of the potential adverse effects of HPF intake on infant reward processing, eating behavior, and lifelong obesity risk. In addition, future prevention and intervention efforts should focus on delaying exposure to HPF during this critical period of development.

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 University at Buffalo IRB. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

KK initiated and developed the research question and study design, assisted with the analytic plan, and drafted the manuscript. TF initiated and developed the research question, led the analytic plan, and drafted the manuscript. KR contributed to the data analyses, results interpretation, and revision of the manuscript. KM contributed to the data collection, nutrition data analyses, results interpretation, and revision of the manuscript. All authors approve the submitted and final versions.

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An Ecological Perspective of Food Choice and Eating Autonomy Among Adolescents

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Adolescence is an important developmental period marked by a transition from primarily parental-controlled eating to self-directed and peer-influenced eating. During this period, adolescents gain autonomy over their individual food choices and eating behavior in general. While parent-feeding practices have been shown to influence eating behaviors in children, little is known about how these relationships track across adolescent development as autonomy expands. The purpose of this qualitative study was to identify factors that impact food decisions and eating autonomy among adolescents. Using the food choice process model as a guide, four focus groups were conducted with 34 adolescents. Focus group discussion was semi-structured, asking teens about influences on their food choices across different food environments, their involvement with food purchasing and preparation, and perceived control over food their choices. Focus group transcripts were analyzed using deductive and inductive code creation and thematic analysis. This study found six leading influences on adolescents' food choices and identified additional factors with prominence within specific environmental contexts. This study distinguished a broader spectrum of factors influencing adolescent food choice that extend beyond "convenience" and "taste" which have previously been identified as significant contributors. The degree of control that teens reported differed by eating location, occasion, and social context. Finally, adolescents demonstrated various levels of engagement in behaviors related to their eating autonomy. Identifying the emergent themes related to adolescent autonomy was the first step toward the goal of developing a scale to evaluate adolescent eating autonomy.

Keywords: adolescence, autonomy, eating behavior, food choice, food environment, pediatrics

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INTRODUCTION

Adolescence is an important developmental period marked by a transition from primarily parental-controlled eating to more self-directed eating (Kelder, 1994). Adolescence spans the period from ages 10–19 and is characterized by rapid physical, mental, and emotional development (Sawyer et al., 2018). During this life stage, adolescents' food choices and eating are influenced by parents, peers, and the surrounding environment (Story et al., 2002). Since studies have shown that the food choice behaviors of children and adolescents track into adulthood, it is valuable to gain a better understanding of factors that influence adolescent eating behavior (Devine, 2005). In addition, the degree to which an adolescent has control, or autonomy, related to food choices may be associated with other health outcomes, such as eating disorders or obesity.

Much of the prior work in adolescents has focused on disordered eating behaviors, eating in specific contexts, or types of foods. For example, there is a large body of evidence surrounding maladaptive adolescent behaviors such as meal skipping (Nicklas et al., 2001), extreme dieting, (Patton et al., 1997), and binge eating (Swanson et al., 2011; Pearson et al., 2012). There is also a robust literature showing that food parenting practices and parenting styles may influence the eating behaviors of offspring, but less is known about the effects on adolescents specifically (Savage et al., 2007; Vaughn et al., 2016). Age-based characteristics, such as higher susceptibility to peer pressure, have also been found to impact adolescent food perceptions and choices, primarily in the school environment (Maxwell, 2002; Andersen et al., 2016; Macchi et al., 2017). Finally, much of the work examining adolescents' food choice process has been limited to a sub-set of the diet, such as making "healthy" food choices (French et al., 2001) despite consistent findings showing that teens do not follow healthy eating recommendations (Croll et al., 2001). More research is needed that broadly examines adolescent eating behavior across a variety of eating contexts and eating occasions.

The present study is informed by several models and theories. The food choice process model provides a framework for examining the complex nature of food decision making across the life course (Sobal et al., 2006). This model, adapted from Connors et al. (2001), was developed based on qualitative investigations of the food choice process in adults; acknowledging that there is individual variability in factors involved in the food choice process (**Figure 1**). One of the main components of the model is "personal food system" which is the operationalization of perceived influences on food choices across various contexts (Connors et al., 2001). Identifying the factors that an individual has agency over helps to describe active considerations and social negotiations related to making food choices. The food choice process model further explains that within the personal food system, these factors often compete for prioritization based on their value in each context. Expansions of this model have included food behaviors (such as acquisition, preparation, and consumption) produced through food choice decisions (Bisogni and Sobal, 2009). There are important differences between how adults and adolescents conceptualize factors involved in making food choices, but more work is needed to understand the adolescent perspective (Share and Stewart-Knox, 2012).

However, no single theory completely explains food decision making behavior and the food choice process (Bisogni and Sobal, 2009). While, the food choice process model illuminates the importance of understanding adolescents' perceptions of the factors that influence their food choices, some other models heavily emphasize social and environmental influences on eating behavior. Story et al. (2002) proposed a conceptual model of adolescent food choice based on a combination of Social Cognitive Theory (SCT) and the Social Ecological Model (SEM) (Story et al., 2002). This model highlights the importance of examining interactions across the main areas of influence (individual/intrapersonal, social environment/interpersonal, physical environment/community, and macrosystem/societal) within an individuals' food choices.

There have been limited analyses of factors that impact adolescent food choice. Some recent qualitative investigations examined school lunch food choices (Contento et al., 2006; Waddingham et al., 2018). Of those, one asked teens to compare their lunch decisions to other meals or times of day (Contento et al., 2006). Other studies used a recall activity to help adolescents describe the food choices they had made the previous day; one within a school-based, focus group setting (Neumark-Sztainer et al., 1999), and the other through a focus group and individual interviews (Sommer et al., 2014). There has also been at least one study assessing adolescents' food choice process within the home environment (Holsten et al., 2012). More work needs to be done to understand the environmental and psychosocial factors that impact adolescent food choices. To our knowledge, there has not been a qualitative assessment of adolescents' food choices conducted outside of the school or home settings.

Children and adolescents are increasingly recognized as having active roles in their experiences and holding unique perspectives which should be investigated firsthand (Smith, 2007). Understanding the adolescent perspective is particularly important during the life stage where autonomy development occurs across many contexts, including food choice and eating behavior (Spear and Kulbok, 2004; Stok et al., 2010; Dahl et al., 2018). The psychology and development literature suggest that an adolescent's autonomy is related to substance use behavior (Allen et al., 2012), susceptibility to peer pressure (Allen et al., 2006), and self-esteem (Allen et al., 1994). Importantly, a conceptual analysis of the previous adolescent autonomy literature highlights a vacancy in studies examining autonomy relationships with adolescent lifestyle behaviors, such as food choices (Spear and Kulbok, 2004). An association between adolescent autonomy and unhealthy snack purchasing has been identified (Stok et al., 2010), but no other work has been done in this area. Understanding adolescent autonomy related to eating behaviors may be key for tailoring adolescent eating behavior interventions toward clinically significant improvements in dietary and health outcomes.

When adolescents act autonomously, they take on a level of responsibility for and control over their food choices (Teixeira et al., 2011). The terms "autonomy" and "independence" can both reflect freedom from external control, but "independence" can also be used to convey physical separation. Therefore, throughout this work we have defined autonomous food choices as those made without direct parental guidance, using the term "independent" to communicate instances of food choices when adolescents are apart from parents.

To date there is no established way of assessing adolescents' autonomy within the realm of food choice and eating behavior. We have operationalized adolescent eating autonomy as an adolescents' individual decision making related to, and

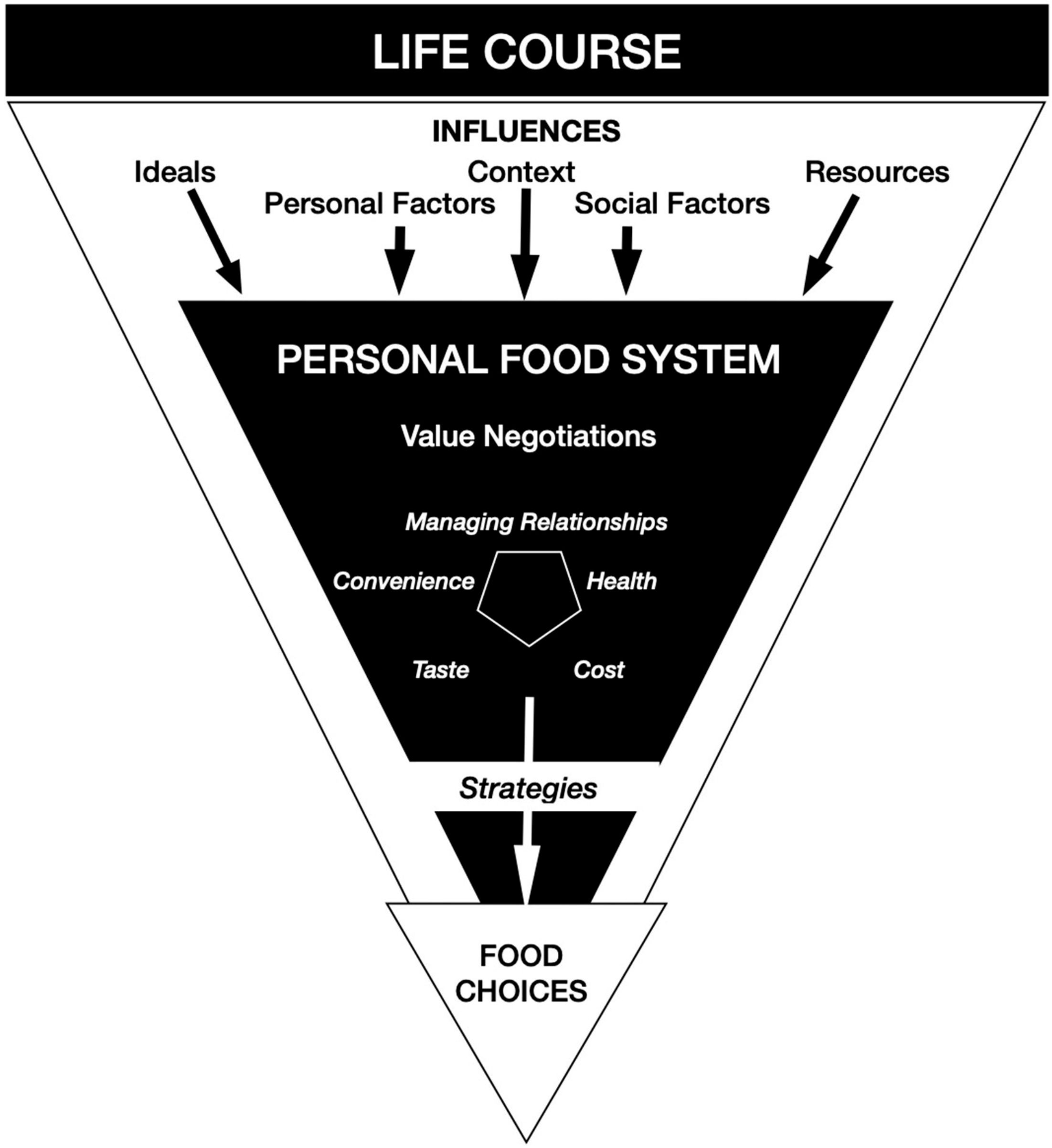

FIGURE 1 | The food-choice process model adapted from Connors et al. (2001).

perceptions of control over, their food choices. The primary aim of this study was to identify the predominant factors involved in adolescents' food choices across a variety of ecological environments and social contexts. The secondary aim of this work was to identify the themes related to the perceived control that adolescents' have over their eating. This formative work is a first step toward developing a scale to assess adolescent eating autonomy.

MATERIALS AND METHODS

This study used qualitative methods to gain an understanding of adolescents choices related to food. Four focus groups were conducted with adolescents aged 13–17 years between November and December 2019. Discussion focused on exploring the decisions adolescents make, and perceived control, around their food choices.

Focus Group Recruitment and Setting

Adolescents were recruited via physical and digital flyers distributed to multiple school-districts and list-serves in the Western New York area from October through November 2019. Using convenience sampling, parent(s)/guardian(s) [hereafter referred to as parent(s)] of interested teens were invited to contact the research lab for further information and to complete an eligibility screening. Parents provided demographic information during the screening process. Adolescents were eligible if they were between 13 and 17 years of age, spoke English, and were not concurrently enrolled in another study by our research team. Enrollment was structured to obtain a representative sample of adolescents from different geographic backgrounds (i.e., from urban, suburban, and rural areas). The recruitment coordinator (AMG) used elements of purposive selection to balance scheduled participation in each focus group as evenly as possible based on sex, age, and school to maximize heterogeneity within each focus group sample.

Focus groups were conveniently located based on participant preference. Each focus group followed a near identical flow of events and lasted 1.5 h. Upon arrival to each focus group, teens received an identification number and selected a first name (allowing for anonymity). Then the participant and their parent were guided to a semi-private area where a trained research assistant performed a written parental consent and adolescent assent process. After signing these documents, families were offered a self-serve taco bar dinner to increase rapport with participants and decrease the time burden to participants during the weeknight. After eating, parents left the room and the food was removed until after the focus group finished. Upon completing the discussion questions, teens completed a brief survey packet and received cash compensation for their participation. All procedures were approved by the University at Buffalo Institutional Review Board.

Discussion Guide

Focus groups followed a semi-structured discussion guide. Participants were told that "we want to better understand how teens decide on the foods that they eat and where they get them." The discussion questions were designed to be open ended, covering topics such as how teens decide what to eat in a variety of settings, participation in the grocery shopping process, and identifying how and when teens feel the most control over their food choices. The discussion moderator guide, seen in **Table 1**, laid out priority questions with possible follow-up prompts, to stimulate a conversation that was naturalistic, detailed, and informative about the individual and environmental factors that may play a role in adolescent food choices.

TABLE 1 | Focus group discussion guide questions and probes.

Question	*Probe*
What are some of your favorite foods?	*How often do you eat them?*
What types of snack foods do you like best?*	*Where do you usually get snacks?*
How do you feel about the food options in your house?	*at school?*
How do you choose what to eat when you need to pick something out yourself?	*What things/factors are important to you when you are choosing what to eat?* *Do you have more choices over certain meals? -Times of day? How would you describe your process of picking food after school?*
How much input do you have in grocery shopping?	*Do you help make lists or go along shopping? Some other way?* *How often do you get the things you want?*
What things do you have independence/ control over with your eating?	*Certain meals? Times of day? Locations?*
How do you make meal choices when you are not with your parent/caregivers?	*What motivates you toward certain foods?* *Do you spend your own money on foods/snacks?*
What makes your food choices different than your parent/guardians?	*-different than siblings? Peers?*
If it was up to your parents or parent/caregivers would you eat differently?*	*What would they like you to eat more of? - less of?*
How much do your parents/caregivers know about what you eat when you are not with them?*	*Is there anything you specifically don't tell them? - Why?*
Is there anything you wish was different about how you choose your food?*	

**Represents lower priority questions.*

Data Analysis

Recordings were transcribed and reviewed for discrepancies by a research assistant not directly involved in the focus group discussion. Transcripts were independently coded by 3 coders using Atlas.ti 8 (Atlas.ti Scientific Software Development, Berlin, Germany) software. The coders were trained by a co-investigator with qualitative data collection and analysis expertise. Coding and analyzing the data followed a multi-pass thematic coding process. The initial round of coding involved a deductive process of open coding by each independent coder (AMZ, CMK, THM) of all 4 focus groups. The coders met to reconcile differences and begin the development of a codebook. The codebook was utilized for a second round of refined, or focused, coding in which the coders met regularly to debrief, refine the codebook, and begin the inductive process of generating overarching themes. Finally, all coders' transcripts were merged into a final project in which the codes were reconciled among coders and predominant themes were identified. The coders determined that code saturation had been reached when coding of additional focus group transcripts produced codebook revisions related to the use of existing codes rather than generating new codes. Meaning saturation was sufficiently captured through 4 focus groups and confirmed by the same predominant themes emerging across the focus group strata (Hennink et al., 2019).

Sample Characteristics

There were 69 adolescents that were eligible to participate. Thirty-four eligible teens did not participate: 1 did not show up as scheduled, 8 did not respond to contact, 10 declined participation, and 15 were unable to participate due to scheduling conflicts. The final sample included 35 adolescents, 18 males and 17 females, with mean age of 14.9 years. The final size of each of the four focus groups ranged from 6 to 12 participants: Focus group A (n = 7; 4F, 3M), Focus group B, (n = 10; 5F, 5M), Focus group C (n = 12; 6F, 6M), and Focus group D, (n = 6; 2F, 4M). The teens represented a wide range of economic, racial/ethnic, and geographic backgrounds. Fifteen adolescents were from high population density areas, 11 from medium, and 9 from low population densities. These teens attended 26 unique schools. Just over 31% of the sample qualified for free or reduced-price school lunch, however the majority of the sample were from middle- and high-income brackets. In terms of racial/ethnic background, 77.1% identified as White/Caucasian and 14.3% as Black/African American, and 8.6% multi-racial. This is representative of the Western New York population under 18 years old; with 79.3% of the population identifying as White/Caucasian, 14% Black/African American, and 5.8% Hispanic (US Census Bureau, 2020).

RESULTS

The focus group analysis revealed that the predominant factors impacting adolescents' food choices differ across environments (home, school, restaurants, and stores). Additionally, throughout the focus group analysis, attention was paid to uncover thematic areas unique to the adolescent perspective, where adolescents may experience a range of autonomy over their food selections. These emergent themes identified key elements of the adolescent eating autonomy construct.

Factors in Adolescents' Food Choices

Adolescents identified many factors that impact their food choices across different contexts. The six predominant factors that adolescents considered when making independent food choices include: schedule and time priorities, hunger level and/or satiety, healthfulness, convenience (and ease of preparation), availability, and physical activity. Predominant factors were those mentioned most across focus groups; defined as the factors voiced by 7–10 adolescents. Less frequently mentioned factors in adolescents' food choices (mentioned by 4–6 adolescents) were cost, portion size/amount, daily nutritional balance, openness to new food, variety, and taste. Notably, the most discussed food selections that adolescents make when making independent choices include mixed dishes (such as sandwiches and pizza), crunchy and salty snacks (such as chips and popcorn), fruits and vegetables, and sweets (such as candy and cookies).

The Socio-Environmental Context of Adolescent Food Choices

Table 2 shows the summary of results surrounding the predominant factors influencing adolescents' food choices organized by environment. Given that this study draws from SCT, SEM, and the food choice process model, we anticipated the home and school to be common environmental contexts for adolescent food choice. Throughout the coding process other locations, such as restaurants and stores, also emerged as environments in which adolescents' often make food choices.

Home

About a third of participants described food choices taking place at home. Within the home environment, the leading food choice factors were schedule and time priorities, availability, and convenience. Many teens indicated making decisions based on what time they arrive at home and proximity to mealtime. One teen explained making their food choices based on *"... [the] time I get home from practice and how close it is to dinner, or when I have to leave or something..."* They also described that they would settle for more convenient/available, but less-preferred foods, based on their hunger level.

Adolescents expressed various levels of involvement in household meal planning ($n = 11$). Some adolescents help their families plan meals in advance every week, which serves as an opportunity to request specific items or meals. One teen described, *"My family, we like plan out our meals every Sunday. I mean this is recent so we can decide like what we want to eat....we just say whatever we want and when we say what we want we get it."* Others indicated that the parent(s) decide the household meals without teen input, which is acceptable to some, but not others.

Adolescents participate in varying degrees of food preparation at home ($n = 21$). About half of participants described that when preparing meals for themselves, they choose something simple that they know how to prepare. They make something quick "*like grilled cheese or mac 'n cheese*" or items that require minimal preparation *"like frozen chicken fingers or something like frozen veggies."* Adolescents decide what to prepare based on availability in the home, citing they will make *"whatever is in the kitchen to cook."* However, despite occasions of parents leaving food preparation instructions while they are away, some teens stated that they choose more convenience foods anyway: "*But when we get home from school, my sister and me, we don't want to make food so we usually just grab chips or something."* While some adolescents said they do not cook at all, five participants mentioned that they prepare meals for the family as a whole. Apart from one mention of cooking with a sibling, other individuals were not described within the context of impacting adolescents' food choices at home.

Adolescents' engagement in packing school lunches ranged considerably ($n = 11$). In some cases, parents pack an adolescent's lunch without input, while other teens stated that they regularly select some, or all, of their own packed-lunch food items. Those who packed their own lunch explained that packing lunch is not always possible due to time priorities. Packing one's lunch was described as giving teens higher control over their lunch food choices. When packing their lunch, adolescents make food decisions based on item availability and their anticipated hunger level by considering their physical activity schedule. One explained, *"For me, it's usually just like what I have, because normally I expect a sandwich and, like, a side, like, usually it's yogurt for me, because that's just always what we have in our house. So really, I just pack what's, like, available for me. You know?"*

School

About half of participants described their food choices related to the school environment. While some teens noted convenience or scheduling considerations as factors related to their food decisions at school, other major factors unique to the school context emerged. Food quality, freshness, doneness, and the taste of the food were leading considerations for adolescents in this environment. Adolescents frequently expressed their perceptions of the school food environment, in relation to variety and the need for improvement. In the majority of cases, teens shared their reasons for choosing *not* to obtain food from school due

TABLE 2 | Summary of factors influencing adolescents' food choices by environment.

Environment	Factor	Expanded context
Home (n = 13)	Schedule and time priorities	Time of arrival, proximity to mealtime
	Availability	Prioritized more as hunger increased
	Convenience and ease of preparation	Prepared simple, familiar items
		Interpersonal relationships not often mentioned
School (n = 16)	Schedule and time priorities	School lunch consumed because time or energy for packing a lunch is limited
	Convenience	
	Food quality**	Selections described as needing improvements in terms of variety, taste, quality, freshness, consistency, or preparation method
	Taste*	
	Variety*	More variety of options perceived positively
		Interpersonal relationships not often mentioned
Restaurant (n = 14)	Convenience	
	Cost*	More cost-conscious choices made when dining without family
	Healthfulness	Categorized options as healthy or unhealthy
	Openness to new foods*	Use of communal behaviors when dining with peers
Store (n = 13)	Convenience	Convenience stores and gas stations were frequent and accessible locations where adolescents described making food choices
	Cost*	Selected special items, not normally consumed
		Often with peers
General Environments#(n = 3)	Hunger and satiey	Considered hunger both in food choices made in the present moment and based on anticipated hunger when planning meals/snacks or packing lunch.
	Physical activity	

Predominant Factors are those that were mentioned by 7–10 adolescents across focus groups. Less dominant factors were mentioned by 4–6 individuals across focus groups. Symbol Key.
**reflects emergence of a less dominant factor in this context.*
***reflects emergence of a factor unique to this context.*
 # This section lists predominant factors generally mentioned without a location context.

to the selections needing improvements in terms of variety, taste, quality, freshness, consistency, or preparation method. Another stated, *"I bring my lunch every day because the school food is really nasty."* Adolescents that positively regarded their school food options also perceived that there was a lot of variety of the offerings, stating satisfaction with the school food options was "*Because at my school, there is a lot to pick from."*

Others described eating school lunch as a consequence for not having time or energy to pack a lunch. Adolescents also explained that their busy schedules lead them to consume items from the school vending machine between practices/meetings as a snack or as a meal replacement. Interestingly, only two participants mentioned the influence of peers on their choices within the school environment; with one describing trading food items that they buy at school (such as stuffed crust pizza) for "treats" friends bring from home (such as cookies) and the other explaining that they get breakfast at school *"because all of my friends do it and they have cereal and stuff."*

Restaurants

Forty percent of adolescents described making independent food choices in restaurant establishments. The prominent factors that influence food choices in the restaurant setting include cost, healthfulness, openness to trying new foods, and convenience. Discussion of restaurant dining included fast-food/fast-casual establishments, coffee shops, or "restaurants" that were not specified. Of those discussing restaurant food choices, 40% specifically mentioned being in the company of friends when making food choices at various restaurants.

Participants stated that cost and availability of spending money influence the choice of restaurant and food choice when eating independently. Participants suggested that their restaurant food choices were cheaper when eating without family, stating, *"I usually order something, like, cheaper ... I would get, like, just like five chicken wings or something instead of, like, what we would order with family."* Others cited restrictions when dining at restaurants with family and expressed that they have more freedom to *"just get what I want"* when eating among friends. Peers influenced adolescents' food choices through communal behaviors, such as taking turns paying for food and sharing items. However, while some teens were amenable to buying and sharing food, others noted that they would not share with friends if they spent their own money on the items. Additionally, eating at a restaurant with peers was cited as an opportunity to try new foods, "*that's when I try new stuff - when I'm not with my parents or my family. I just... I'm like, oh that looks good. Let me try it."*

Stores

About one third of participants described making independent food choices at stores, with convenience stores (including gas stations) being the primary location, followed by grocery stores, and drug stores. Adolescents' descriptions of food choices at stores were uniquely social compared to other environments. Among participants that mentioned making food choices at a store, 88% included the company of a friend or cousin. The season was specifically mentioned in about 30% of these descriptions, such as *"During the summer I went to NOCO Speedway with my friends sometimes."* Some mentioned shopping without parents at grocery stores in the context of being able to buy what they want without parental approval. Often teens shop at grocery stores with friends in preparation for a group hang out. *"Whenever me and my friend hang out, we go to a grocery store. It's like the only time I buy food for myself."* However, when shopping for household groceries, adolescents mentioned sticking to a grocery list.

Emergent Themes Related to Adolescent Eating Autonomy

Food Acquisition

The theme of independently seeking out food (i.e., acquisition) emerged related to adolescent eating autonomy. Forty percent of participants indicated that they coordinated their own transportation to obtain desired food or drink. Walking and public transit were the most often cited means of independent travel. Adolescents walked to drug stores, convenience stores, restaurants, and grocery stores for food purchases. Lesser used modes of transportation include biking, driving, or getting a ride. Biking was mentioned as a means of independent transit, used in the summer and typically with peers. One teen explained: "… *my cousins and I, we rode up to get ice cream and maybe … we got fries. Then, at 7-Eleven, I would normally get like a can of pop [soda/cola], and either a Slurpee or a snack."* Driving was described as a means of transport for food acquisition in three distinct ways: through driving oneself, by asking a sibling for a ride, or negotiating a ride from a parent/guardian. Among those that described independent food acquisition, half indicated that they were with peers.

Food Spending

Adolescents exert their autonomy related to food choice through food spending. Most ($n = 25$) adolescents discussed their use of personal spending money, either provided on their own or by a parent, to make independent food purchases. Forty percent of these quotations mentioned the company of friends. While most teens described choices made when spending their own money, a few teens discussed exclusively spending money provided by parents. For example, when spending parents' money, adolescents referenced choosing a food establishment based on how much money was available to them. When spending their own money, teens indicated that they make different food choices compared to when a parent pays. Adolescents described being cost conscious; often buying cheaper items or *"something that's going to last me a long time… [such as] a big box of ramen."* One participant described the food spending decisions this way: *"I like to go to Chipotle because I associate that with being healthier, because it's just like healthy ingredients and stuff like that. But if money is kind of pressed, I really want to go out to eat I'll just get Wendy's because it's probably the cheapest option."* Additionally, we found that adolescents use their own funds on grocery and restaurant food items that parents refuse to purchase or on items that they do not normally eat. Adolescents indicated that their parents' level of trust in their ability to make responsible purchases may impact their food choices. On teen explained, "*Like they trust I'm not just going to blow my money on just junk food and stuff. They know that I'll pick like something healthy and something that's not as healthy."*

Adolescent Influences on the Household Food Environment

In discussion of food choices in the home, adolescents described their role in shaping the food options available in the home food environment. Adolescents have various levels of involvement in grocery planning and shopping which may demonstrate elements of their eating autonomy ($n = 27$). Some adolescents described that they could contribute to a household grocery list throughout the week. Most adolescents mentioned that their grocery requests are purchased at least some of the time. One teen detailed the process of choosing grocery food items in their household:

> *"… If you ask for more stuff then there's less chance to get it. It's basically just a timing thing- because my mom is super organized, and she has a list inside, and it's like it's sectioned off for, like, produce and cleaning supplies. And if you can get it on the list before it's taken down on Sunday, then she could get it for you. But [not] if you miss the deadline."*

Adolescents described that parents' ultimate purchasing of requested foods are often dependent on the number, type, or cost of the items an adolescent suggests. Some adolescents explained that they are motivated to accompany parents during grocery shopping since being physically present increases the likelihood of their parent(s) purchasing an adolescents' requested food items. Still, others indicated they are not involved in selecting grocery items for their household either in advance or during a shopping trip.

Control Perceptions

Differing perceptions of control over their food choices was a dimension of adolescent eating autonomy that emerged in focus groups. Adolescents described having differential control over their food choice in association with eating occasions (such as dinner or snacks), time periods (such as weekends), and physical environments (such as home or restaurants). When participants described control in terms of eating occasion, about one third of adolescents referenced lunch and nearly one third mentioned breakfast as eating occasions in which they experienced higher levels of control over their food choice. Adolescents also described differences in control over their food choices based on schedule and time priorities; where reduced control was related to busy schedules and higher control was associated with periods of free time (such as the weekend). *"… So, like at home a little bit more freedom. Weekends, little bit more, but not during the day at school."*

Adolescents also commented on their perceived level of control over their food choices in specific environments. The most commonly mentioned settings (one-third of participants) in which adolescents expressed having a high degree of control over their food choices were home and restaurants. However, the home setting was also commonly cited as a setting in which adolescents perceived low control (25% of participants) depending on the meal. Expressions of low control over food choices in the home were commonly associated with the dinner/family meal and having to eat what parents prepare, having *"no choice in the matter"*. When adolescents expressed having high control over food choice at restaurants, it was described mostly within the context of control over one's meal choice or choice over the restaurant itself. Only 3 adolescents expressed having high control over their food choices at school.

Perceived Parental Restriction

Adolescents reported that their food choice autonomy is restricted by parent(s) through various means. Teens described experiencing parental restriction through limitations on "unhealthy" food consumption, food costs, to prevent food waste, and parental over-promotion of "healthy eating." Adolescents explained that some parents attempt to limit anything *"too unhealthy" (*such as chips and sugary items) by not purchasing them or verbally discouraging their consumption. Some expressed that they wished their food choices were less restricted by parents because they want to experience new foods inside the home and at restaurants. One teen explained, *"…I want to be able to eat stuff and trying new stuff. But sometimes she does restrict me more than she probably should."* Some adolescents noticed differences in how family members influence the restriction of the adolescent's food choices. For example, one teen explained that their father's strictness about healthy eating results in less choice when in their company than compared to when alone or with someone else. Other adolescents described their food choices being more restricted when the whole family was home or related to dinner or the family meal.

Perceived Parental Awareness and Approval of Adolescents' Food Choices

Adolescents make food choices that may or may not align with their parents' wishes. Two out of three adolescents felt that their parent(s) would like them to make different food choices; adolescents cited that their parents wanted their food choices to reflect more overall balance, reduced sugar intake, and increased fruit and vegetable consumption. Adolescents also perceive a range of parental awareness regarding their food choices. About one in five adolescents referenced their parent(s) being largely aware of the food choices made when they are not present. Another 18% of adolescents mentioned moderate parental awareness and 15% perceived their parent(s) were only minimally aware of what they eat and drink on their own.

Differences in parental awareness regarding adolescents' independent food choices may be based on different levels of parental inquiry. Many adolescents stated that their parent(s) ask about their independent food choices at least some of the time. In response to parent inquiry, some adolescents openly disclose information, while others intentionally omit items that their parent(s) disapprove of, or do not disclose their food choices at all. *"No. I don't tell them. Like I'm not supposed to eat chewy things, but I still do."* Some adolescents stated that their parent(s) never inquire about their independent food choices. In some cases, parents not asking about independent food choices was perceived as a sign of parental trust in the adolescents' decision making. Others expressed that their parent(s) approve of their independent food choices, partially because they regularly eat healthy, balanced diets in the home, so their parents are less concerned about unhealthy dietary choices made when adolescents are on their own.

DISCUSSION

This study examined factors adolescents perceive to influence their food choices across a range of environments. The study is unique in its investigation of adolescent food choices across an expansive range of environments, extending beyond the previous work of food choice within the home or school, and including factors across other settings (namely, stores and restaurants). In addition, adolescents were asked to consider both the eating occasion and social context, which makes this study more comprehensive than the prior work. Through this study, we identified the key features of the construct of adolescent eating autonomy toward the goal of better understanding adolescent food decision making. This is important because adolescence is a developmental period where eating habits are established that track into adulthood.

These results were used to organize our initial conceptualization of adolescent eating autonomy. **Figure 2A** summarizes the food-related behaviors in which adolescents experience a range of autonomy. Each of the food-related behaviors included here emerged from the focus group data as an autonomous behavior-of-interest, based on more than 30% of participants commenting on their experience in each area. **Figure 2B** presents some of the factors, identified from the autonomy development literature and throughout these results, that may enhance or infringe upon an adolescent's experience of eating autonomy.

Factors in Adolescent Food Choices

Research on determinants of food choice has found individual differences in the factors that are considered most influential (Köster, 2009). Under the personal food system of the food-choice process model, the top five values that have consistently emerged according to adults are taste, health, cost, convenience, and managing relationships (Connors et al., 2001). When examining adolescent food choices, our study found the most influential factors generally mirror those described in adults but differ based on environmental context. Consistent with prior qualitative work on adolescent food choices (Neumark-Sztainer et al., 1999; Sommer et al., 2014; Waddingham et al., 2018), this study found convenience and ease of preparation to be top factors in adolescent food decisions in the home, school, restaurant, and store environments. The current study replicated that schedule and time priorities were important factors in the contexts of the home and school environments (Neumark-Sztainer et al., 1999;

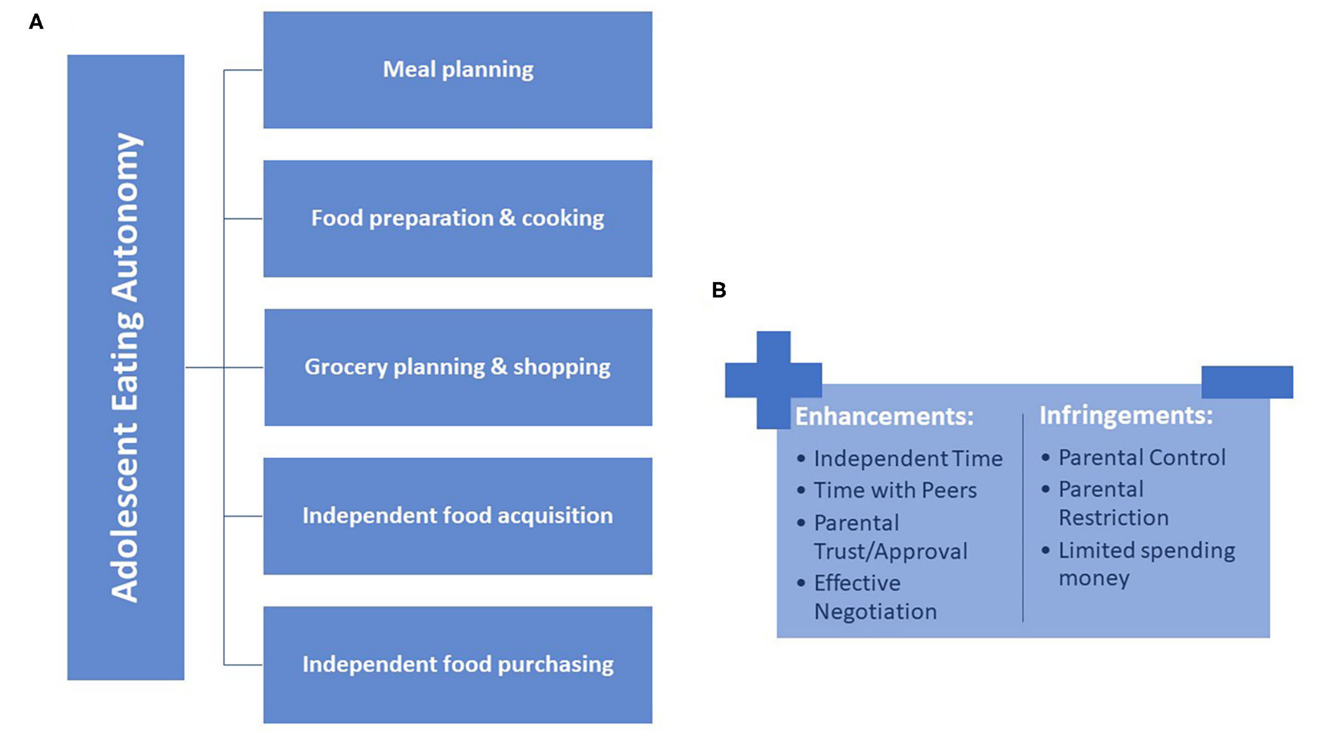

FIGURE 2 | Conceptual elements of adolescent eating autonomy. **(A)** Shows the emergent autonomous food-related behaviors in which adolescents have a range of engagement. **(B)** Shows the preliminary factors that may enhance or infringe upon an adolescent's experience of eating autonomy.

Contento et al., 2006; Holsten et al., 2012; Sommer et al., 2014), but not in restaurants and stores. We also found that when food healthfulness was mentioned, it was typically within the context of identifying whether a chosen food was considered unhealthy or not, rather than explaining that a food was selected based on health values. This is consistent with previous work showing that a food's perceived healthiness is not a dominant factor in adolescents' food choices (Croll et al., 2001; French et al., 2001; Waddingham et al., 2018).

Previous literature often cites the taste or physical properties of food as a top factor in food choices, among both adults (Köster, 2009) and adolescents (Neumark-Sztainer et al., 1999; Contento et al., 2006; Holsten et al., 2012; Sommer et al., 2014; Bawajeeh et al., 2020). However, we found that taste was only a predominant factor in discussions about food choices at school. This mirrors work by Share and Stewart-Knox (2012) who found, through quantitative factor analysis, that taste properties were not primary determinants of Irish adolescent food choices. One reason for this is the taste of food may be more highly valued in school-based food choices, where adolescents' selections are limited to options that are perceived to be low in palatability. In contrast, at home or at a restaurant, adolescents may have more palatable options from which to choose. Our work supports the idea that adolescents have reciprocal influences on their parents' behaviors which may play a role in ensuring their home food environment regularly contains items that they approve of in terms of taste (Crosnoe and Johnson, 2011).

Cost was a prominent factor in adolescents' descriptions of food choices in restaurants and stores. To our knowledge, only one previous study has identified cost as a factor in food decisions outside the home among adolescents with obesity (Watts et al., 2015). It is possible that cost is not commonly cited as a top factor in other work about adolescent food choices because a multitude of studies have focused on adolescent food choice when the food is freely available, such as in the home or in school, and not when food selection may be influenced by making a purchase with their own funds. It is also plausible that other studies have not often seen the prominence of cost because the concepts of cost and convenience may be highly linked according to adolescents (Share and Stewart-Knox, 2012).

Eating is a social experience for adolescents (Holsten et al., 2012; Sommer et al., 2014; Waddingham et al., 2018). We found that food choices described in restaurants and stores more often co-occurred with the presence of friends compared to school and the home, which had virtually no mentions of family or friends. Furthermore, we found that adolescents were often motivated by an openness to try new foods when at restaurants (including coffee shops), where teens may feel less constrained or find trying new foods more appealing among friends. Similarly, another study investigating food choice demonstrated the "enjoyment of foods as a learning process" as a main motivator particularly in the context of dining out at restaurants, where those adolescents with food allergies felt their freedom to experience openness was limited by their dietary restrictions (Sommer et al., 2014). While our work did not find adolescents' food choices to be motivated by peer influences specifically, other studies have shown that adolescents may select foods in order to conform to those around them, to comply with gender stereotypes (Chapman and Maclean, 1993), or to meet a perceived need to select "children's food" (like chicken nuggets or a white bread sandwich) as opposed to "adults' food" (such as a salad) (Ludvigsen and Scott, 2009).

Elements of Adolescent Eating Autonomy

This analysis identified the predominant elements comprising the construct of adolescent eating autonomy. While prior work identified concepts related to adolescent control over eating, this study is the first to synthesize and conceptualize the components of the construct. Initially, we defined adolescent eating autonomy as an adolescents' individual decision-making related to, and perceptions of control over, their food choices. This work further developed our understanding of the construct as being comprised of autonomous food-choice behaviors, for which adolescents have a range of engagement and perceived control. Furthermore, each of the autonomous food-choice behaviors may be influenced by factors which can expand, or infringe, upon adolescents' eating autonomy.

Bassett et al. (2008) suggest that adolescents' food choices are actively co-constructed through adolescents' exertions of autonomy and parental control mechanisms, which are expected to change over time (Bassett et al., 2008). For most of adolescence, we assume a parent/adolescent dynamic that is by nature interdependent. A number of food parenting practices (such as discussion, negotiation, and autonomy support) are known to play a role in building a child's self-regulation related to food (Di Pasquale and Rivolta, 2018). It is possible that autonomy-enhancing parenting practices may be related to adolescents' food choices during independent eating occasions (Reicks et al., 2020), but more controlled work needs to be done in order to distinguish adolescents' autonomous food decision making from parental influences.

Adolescents' perceptions of control over their food choice in different contexts may provide insight into their situational eating autonomy. Teens express having a range of control over their food choices based on eating occasion, time period, and environment, but the reasons for the differences in perceived control are unknown (Sommer et al., 2014). Our results mirror those of Contento et al. (2006) showing that dinner was the meal that demonstrated the greatest differences in perceived control (Contento et al., 2006). In most cases, their sense of control during dinner was constrained by the family meal in the home, unless the adolescents were engaged in other components of the meal planning, shopping, or preparation process. Availability of a variety of offerings at a given time was associated with higher perceived control over food choices in many environments. This points to the nuance of the element of control, where some may feel higher levels of control in situations where they simply have more items to choose from (such as on a restaurant menu). Others may feel more control in their immediate food choices (those based on hunger, taste, convenience) compared to choices based on more distant considerations addressed through complex behaviors (such as grocery shopping and planning).

Adolescents can demonstrate their eating autonomy through their food spending habits. This study found that adolescents often buy items that they want but a parent will not buy for them (such as popcorn at the movies or an energy drink at the grocery store). However, these autonomous spending behaviors were often associated with adolescents purchasing items viewed as treats, special occasions, items they normally don't have access to, or items outside of the household's meal plan. These findings suggest that adolescents' independent food choices are not indicative of their broader eating habits. Therefore, to better understand adolescents' food choices, we should first examine the extent and frequency for which different autonomous food-related behaviors occur.

Strengths and Limitations

This study has many notable strengths. First, it was conducted among a diverse group of unassociated adolescents in a community location, outside of the school and home environments. Second, the research team was guided by those with extensive experience in qualitative methodology and all focus group transcripts were coded by 3 independent coders. Third, this study investigated the food choices of adolescents, which is an understudied group. Finally, the results of this work have helped to define and delineate the novel construct of adolescent eating autonomy. This work begins to address the knowledge gap related to adolescents' food choice process.

This work also has a few limitations. While the sample was racial/ethnically representative of the population under age 18 in Erie County, NY, it was still a largely white population with a higher proportion of participants were from middle- and high-income categories, compared to the local population. Also, this qualitative analysis coded independent food choices only with explicit mentions of being without parent(s); therefore, some factors may have been missed if a participant failed to provide enough context. Finally, eating contexts with a high degree of overlap (for example the dinner meal, the home environment, and parental influences) presented challenges in drawing inferences from results.

CONCLUSIONS

Prior to this work, the factors related to adolescents' food choices had not been studied across the entirety of the diet and in a neutral setting. This study identified the main elements of adolescent eating autonomy with the aim of being able to quantify adolescents' amount of agency over their food choices. The findings from this study are being used to generate an adolescent eating autonomy scale, which is being tested, validated, and published by co-authors from this group. Assessing the level of involvement in specific autonomous eating behaviors will allow us to quantify the amount and frequency of adolescent's engagement in many food-related behaviors. We suspect that some dimensions of the eating autonomy construct may be strongly related to overall diet quality, obesity, dieting behavior, and other adolescent health outcomes.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the data are coded, merged qualitative transcripts of verbal conversations in the Atlas.ti program. Requests to access the datasets should be directed to Amanda M. Ziegler, amz9@buffalo.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The University at Buffalo Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AZ was responsible for study design, recruitment, data collection, coding, analysis, writing, and manuscript preparation. CK was responsible for coding, analysis, writing, and manuscript preparation. TM was responsible for data collection, coding, analysis, writing, and manuscript preparation. AG, RB, and LH was responsible for recruitment, data collection, and writing. LL and JT was responsible for study design, writing, and manuscript preparation. All authors contributed to the article and approved the submitted version.

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The Relative Reinforcing Value of Cookies Is Higher Among Head Start Preschoolers With Obesity

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The relative reinforcing value (RRV) of food measures how hard someone will work for a high-energy-dense (HED) food when an alternative reward is concurrently available. Higher RRV for HED food has been linked to obesity, yet this association has not been examined in low-income preschool-age children. Further, the development of individual differences in the RRV of food in early childhood is poorly understood. This cross-sectional study tested the hypothesis that the RRV of HED (cookies) to low-energy-dense (LED; fruit) food would be greater in children with obesity compared to children without obesity in a sample of 130 low-income 3- to 5-year-olds enrolled in Head Start classrooms in Central Pennsylvania. In addition, we examined individual differences in the RRV of food by child characteristics (i.e., age, sex, and reward sensitivity) and food security status. The RRV of food was measured on concurrent progressive-ratio schedules of reinforcement. RRV outcomes included the last schedule reached (breakpoint) for cookies (cookie Pmax) and fruit (fruit Pmax), the breakpoint for cookies in proportion to the total breakpoint for cookies and fruit combined (RRV cookie), and response rates (responses per minute). Parents completed the 18-item food security module to assess household food security status and the Behavioral Activation System scale to assess reward sensitivity. Pearson's correlations and mixed models assessed associations between continuous and discrete child characteristics with RRV outcomes, respectively. Two-way mixed effects interaction models examined age and sex as moderators of the association between RRV and Body Mass Index z-scores (BMIZ). Statistical significance was defined as $p < 0.05$. Children with obesity (17%) had a greater cookie Pmax [F (1, 121) = 4.95, p = 0.03], higher RRV cookie [F (1, 121) = 4.28, p = 0.04], and responded at a faster rate for cookies [F (1, 121) = 17.27, $p < 0.001$] compared to children without obesity. Children with higher cookie response rates had higher BMIZ (r = 0.26, $p < 0.01$); and RRV cookie was positively associated with BMIZ for older children (5-year-olds: t = 2.40, p = 0.02) and boys (t = 2.55, p = 0.01), but not younger children or girls. The RRV of food did not differ by household food security status. Low-income children with obesity showed greater motivation to work for cookies than fruit compared to their peers without obesity. The RRV of HED food may be an important contributor to increased weight status in boys and future research is needed to better understand developmental trajectories of the RRV of food across childhood.

Keywords: reinforcing value of food, obesity, energy density, children, low-income, food insecurity

INTRODUCTION

In the United States, changes in the environment, which have facilitated greater expression of obesity-related genes at a population level, are largely responsible for the obesity epidemic (Novak and Brownell, 2011). The current food environment promotes positive energy balance (Jeffery and Utter, 2003) due to easily accessible and abundant highly palatable, energy dense foods that, compared to healthier options, are cheaper and require minimal effort to obtain (Drewnowski, 2004; Novak and Brownell, 2011). Human brain circuitry is hard wired to respond to foods high in calories, sugar and fat (King, 2013). One factor that may contribute to excess energy intake in our modern food environment is the relative reinforcing value (RRV) of food, or motivation to eat, defined as how hard an individual will work to access a food when an alternative food or non-food reward is concurrently available (Epstein et al., 2007). Low-income children are disproportionately affected by obesity. On average, 23% of United States preschoolers have overweight or obesity (Ogden et al., 2014) while the prevalence of overweight and obesity among low-income preschoolers has been shown to range from 32 to 35% (Williams et al., 2004; Edmunds et al., 2006; Kimbro et al., 2007). The diets of low-income children are well below national dietary recommendations (Leung et al., 2013) and evidence suggests that among low-income children, those experiencing food insecurity (FI) are exposed to more obesogenic home food environments than their food secure counterparts (Nackers and Appelhans, 2013). The RRV of food is associated with higher weight across childhood (Temple et al., 2008; Rollins et al., 2014b; Kong et al., 2015; McCullough et al., 2017; Vervoort et al., 2017; Wong et al., 2019), yet this relationship has not been examined in low-income preschool-age children. Further, the association between FI and weight status in young children is mixed (Dinour et al., 2007; Eisenmann et al., 2011).

Rollins et al. (2014b) established a modified RRV task suitable for 3- to 5-year-olds in the childcare setting. Results showed that children with higher Body Mass Index z-scores (BMIZ) responded for food at a faster rate. Other studies with this age group reveal that the RRV of high-energy-dense (HED) to low-energy-dense (LED) food and the RRV of HED food to a non-food alternative (e.g., coloring or doing puzzles) are associated with overweight and higher BMIZ, respectively (McCullough et al., 2017; Wong et al., 2019). The generalizability of these findings is limited. First, study samples were relatively small and homogenous—highly educated, middle-to-upper-income. Second, two studies (McCullough et al., 2017; Wong et al., 2019) used sequential designs where children work for each reward one at a time, which may not generalize to the real world where eating typically involves choices between multiple foods (Epstein et al., 2007). Finally, although Rollins et al. (2014b) used a concurrent design, children worked for similar foods [two different shaped HED graham crackers (4.5 calories/gram)], prohibiting the examination of RRV by energy density.

It is also unclear how individual differences in the RRV of food develop across childhood. Child characteristics that have been linked to the RRV of food include age, sex, and reward sensitivity, a temperamental trait implicated in appetitive motivation and obesity risk (Blair, 2003). Two prior studies showed a positive (Rollins et al., 2014b) and null (Vervoort et al., 2017) association between the RRV of food and reward sensitivity. In addition, research examining sex and age differences is limited to a few studies. Research with preschoolers (Rollins et al., 2014b) and adolescents (Vervoort et al., 2017) shows that boys work harder for food than girls, yet a study conducted with school-age children found an association between the RRV of food and BMIZ among girls only (Gearhardt et al., 2017). With regard to age, responding for both food and monetary rewards increases from age three to five (Rollins et al., 2014b) and four to 14 years (Chelonis et al., 2011), respectively. However, it is unknown whether the association between the RRV of food and child weight becomes more pronounced across childhood and additional research on sex differences is needed given the inconsistent findings. Similarly, whether factors in the home environment influence the development of the RRV of food in children is poorly understood. Food deprivation increases the RRV of food (Epstein et al., 2003; Raynor and Epstein, 2003); and although caloric deprivation is no longer common in the United States, limited access to food resulting from FI may lead to increases in food reinforcement (Crandall and Temple, 2018). Two recent studies with adults support this notion (Crandall and Temple, 2018; Crandall et al., 2020). One study showed increases in the RRV of food in response to experimentally manipulated scarcity among food insecure, but not food secure individuals (Crandall and Temple, 2018). Another study conducted with pregnant women found an association between very low food security and higher RRV of food (Crandall et al., 2020). Whether the RRRV of food differs by food security status has not been examined in children.

The current cross-sectional study examined the RRV of HED (cookies; >4 kcal/g) to LED (fruit; <1 kcal/g) food in a sample of low-income 3- to 5-year-olds using a concurrent design in the children's naturalistic setting (i.e., school). The first objective was to test the hypothesis that children with obesity would have a higher RRV of cookies vs. fruit than children without obesity. The second objective was to examine whether the RRV of food is associated with child characteristics (i.e., age sex, and reward sensitivity) and food security status, and to explore children's age and sex as moderators of the association between the RRV of food and BMIZ. Based on previous research (Rollins et al., 2014b; Vervoort et al., 2017; Crandall and Temple, 2018; Crandall et al., 2020), we hypothesized that: (1) compared to girls, boys would respond more and at a faster rate for both cookies and fruit, (2) older children would respond more for cookies and fruit, and (3) the RRV of cookies to fruit would be positively associated with BMIZ, reward sensitivity, and FI.

MATERIALS AND METHODS

Participants

Child-caregiver dyads enrolled in Head Start in Central Pennsylvania were recruited from 15 full-day classrooms within eight Head Start centers. Teachers sent recruitment letters and study packets home with all children in participating classrooms at the beginning of fall 2018 (seven classrooms) and spring 2019 (eight classrooms). Study packets included a caregiver survey and a child consent form. The caregiver survey utilized implied consent, and instructions were provided for returning the survey in the mail. Out of 235 study packets distributed across both semesters, 199 caregiver surveys were returned (85%). The child consent form included directions for signing one of two signature lines: one that provided consent for their child's participation or one that denied consent. Caregiver participation in the survey was not required for consented children to participate in the RRV task or to obtain height and weight measurements ($n = 213$; 91%). Caregivers received a $40 gift card for returning the survey and each participating classroom was compensated with a $100 gift card to purchase supplies for their classroom. The majority of caregiver respondents were parents/legal guardians (94%; 5% grandparents; 1% foster parent) and are referred to as parents hereinafter.

The current study was designed to examine the relationship between FI and the RRV of food, which has not been previously studied in children. Prospective power calculations to determine sample size were made based on a study with preschoolers reporting mean differences in the RRV of food by weight status (McCullough et al., 2017). Our power calculations indicated that we would need 48 participants per each of two food secure groups (total of 96), to detect an effect size (Cohen's d) of 0.58 (McCullough et al., 2017), assuming nominal power of 0.80, and $p < 0.05$. Based on previous data (Na et al., 2020), we anticipated a FI rate between 30 and 40% and five to seven children from FI households per each classroom of approximately 18 children. We also anticipated the possibility of low child enrollment in our study. Thus, to ensure that we reached our enrollment goal of 48 FI children, we aimed to recruit a minimum of 12 classrooms (i.e., ∼140 food secure children and 75 FI children). A consort diagram showing study recruitment, with enrollment statistics, is provided in **Figure 1**. Resources were limited (e.g., staff time, travel costs) due to higher-than-expected child enrollment during fall 2018. Additionally, as predicted, we had an imbalance in the number of FI participants at the end of fall 2018 (i.e., 25 FI vs. 47 food secure). Thus, to reduce costs and to ensure reasonable representation of the FI group, a weighted selection process was developed and used in classrooms that participated in spring data collection. One research staff member, who did not participate in data collection, examined parent surveys and determined food security status. For each classroom, survey results on food security status were used to categorize consented children as FI or food secure. The same research staff member randomly selected a child from a food secure household for each participating FI child per classroom to ensure that research staff collecting RRV data remained blinded to children's food security status. Data collection was discontinued in Spring 2019 once all FI children with a completed survey had participated in the RRV task, which resulted in 113 children with food security and RRV data (41% FI; 59% food secure). As a result, 64 consented children were not selected to participate in the RRV task. Head Start teachers provided children's food allergy information, and one child was excluded prior to data collection due to an allergy to a study food. Children were also dropped from the study because they withdrew from Head Start ($n = 5$), refused to participate in the RRV task ($n = 8$), or had the session terminated prior to the task due to behavioral difficulties ($n = 1$).

Procedure

Prior to data collection, study staff members visited each participating classroom to familiarize children with the study foods. Study foods were introduced one at a time and children had the opportunity to taste each food. Up to two make-up familiarization days were provided for classrooms in which children were absent at the initial visit. Three participants were absent on all familiarization days. Excluding these three children did not change results, thus they were retained in the current analyses. The RRV task was administered in a study session initiated 60–120 min after children had a typical Head Start provided lunch. In the study session, children completed the hunger assessment, liking assessment, and the RRV of food task. Following completion of the RRV task, children had the opportunity to eat the food portions earned during the task. The hunger assessment was then re-administered, and foods were weighed in order to calculate energy intake. This study was approved by the Office for Research Protections at The Pennsylvania State University, United States.

Measures

RRV of Food Task

The RRV of cookies and fruit were assessed using the RRV of food task (Epstein et al., 2007), adapted for young children and suitable for use in the childcare setting (Rollins et al., 2014b). The RRV task was administered to children in individual data collection stations at Head Start centers. Stations were set up following the protocol developed by Rollins et al. (2014b) (**Figure 2**). With the exception of one classroom that was its own free-standing building, children were removed from their classroom and completed the RRV task in a separate room. To reduce distractions, children were asked, but not required, to wear noise canceling headphones during the task. Children had the option to work to gain access to small portions of cookies on one mouse or small portions of fruit on a second

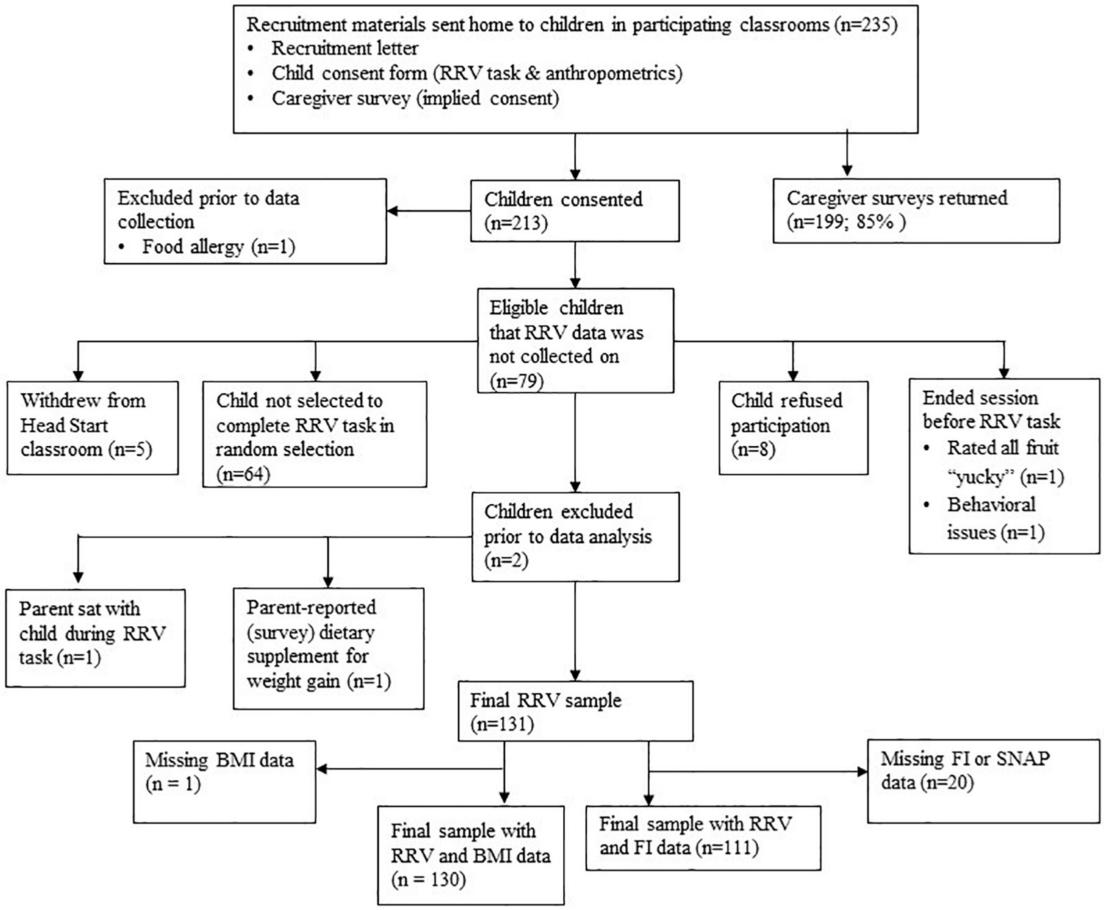

FIGURE 1 | Consort diagram.

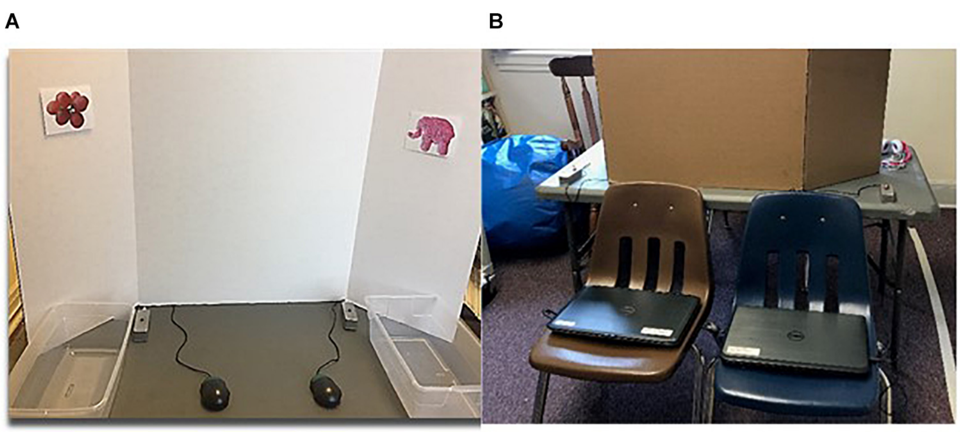

FIGURE 2 | Data collection station for the relative reinforcing value (RRV) of food task. **(A)** Child's view during the RRV task. **(B)** Computer set-up that is hidden from children's view.

mouse. Children were instructed that pressing the mouse to their right would earn them cookies and pressing the mouse to their left would earn them fruit. A picture of the cookie and fruit was placed above its corresponding mouse and a light was positioned next to each picture that indicated when a food reward was earned. The foods were pre-portioned in clear condiment cups with lids. The three fruits were matched according to the weight of one portion as best as possible; fruit portions:

grapes (halved; ~18.2 g/portion), canned mandarin oranges (~16.5 g/portion), and canned pineapple (~17.9 g/portion); as were the weights for the cookies: Oreo minis™ (~6.4 g/portion), Fudge stripes minis™ (~7.1 g/portion), and Circus animal® cookies (~7.1 g/portion). Within food categories, gram weight was balanced to keep calories consistent regardless of the fruit or cookie chosen. Matching across food categories would have resulted in larger portions of fruit compared to cookies. To avoid a potential portion size effect (i.e., clicking more for fruit or consuming more fruit as a function of a size-related visual cue) (Fisher and Kral, 2008), the gram weight was not matched across food categories. The canned fruits were in 100% juice and the juice was drained prior to being portioned out. Upon earning a reward, the pre-portioned food was placed in a clear bin next to its respective mouse. Both mice, which were connected to hidden computers, were on independent, concurrent progressive-ratio (PR) schedules of reinforcement. The PR schedules began at four and doubled each time a reward was earned; this means that a food portion was earned after 4 clicks on the first trial, then 8 clicks on the second trial, and so on, with a maximum of 8 trials (i.e., 4, 8, 16, 32, 64, 128, 256, and 512 clicks). This PR schedule has been used in prior studies with older children and preschoolers (Temple et al., 2008; Rollins et al., 2014b).

Before the RRV task, instructions were given (and repeated back) and children completed a practice round. Children were told that they could only click one mouse at a time, that they could stop earning food at any time, and that they could not eat their food rewards throughout the task but would have the opportunity to eat what they earned after the task. A scripted phrase (i.e., "here's what you earned. You can earn more [food #1] by pressing the same button. You can earn [food #2] by pressing the other button") was stated after the first food portion was earned to ensure children's understanding. Scripted reminders of the rules (e.g., "remember, press this button to earn fruit and this button to earn cookies") were provided at the beginning of the task if a child looked confused. Children completed the task independently while a research staff member was nearby to provide food portions earned, to answer questions, or when necessary, to remind the child of the rules. Children had up to 20 min to complete the task but could stop prior to 20 min upon indicating they were done. If a child looked as if they had completed the task, they were asked if they were finished and confirmed by asking, "are you done playing"? Next, children were given a 10-min snack session to eat the cookies and fruit that they earned during the task. Cookies and fruit were placed in separate bowls and were weighed pre- and post-snack time to determine the amount consumed (gram weight). Product label information was used to determine the energy density (ED) (kcals/grams) of each food and energy intake was calculated (kcals = ED × grams).

The RRV of food, operationalized as the breakpoint for one food in proportion to the breakpoint for both foods, was calculated for cookies [RRV cookie = cookie Pmax/(cookie Pmax + fruit Pmax)] (Kong et al., 2015). The breakpoint for each food, operationalized as the highest trial in which responses were made, was determined for cookies (cookie Pmax) and fruit (fruit Pmax). The breakpoint reflects the reinforcing value of a reward, and a reward with a higher breakpoint is considered more reinforcing than a reward that a participant stops responding for earlier (Epstein et al., 2007). RRV of cookie greater than 0.5 indicates that more trials were completed for cookies (i.e., had a higher breakpoint for cookies) and that the child was more motivated to gain access to cookies compared to fruit. A mean response rate for each food was calculated by averaging the number of responses (button presses) per minute across all trials (Rollins et al., 2014b).

Hunger Assessment

Children's hunger level before and after the RRV task was measured using a modified version of a protocol that has been used in previous studies with preschoolers (Fisher and Birch, 2002). Children were read a story about a little boy/girl who can see inside his/her tummy. Three pictures were presented ranging from hungry to full, depicted by the child with (1) an empty stomach, (2) a half empty/full stomach, and (3) a full stomach. Children were asked to repeat back which picture showed the child with the empty, half empty/full, and full stomach to ensure children's comprehension. Next, children were asked to think about how their stomach feels and to indicate their own level of hunger/fullness on a three-point scale using the three pictures of the little boy/girl.

Liking Assessment

Children's liking of the study foods was measured prior to the RRV task using a liking assessment established by Birch (Birch, 1979). Children were first familiarized with three faces visually representing "yummy," "just okay," and "yucky." Each food, pre-portioned for the RRV task in a clear condiment cup, was presented to children one at a time in a pre-selected order. The three fruits (i.e., red grapes, oranges, and pineapple) were presented first followed by the three cookies [i.e., Oreo minis™ (Nabisco Co., East Hanover, NJ, United States), Fudge stripes minis™ (Keebler Co., Battle Creek, MI, United States), Circus animal® cookies (Mother's Co., United States)]. Children did not taste the foods due to time constraints at schools, but each food was identified before (e.g., "these are grapes") and during (e.g., "Do you think grapes are yummy, yucky, or just okay?") the rating for each food. Utilizing the three pictures, children were asked to categorize whether they thought each fruit was "yummy," "yucky," or "just okay." If a child categorized more than one fruit as "yummy," they were asked to choose the "yummiest." If none of the fruits were categorized as "yummy," children were asked to select the "yummiest" from the fruits categorized as "just ok." This process was then repeated for cookies. A child's highest rated fruit and highest rated cookie were utilized for the subsequent RRV of food task. The RRV task was not performed if a child rated all three fruits or all three cookies as "yucky" ($n = 1$).

Child Anthropometry

Trained research staff measured children's height and weight in duplicate. A portable stadiometer (Model 217; Seca Corporation) and digital scale (Model 843; Seca Corporation) were used to measure height and weight, respectively. A third height measurement was made if the first two differed by more than 1 cm, and a third was made for weight if the first two differed at all. BMI percentiles and BMIZ were calculated based on the 2000 CDC Growth Charts (US Centers for Disease Control and Prevention, 2002). Height and weight measurements were averaged for BMI percentile calculations; child age was calculated using children's date of birth and the date that measurements were obtained. BMI percentiles <85th, ≥85th, and ≥95th classified children as having normal weight, overweight, and obesity, respectively. Due to space and time constraints, we were unable to measure children's heights and weights immediately following the RRV task, therefore measurements were taken on the same day for most children in each classroom following RRV data collection. If participating children were absent when measurements were obtained, make-up days were scheduled through the end of data collection during each semester. On average, anthropometric data were collected 19 days after data collection, with a range of 0 to 64 days. Five children's measurements were obtained two to 14 days prior to RRV data collection.

Questionnaires

Parents reported household food security status using the 18-item U.S. Department of Agriculture Household Food Security Module (HFSSM) (Coleman-Jensen et al., 2019). Children were considered FI if three or more of the 18 items were answered affirmatively and food secure if less than three of the 18 items were answered in the affirmative. Parent-reported reward sensitivity was measured using the child version (Blair, 2003; Blair et al., 2004) of the Behavioral Activation System (BAS) scale (Carver and White, 1994), a 13-item measure consisting of three subscales: drive ("My child goes out of his/her way to get something he/she wants"; four items), reward responsiveness ("It would excite my child very much to win a prize"; five items), and fun seeking ("My child acts on the spur of the moment"; four items). Response options range from 1 = "extremely untrue" to 7 = "extremely true." A mean score of the three subscales was calculated to create a composite BAS scale ($\alpha = 0.88$). Parents also self-reported their age, race/ethnicity, height/weight, education, marital status, income, employment, participation in the Supplemental Nutrition Assistance Program (SNAP) and the Supplemental Nutrition Program for Women Infants and Children (WIC) over the past 12 months, and child race/ethnicity. Child sex and date of birth were obtained from Head Start administrators.

Statistical Analysis

The RRV outcomes analyzed included: the breakpoint for cookies (cookie Pmax), the breakpoint for fruit (fruit Pmax), the RRV of cookies as described previously, response rates for cookies and fruit, and post-task energy intake. To examine mean differences between cookies and fruit for the RRV outcomes and post-task energy intake, paired *t*-tests were used. To examine associations between RRV outcomes and continuous child characteristics (i.e., age in years, BMIZ, reward sensitivity), Pearson correlations were used. In addition to the total sample, correlations between RRV outcomes and continuous child characteristics were examined among children with normal weight ($n = 76$) and among children with overweight or obesity ($n = 54$). To examine differences in RRV outcomes by discrete characteristics (i.e., sex and age group), individual mixed models were conducted with the child characteristic as the independent variable and each RRV outcome as the dependent variable. *Post hoc* analysis with a Tukey's adjustment for multiple comparisons was used to determine differences between 3-, 4-, and 5-year-olds. For mixed models with child sex as the independent variable, controlling for child age did not change results. For mixed models with child age as the independent variable, controlling for child sex did not change results. In addition, results regarding age and sex were similar after adjusting for BMIZ. Individual two-way mixed effects interaction models were used to examine the potential moderating role of age and sex on the association between the RRV of food and BMIZ. To examine differences in RRV outcomes by food security status, individual mixed models were conducted for each RRV outcome with household food security status as the independent variable. Results from models that included potential covariates (i.e., child sex, age, BMIZ, and SNAP participation) were similar, thus unadjusted models for differences in RRV outcomes by food security status are presented.

To assess differences in RRV outcomes by child weight status, individual mixed models were conducted. Initially, we examined differences in RRV outcomes for children with normal weight, overweight, and obesity. Based on trend-level differences for children with obesity compared to children with normal weight and children with overweight ($0.05 < p < 0.10$), and the observation that least squares means (LSmeans) responses for children with overweight were similar to children with normal weight, results are presented comparing children with obesity to children without obesity. One child was categorized as underweight (i.e., BMI percentile < 5%). Excluding this child did not change results, thus was retained in analyses examining the RRV of food by child weight status. In these models, two-way and three-way interactions between age, sex, and weight status on RRV outcomes were first tested. Interactions were not significant, and results did not change with the inclusion of age and sex as covariates, thus unadjusted main effects are presented.

Children's pre-task hunger and the time between the end of lunch and the start of the RRV task were considered as covariates in all mixed models examining RRV outcomes as the dependent variable. These variables were not associated with RRV outcomes, child BMIZ, or household food security status (all p values > 0.05), and were not included in final models. Because children were sampled from eight Head Start centers, center location was included as a random effect in all mixed models. The caregiver survey asked parents to describe any medications that their child currently takes. One child was excluded from the analytic sample due to daily use of a dietary supplement for weight gain. An additional child was excluded because a parent sat with the child during the RRV task. Children with missing BMI data ($n = 1$) were excluded resulting in a final analytic sample of 130. An additional 20 participants were missing food security or SNAP data resulting in an analytic sample of 111 for analyses examining the relationship between FI and RRV outcomes. All analyses were performed using SAS Version 9.4 (SAS Institute

Inc., Cary, NC, United States). Statistical significance was defined as $p < 0.05$ for all analyses.

RESULTS

Sample Characteristics

Parent and child characteristics are shown in **Table 1**. The majority of parents were female (89%). On average, children were 4.49 ± 0.55 (Mean ± SD) years old and approximately half of the sample was female (52%). Children were predominantly white, non-Hispanic and from low-income, less educated households. Child BMI percentiles were 72.62 ± 24.98 (M ± SD), 25% of children were classified as having overweight, and 17% of children had obesity, which exceeds the national estimate for obesity prevalence among 2- to 5-year-old children (Hales et al., 2017). The prevalence of household FI was high (41%) and 77% of parents reported SNAP participation.

Descriptive statistics for the study session (i.e., hunger, liking, and RRV outcomes) are presented in **Table 2**. Two children earned the maximum number of cookie and fruit portions (i.e., eight portions of each food), six children worked for cookies only, and 10 children worked for fruit only. On average, children worked 9.5 ± 6.1 min (mean ± SD) to access the foods. Paired *t*-tests showed that children had a higher breakpoint (5.0 ± 2.1 vs. 4.6 ± 2.2, $p = 0.02$) and had higher response rates (63.9 ± 30.0 vs. 58.7 ± 30.0, $p = 0.03$) for cookies compared to fruit. All RRV outcomes were correlated; RRV cookie was positively associated with cookie response rates ($r = 0.31$, $p < 0.001$) and negatively associated with fruit response rates ($r = -0.41$, $p < 0.001$). Cookie Pmax was positively associated with fruit Pmax ($r = 0.50$, $p < 0.001$), cookie response rates ($r = 0.65$, $p < 0.001$) and fruit response rates ($r = 0.32$, $p < 0.001$). Finally, fruit Pmax was positively associated with both cookie ($r = 0.27$, $p < 0.01$) and fruit ($r = 0.57$, $p < 0.001$) response rates. Additionally, RRV cookie, cookie and fruit Pmax, and response rates were positively associated with post-task energy intake (*r*'s = 0.17–0.62, *p* values < 0.05).

Differences in the RRV of Food by Weight Status

Mixed model analyses revealed differences in the RRV of cookies by child weight status (**Figure 3**). Children with obesity had higher RRV cookie [F (1, 121) = 4.28, $p = 0.04$], cookie Pmax [F (1, 121) = 4.95, $p = 0.03$], and cookie response rates [F (1, 121) = 17.27, $p < 0.001$] compared to children without obesity. There were no differences by weight status for fruit Pmax, fruit response rates, or post-task energy intake.

The RRV of Food and Child Characteristics

Bivariate associations between the RRV of food and child characteristics are shown in **Table 3**. In the total sample, cookie Pmax ($r = 0.17$, $p = 0.049$), cookie response rates ($r = 0.29$, $p = 0.001$), and fruit response rates ($r = 0.20$, $p = 0.024$) were positively associated with child age. Cookie response rates were

TABLE 1 | Child and parent characteristics by child sex.

		Total Sample (*n* = 130)	Male (*n* = 62)	Female (*n* = 68)	
Characteristic	**N[2]**	***M* (SD)**	***M* (SD)**	***M* (SD)**	***p* value**
Parent and household					
Age[1], years	106	31.49 (8.60)	32.08 (10.61)	30.94 (6.24)	0.76
Sex (%)	113				0.47
Female		89	91	86	
Male		11	9	14	
BMI	112	30.81 (9.95)	31.17 (11.71)	30.47 (8.07)	0.71
Race, *n* (%)	111				0.88
White		91	91	91	
Non-white		9	9	9	
Ethnicity (%)	107				0.57
Hispanic		5	94	96	
Non-Hispanic		95	6	4	
Education, *n* (%)	113				0.10
<High school degree		17	11	22	
High school degree		38	39	37	
Some college/technical school		32	37	27	
College degree		12	11	12	
Post-graduate training/degree		2	2	2	
Marital status, *n* (%)	113				0.28
Married		25	19	31	
Living with a partner		26	20	31	
Single		28	37	20	
Divorced/separated		19	20	19	
Widowed/other		2	4	0	
Annual household income, *n* (%)	93				0.20
<$10,000		32	35	30	
$10,000–$19,999		18	16	20	
$20,000–$29,999		24	19	28	
$30,000–$49,999		22	23	20	
≥$50,000		4	7	2	
Employment (%)	113				0.05
Unemployed		39	30	53	
Employed		61	70	47	
Food security status (%)	111				0.46
Food insecure (FI)		41	37	44	
Food secure		59	63	56	
SNAP participation (%)	112				0.18
Yes		78	72	83	
No		22	28	17	
WIC participation (%)	109				0.22
Yes		64	58	70	
No		36	42	30	

(Continued)

TABLE 1 | Continued

Characteristic	N[2]	Total Sample (*n* = 130) *M* (SD)	Male (*n* = 62) *M* (SD)	Female (*n* = 68) *M* (SD)	*p* value
Child characteristics					
Age, years	130	4.49 (0.55)	4.52 (0.55)	4.47 (0.55)	0.61
Race, *n* (%)	109				0.50
White		84	87	82	
Non-white		16	13	18	
Ethnicity, non-Hispanic (%)	107				0.60
Hispanic		7	8	5	
Non-Hispanic		93	91	95	
BMI percentile	130	72.61 (24.98)	71.56 (24.68)	73.56 (25.40)	0.65

SNAP, Supplemental Nutrition Assistance Program; WIC, Special Supplemental Nutrition Program for Women, Infants, and Children (WIC).
Differences in participant characteristics by sex were examined using t-test for normal continuous variables, the Mann–Whitney U test for non-normal continuous variables, [1]Chi-square test for binary variables, and Mantel-Haenszel chi-square for categorical variables. [2]Missing data for parent-reported characteristics because child participation was not contingent on parents completing a survey.

also positively associated with age among children with normal weight ($r = 0.25$, $p = 0.03$) and children with overweight/obesity ($r = 0.32$, $p = 0.02$); however, fruit response rates were only associated with age among children with normal weight ($r = 0.36$, $p = 0.001$). In addition, fruit Pmax was positively associated with age among children with normal weight only ($r = 0.25$, $p = 0.03$). Cookie response rates were positively associated with BMIZ ($r = 0.26$, $p = 0.003$) in the total sample, but this association was driven by children with overweight/obesity ($r = 0.33$, $p = 0.02$). Among children with overweight/obesity only, RRV cookie ($r = 0.28$, $p = 0.04$), post-task cookie intake (kcals; $r = 0.28$, $p = 0.049$), and total energy intake (kcals; $r = 0.28$, $p = 0.04$) were positively associated with child age; and RRV cookie was positively associated with BMIZ ($r = 0.28$, $p = 0.04$). RRV outcomes were not associated with reward sensitivity (p values > 0.05). As shown in **Table 4**, children aged 4 and 5 years responded at a faster rate for cookies [$F(2, 120) = 8.08$, $p < 0.001$] compared to 3-year-olds; and 4-year-olds had a higher breakpoint for cookies (cookie Pmax) [$F(2, 120) = 3.70$, $p = 0.03$] and responded at a faster rate for fruit compared to 3-year-olds [$F(2, 120) = 3.62$, $p = 0.03$]. Sex differences were not observed. Sex was evenly distributed across age groups and did not account for any of the significant associations between RRV and age (data not shown).

Next, we examined the potential moderating effect of child sex and age group on the relationship between RRV outcomes and BMIZ (**Figure 4**). There was an interaction between RRV cookie and child age [$F(3, 123) = 2.86$, $p = 0.04$] such that among 5-year-olds, RRV cookie increased with increasing BMIZ ($t = 2.40$, $p = 0.02$). RRV cookie was not associated with BMIZ among 3-year-olds ($t = -0.65$, $p = 0.52$) or 4-year-olds ($t = 1.55$, $p = 0.12$). In addition, there was an interaction between RRV cookie and sex on BMIZ [$F(2, 126) = 3.25$, $p = 0.04$] such that RRV cookie increased with increasing BMIZ for boys ($t = 2.55$, $p = 0.01$) but not girls ($t = -0.13$, $p = 0.90$). The interactions between RRV cookie and sex and RRV cookie and age on BMIZ did not change in models adjusting for age and sex, respectively (data not shown).

The RRV of Food and Household Food Security Status

Least squares mean (LSmean) differences in RRV outcomes did not differ significantly by household food security status (p values > 0.05).

DISCUSSION

This study assessed differences in the RRV of HED (cookies) to LED (fruit) food by weight status and examined whether the

TABLE 2 | Descriptive statistics for the RRV of food task (*n* = 130).

Measure	Mean (SD)	Range	
Time from lunch end to task start (min)	90.8 (17.5)	50.0–138.0	
Task duration, min	9.5 (6.1)	1–20	
Hunger assessment			
Pre-task	2.3 (0.8)	1–3	
Post-task	2.6 (0.7)	1–3	
Liking assessment–cookies, *n* (%) yummy[1]			*n* (%) chosen
Oreo minis™	97 (75)	1–3	35 (27)
Fudge stripes minis™	82 (63)	1–3	22 (17)
Circus animal® cookies	99 (77)	1–3	73 (56)
Liking Assessment–fruit, *n* (%) yummy[1]			*n* (%) chosen
Red grapes	98 (75)	1–3	79 (61)
Mandarin oranges (canned)	75 (58)	1–3	35 (27)
Pineapple (canned)	66 (51)	1–3	16 (12)
RRV task outcomes			
RRV cookie	0.53 (0.2)	0–1	
Cookie Pmax	5.0 (2.1)	1–8	
Fruit Pmax	4.6 (2.2)	1–8	
Cookie response rate (responses/min)	63.9 (30.0)	0.0–132.2	
Fruit response rate (responses/min)	58.7 (30.0)	0.0–124.2	
Post-task energy intake (kcals)			
Total	161.0 (86.0)	0.0–403.8	
Cookies	132.7 (79.3)	0.0–371.8	
Fruit	28.3 (25.7)	0.0–108.1	
Post-task energy intake (grams)			
Total	77.4 (46.0)	0.0–183.8	
Cookies	26.1 (15.5)	0.0–71.5	
Fruit	51.2 (42.3)	0.0–143.7	

Pmax, maximum schedule of reinforcement reached; RRV, relative reinforcing value. RRV cookie is the breakpoint for cookies in proportion to the total breakpoint for both cookies and fruit [RRV cookie = Cookie Pmax/(Cookie Pmax + Fruit Pmax)]. Calories (kcals) consumed were calculated using the post-weight and energy density (ED) of the food (kcals = ED × gram weight). Product label nutrition facts were used to determine the ED of study foods: Oreo minis™ (4.83 kcals/g); Fudge stripes minis™ (5.00 kcals/g); Circus animal® cookies (5.20 kcals/g); red grapes (0.40 kcals/g); mandarin oranges (0.85 kcals/g); pineapple (0.85 kcals/g).
[1]Children indicated whether each food was yummy (1), just ok (2), or yucky (3).

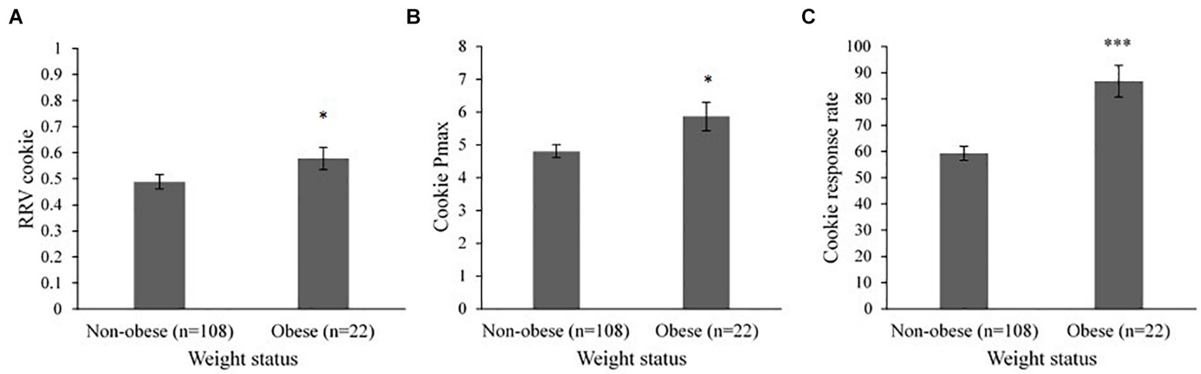

FIGURE 3 | Mixed model analysis showing least squares means (LSmeans) ± SE differences in RRV cookie, cookie Pmax, and cookie response rates for children without obesity vs. children with obesity (n = 130). Head Start center (n = 8) was included as a random effect in all models. **(A)** Children with obesity (LSmean = 0.58 ± 0.04) had higher RRV cookie compared to children without obesity (LSmean = 0.49 ± 0.03, p = 0.04). **(B)** Children with obesity (LSmean = 5.86 ± 0.43) had higher cookie Pmax compared to children without obesity (LSmean = 4.81 ± 0.20, p = 0.03). **(C)** Children with obesity (LSmean = 86.78 ± 6.03) had higher cookie response rates compared to children without obesity (LSmean = 59.27 ± 2.72, $p < 0.001$). RRV, relative reinforcing value; Pmax, maximum schedule of reinforcement reached. RRV cookie is the breakpoint for cookies in proportion to the total breakpoint for both cookies and fruit [RRV cookie = Cookie Pmax/(Cookie Pmax + Fruit Pmax)]. Response rate is responses per minute. *$p < 0.05$, ***$p < 0.001$.

TABLE 3 | Pearson's correlation coefficients for RRV outcomes and child characteristics by weight status (n = 130).

	Total sample (n = 130)			Normal weight (n = 76)			Overweight/obesity (n = 54)		
	Age (years)	BMIZ	Reward Sensitivity	Age (years)	BMIZ	Reward Sensitivity	Age years)	BMIZ	Reward Sensitivity
RRV cookie	0.02	0.13	0.10	−0.17	0.05	0.15	**0.28***	**0.28***	0.04
Cookie Pmax	**0.17***	0.09	0.12	0.14	0.05	0.15	0.22	0.13	0.06
Cookie response rate (responses/min)	**0.29****	**0.26****	0.12	**0.25***	0.00	0.18	**0.32***	**0.33***	0.04
Fruit Pmax	0.11	−0.03	−0.03	**0.25***	0.01	−0.01	−0.08	−0.16	−0.08
Fruit response rate (responses/min)	**0.20***	0.00	0.05	**0.36****	−0.06	0.03	−0.02	−0.14	0.08
Post-task cookie intake (kcals)	0.10	−0.03	0.16	0.00	0.09	0.14	**0.27***	−0.06	0.18
Post-task fruit intake (kcals)	0.14	−0.03	−0.02	0.17	0.02	−0.01	0.10	−0.07	−0.03
Post-task energy intake (kcals)	0.14	−0.01	0.14	0.05	0.09	0.13	**0.28***	−0.07	0.16
Post-task cookie intake (grams)	0.11	−0.03	0.15	0.00	0.09	0.15	**0.28***	−0.06	0.15
Post-task fruit intake (grams)	0.10	0.04	−0.02	0.12	−0.02	−0.05	0.06	−0.08	0.01
Post-task energy intake (grams)	0.13	0.02	0.03	0.11	0.02	0.01	0.14	−0.10	0.06

*Pmax, maximum schedule of reinforcement reached. RRV, relative reinforcing value. RRV cookie is the breakpoint for cookies in proportion to the total breakpoint for both cookies and fruit [RRV cookie = Cookie Pmax/(Cookie Pmax + Fruit Pmax)]. Calories (kcals) consumed were calculated using the post-weight and energy density (ED) of the food (kcals = ED × gram weight). Product label nutrition facts were used to determine the ED of study foods: Oreo minis™ (4.83 kcals/g); Fudge stripes minis™ (5.00 kcals/g); Circus animal® cookies (5.20 kcals/g); red grapes (0.40 kcals/g); mandarin oranges (0.85 kcals/g); pineapple (0.85 kcals/g). [1]Behavioral Activation System (BAS) mean score. Response options, 1 = "Extremely untrue" to 7 = "Extremely true" [n = 106 due to missing parent-reported demographics (n = 17) and BAS scale (n = 7)]. *p ≤ 0.05, **p < 0.01. Bold significant correlations indicated with stars for ease of interpretation.*

RRV of food is associated with child characteristics (i.e., age sex, and reward sensitivity) and food security status in a sample of low-income children. Our results showed that children with obesity were more motivated to gain access to cookies relative to fruit compared to children without obesity. On average, children responded more for cookies and at a faster rate for cookies compared to fruit, which is consistent with prior studies (McCullough et al., 2017; Vervoort et al., 2017). Older children responded more for cookies and at a faster rate for both cookies and fruit, and higher BMIZ was associated with a faster rate of responding for cookies. Although proportional responding for cookies to fruit (i.e., RRV cookie) was not directly associated

TABLE 4 | LSmeans (SE) differences in the RRV of cookies and fruit by preschooler age and sex[1].

	Age (years)			Sex	
	3 (*n* = 28)	4 (*n* = 77)	5 (*n* = 25)	Male (*n* = 62)	Female (*n* = 68)
RRV outcome	**LSmeans (SE)**	**LSmeans (SE)**	**LSmeans (SE)**	**LSmeans (SE)**	**LSmeans (SE)**
RRV cookie	0.49 (0.05)	0.51 (0.03)	0.52 (0.04)	0.50 (0.03)	0.52 (0.03)
Cookie Pmax	**4.07 (0.39)[a]**	**5.19 (0.23)[b]**	**5.36 (0.40)[a,b]**	4.97 (0.26)	5.00 (0.25)
Cookie response rate (responses/min)	**45.00 (5.39)[a]**	**68.07 (3.25)[b]**	**72.35 (5.70)[b]**	65.01 (3.83)	62.93 (3.65)
Fruit Pmax	4.06 (0.49)	4.95 (0.34)	4.88 (0.47)	4.80 (0.36)	4.77 (0.36)
Fruit response rate (responses/min)	**48.17 (6.34)[a]**	**65.46 (4.33)[b]**	**62.43 (6.23)[a,b]**	65.10 (4.78)	58.93 (4.69)
Post-task cookie intake (kcals)	122.36 (15.05)	133.26 (9.07)	142.54 (15.93)	143.52 (10.02)	122.83 (9.57)
Post-task fruit intake (kcals)	25.69 (6.32)	34.17 (4.80)	34.68 (6.01)	32.22 (5.08)	33.93 (4.98)
Post-task energy intake (kcals)	142.90 (16.25)	162.94 (9.80)	175.42 (17.20)	170.99 (10.90)	151.94 (10.40)
Post-task cookie intake (grams)	23.99 (2.94)	26.25 (1.77)	28.20 (3.11)	28.30 (1.96)	24.17 (1.87)
Post-task fruit intake (grams)	48.45 (9.76)	59.56 (7.05)	61.31 (9.38)	58.63 (7.50)	58.28 (7.36)
Post-task energy intake (grams)	71.54 (10.41)	85.08 (7.42)	89.22 (10.05)	86.67 (8.01)	82.09 (7.86)

Pmax, maximum schedule of reinforcement reached. RRV, relative reinforcing value. RRV cookie is the breakpoint for cookies in proportion to the total breakpoint for both cookies and fruit [RRV cookie = Cookie Pmax/(Cookie Pmax + Fruit Pmax)]. Calories (kcals) consumed were calculated using the post-weight and energy density (ED) of the food (kcals = ED × gram weight). Product label nutrition facts were used to determine the ED of study foods: Oreo minis™ (4.83 kcals/g); Fudge stripes minis™ (5.00 kcals/g); Circus animal® cookies (5.20 kcals/g); red grapes (0.40 kcals/g); mandarin oranges (0.85 kcals/g); pineapple (0.85 kcals/g). [1]Mixed model analysis with Head Start location (n = 8) included as a random effect. LSmeans are least squares means ± SE. LSmeans that do not share superscripts differ by p < 0.05 according to Tukey's adjusted post hoc comparisons. Significant differences were bolded for ease of interpretation.

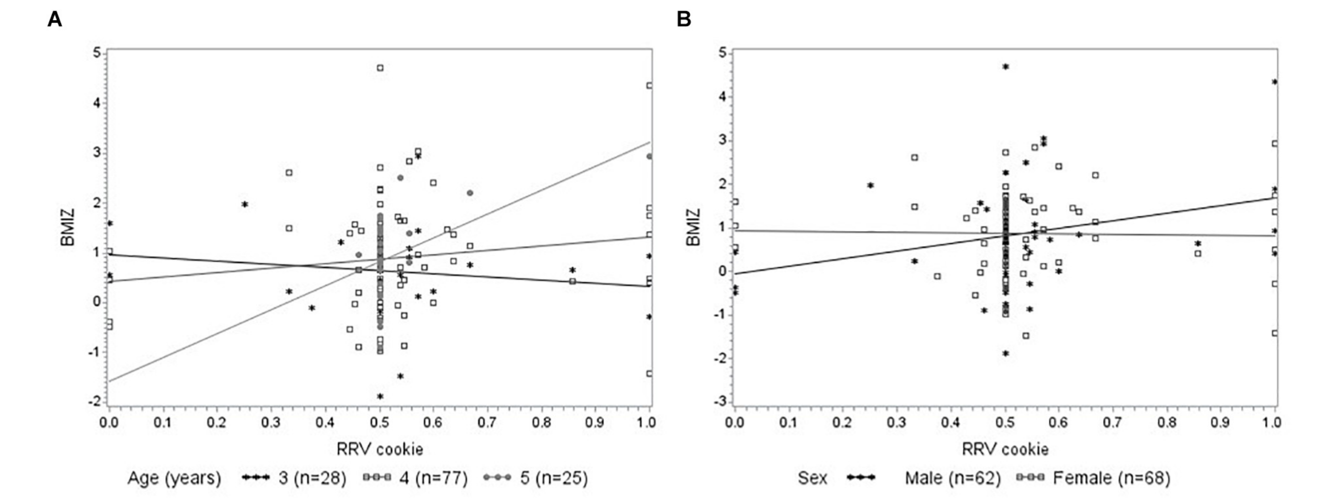

FIGURE 4 | Mixed model analysis showing interactions between RRV cookie with child age and sex on BMIZ (*n* = 130). **(A)** There was an interaction between RRV cookie and child age [*F* (3, 123) = 2.86, *p* = 0.04] such that RRV cookie increased with increasing BMIZ for 5-year-olds (*p* = 0.02) but not for 3-year-olds (*p* = 0.52) or 4-year-olds (*p* = 0.12). **(B)** There was an interaction between RRV cookie and child sex [*F* (2, 126) = 3.25, *p* = 0.04] such that RRV cookie increased with increasing BMIZ for boys (*p* = 0.01) but not girls (*p* = 0.90). Head Start location (*n* = 8) was included as a random effect in all mixed models. BMIZ, BMI z-scores; Pmax, maximum schedule of reinforcement reached; RRV, relative reinforcing value. RRV cookie is the breakpoint for cookies in proportion to the total breakpoint for both cookies and fruit [RRV cookie = Cookie Pmax/(Cookie Pmax + Fruit Pmax)].

with BMIZ, the finding that child age and sex moderated the association between RRV cookie and BMIZ is novel. Our results extend the RRV of food and obesity literature to low-income preschool-age children and provide preliminary evidence for potential developmental and sex differences in this age group.

This is the first study to our knowledge to examine the RRV of food in low-income preschool-age children in a naturalistic setting (i.e., school), and is consistent with previous studies showing that higher RRV of food is associated with greater BMI in children from predominantly middle-to-upper-income, well-educated families (Temple et al., 2008; Rollins et al., 2014b; Kong et al., 2015; McCullough et al., 2017; Wong et al., 2019). While children with obesity worked harder for cookies compared to children without obesity, there was no difference in the reinforcing value of fruit by weight status. This is in contrast to McCullough et al. (2017), who also examined the RRV of cookies to fruit in a higher income sample, and found that the reinforcing value of fruit, but not cookies, differed by weight status such that children with overweight/obesity responded less for fruit compared to children with normal weight. This finding is similar to other studies in more advantaged samples showing that lean children find non-food alternatives (e.g., playing with toys) more reinforcing than children with overweight/obesity (Kong et al., 2015; Wong et al., 2019). The vastly different socioeconomic circumstance of our sample may explain this discrepancy. Greater exposure to a variety of healthy food options and/or cognitive stimulation (e.g., number of books, educational toys) in higher income households (Campbell et al., 2002; Rosen et al., 2020) may increase the salience of these alternative options, particularly for lean children. The RRV is somewhat dependent on the reinforcing value of the alternative choice that is available (Epstein et al., 2007), and it is important to point out that a sequential design, where only one food option is available at a time, is not a true choice paradigm. The RRV of fruit is likely to be lower in a concurrent design where the choice of fruit is directly compared to the choice of a cookie vs. the reinforcing value of fruit in a sequential design in which responding for cookies is measured separately from responding for fruit. Thus, the use of a concurrent design in this study, as opposed to a sequential design used in previous studies with preschoolers (McCullough et al., 2017; Wong et al., 2019), could also explain why responding for cookies, as opposed to fruit, drove differences in the RRV of cookie by weight status (McCullough et al., 2017).

As hypothesized, child age was associated with greater responding for cookies and faster response rates for both cookies and fruit, which is similar to prior research showing that children's age is positively associated with total responses for food (Rollins et al., 2014b) and a higher breakpoint for monetary rewards (Chelonis et al., 2011). Though Rollins et al. (2014b) did not observe an association between age and response rates among a smaller sample (n = 30) of preschoolers, mean response rates were similar to our study (61.3 ± 30.0 vs. 55.8 ± 29.95), which is notable given these are the only two studies with young children having assessed response rates in the context of an RRV task. Partially supporting our hypotheses, cookie response rates, but not the breakpoint for cookies or RRV cookie, was positively associated with BMIZ. However, RRV cookie was positively associated with BMIZ among children with overweight/obesity and age moderated the association between RRV cookie and BMIZ such that greater proportional responding for cookies relative to fruit was associated with higher BMIZ among 5-year-olds, but not 3- or 4-year-olds. The moderating effect of age may indicate a developmental shift in which the RRV of food becomes a more salient predictor of obesity risk as children grow into early childhood, which could be attributed to older preschoolers having more experience with a broader variety of foods and/or more autonomy in making food-related decisions (Kininmonth et al., 2020). As previously suggested, it is also possible that younger children in our sample did not fully comprehend the task when presented with two foods concurrently (McCullough et al., 2017; Wong et al., 2019); or that they were more easily distracted or fatigued, both of which could mask the "true" breakpoint for one (or both) of the foods, thus affecting the reliability of concurrent reinforcement schedules in this age group (Rollins et al., 2014b).

Findings that the RRV of food varies by sex have been mixed in both animal and human studies with adults (Van Haaren et al., 2001; Roth et al., 2005; Goldfield and Lumb, 2008). In contrast to what was hypothesized, the current study did not observe differences in RRV outcomes by sex. Previous studies with children and adolescents show that boys make more responses for food than girls (Rollins et al., 2014b; Vervoort et al., 2017). One potential explanation for this discrepancy is differences in how food rewards are presented to children after earning each reward during the RRV task. Rollins et al. (2014b) allowed children to eat food portions earned throughout the task, but in the current study children received food portions as they were earned but were not allowed to eat the foods until after the task was completed. The current study's methods to assess RRV are similar to the delay of gratification protocol, a commonly used measure of self-control that measures the ability to wait for larger quantities of food (Schlam et al., 2013). A study conducted by Gearhardt et al. (2017) that used methods comparable to our study reported a positive association between RRV and delay of gratification, and performance on the RRV task was similar between boys and girls. Thus, conducting the RRV task in such a way that children must delay a smaller, immediate reward vs. working longer to obtain a larger, delayed reward may be confounded by delay of gratification. Sex differences in the motivation to obtain food rewards may be more apparent in the RRV task when children are allowed to eat each portion of food as earned throughout the task and elements of self-control are not introduced. This nuanced difference in the assessment of RRV may also explain why the current study did not replicate the positive association between reward sensitivity and RRV observed by Rollins et al. (2014b). We did find, however, an interaction between RRV cookie and child sex on BMIZ, with an association between greater proportional responding for cookies to fruit and higher BMIZ among boys but not girls. In contrast, Gearhardt et al. (2017) showed an association between higher RRV and overweight in girls, but not boys, among 7- to 10-year-old low-income children. These incongruent findings may be due to the difference in child age between the two studies and/or the use of toys rather than a LED food as the alternative reinforcer in the study conducted by Gearhardt et al. (2017). Given the limited evidence, more research is needed examining sex differences, how the RRV of food develops in relation to obesity risk across childhood, and whether temperamental traits other than reward sensitivity contribute to individual differences in the RRV of food.

Approximately 41% of low-income families in our sample reported household FI. Different from previous research in adults showing that FI is associated with the RRV of HED snack foods (Crandall and Temple, 2018; Crandall et al., 2020), we did not observe a significant association between household FI and the RRV of HED food. In both adult studies conducted by Crandall and colleagues, participants worked for a non-food alternative (e.g., reading), whereas the alternative reinforcer in our study was a LED food (i.e., fruit). The fruits used in our study, which were well-liked and familiar to children, may have been too reinforcing to see an effect of FI on the RRV of HED food. Similarly, a more desired novel HED food may be required to elicit a FI effect. Future research with children should examine the relationship between FI and the RRV of HED food using a non-food alternative (e.g., toys) and/or using palatable foods such as candy that are typically not allowed in the childcare setting (e.g., candy).

It is important for future research to design and evaluate evidence-based strategies that aim to simultaneously reduce the RRV of HED food and increase the reinforcing value of healthier alternatives. Previous studies with young children shed light on approaches that could be used to increase the reinforcing value of LED foods so that they can compete with more rewarding HED foods. A small, randomized trial with infants showed that a music enrichment program increased music reinforcement and reduced the RRV of food (Kong et al., 2016), suggesting that frequent exposure to a pleasurable non-food alternative has the potential to reduce food reinforcement. Repeated exposure of small tastes of vegetables increases liking and intake of those vegetables (Anzman-Frasca et al., 2012); however, research has not tested whether repeated exposure of healthier foods can sensitize, or increase, their reinforcing value among children. Repeated consumption of a food over a period of days or weeks can lead to a decline in the pleasantness of that food (i.e., monotony) (Hetherington et al., 2002). Alternating between a variety of LED foods within a repeated exposure intervention, or pairing target foods with positive stimuli (Vervoort et al., 2017) could be used to avoid a monotony effect. Although FI was not associated with the RRV of food in our sample, it is important to keep in mind that increasing access to both healthier foods and stimulating activities will pose a greater challenge to low-income families (Carr and Epstein, 2020). Given the RRV of HED food was driven by cookies (and not fruit) in the current study, research should also test if decreasing access to HED foods or if decreasing children's exposure to a variety of HED foods can reduce food reinforcement. However, overt restriction of specific foods, which has been shown to increase their RRV (Rollins et al., 2014a), should be avoided.

There are several strengths and limitations to consider. First, the present study was cross-sectional, thus causality cannot be inferred. Little is known about early developmental changes in motivational processes such as RRV and how such changes might link to variations in obesity risk across childhood. Though our sample was large enough to examine individual differences in the RRV of food in relation to child age, an important next step is longitudinal research that is able to assess RRV in the same children over time. Second, there were minor inconsistencies in delivery of the RRV protocol. For example, rather than providing a standardized meal prior to the task we relied on children's typical Head Start provided lunch, which differs from day to day. Further, children's height and weight measurements were not obtained on the same day that children participated in the RRV task. We cannot rule out the possibility of bias from such inconsistencies; however, this type of measurement error is often biased toward a null finding (Hammer et al., 2009). This is one of a few studies to conduct the RRV of food task outside of a laboratory setting and to examine the RRV of food among low-income children, which is important given economically disadvantaged children are at a greater risk of obesity and often a harder to reach population. On the other hand, the current sample was predominantly white, low-income, and rural. While more research is needed in low-income populations, future research would benefit from larger, more diverse samples in order to better generalize findings. Finally, it is difficult to disentangle delay of gratification as a potential confounder given the current study did not allow children to consume their food rewards until the task was completed. In addition to replicating the current study's findings using methods that do not overlap with delay of gratification, future research should examine the RRV of HED food relative to a non-food alternative in a sample of low-income preschoolers.

In summary, using a choice paradigm to study the RRV of food, the current study found that low-income children with obesity responded more and at a faster rate for cookies and had higher proportional responding for cookies to fruit compared to children without obesity. It will be important to determine whether increasing access to a variety of LED foods or non-food alternatives while decreasing access to a variety of HED foods can facilitate healthy decision making in children (Carr and Epstein, 2020). In our sample of preschoolers, a period in which several developmental milestones are reached as children go from 3 to 5 years, we observed both age and sex differences. Among older children and boys, children with greater proportional responding for cookies to fruit tended to have higher BMI z-scores. The breakpoint for cookies, but not fruit, was higher in children with obesity compared to children without obesity, suggesting that the greater RRV of cookies in children with obesity was driven by greater motivation to access cookies rather than a lower motivation to access fruit. These findings highlight the need to identity approaches to reduce the RRV of HED foods among low-income children with obesity. Household food security status was not associated with RRV outcomes. Research is needed to identify and understand other home environment characteristics that influence the development of individual differences in food reinforcement in order to inform the development of primary obesity prevention programs for low-income children.

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 Office for Research Protections at the Pennsylvania State University, United States. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SGE and JSS designed the research and had primary responsibility for final content. SGE conducted the research, analyzed the data, and wrote the first draft of the manuscript. MEM assisted with statistical analysis. KLK, JLT, MEM, and JSS interpreted the data and revised the manuscript. All authors read and approved the final manuscript.

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Exploring Strategies to Optimise the Impact of Food-Specific Inhibition Training on Children's Food Choices

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Food-specific inhibition training (FSIT) is a computerised task requiring response inhibition to energy-dense foods within a reaction-time game. Previous work indicates that FSIT can increase the number of healthy foods (relative to energy-dense foods) children choose, and decrease calories consumed from sweets and chocolate. Across two studies, we explored the impact of FSIT variations (e.g., different response signals, different delivery modes) on children's food choices within a time-limited hypothetical food-choice task. In Study 1, we varied the FSIT Go/No-Go signals to be emotive (happy vs. sad faces) or neutral (green vs. red signs). One-hundred-and-fifty-seven children were randomly allocated to emotive-FSIT, neutral-FSIT, or a non-food control task. Children participated in groups of 4–15. No significant FSIT effects were observed on food choices (all values of $p > 0.160$). Healthy-food choices decreased over time regardless of condition ($p < 0.050$). The non-significant effects could be explained by lower accuracy on energy-dense No-Go trials than in previous studies, possibly due to distraction in the group-testing environment. In Study 2, we compared computer-based FSIT (using emotive signals) and app-based FSIT (using neutral signals) against a non-food control with a different sample of 206 children, but this time children worked one-on-one with the experimenter. Children's accuracy on energy-dense No-Go trials was higher in this study. Children in the FSIT-computer group chose significantly more healthy foods at post-training ($M = 2.78$, $SE = 0.16$) compared to the control group ($M = 2.02$, $SE = 0.16$, $p = 0.001$). The FSIT-app group did not differ from either of the other two groups ($M = 2.42$, $SE = 0.16$, both comparisons $p > 0.050$). Healthy choices decreased over time in the control group ($p = 0.001$) but did not change in the two FSIT groups (both $p > 0.300$) supporting previous evidence that FSIT may have a beneficial effect on children's food choices. Ensuring that children perform FSIT with high accuracy (e.g., by using FSIT in quiet environments and avoiding group-testing) may be important for impacts on food choices though. Future research should continue to explore methods of optimising FSIT as a healthy-eating intervention for children.

Keywords: inhibitory control training, response inhibition, food choice, childhood obesity, behavior change, digital interventions

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INTRODUCTION

The food we eat has a direct impact on our health (Afshin et al., 2019). A high intake of non-milk extrinsic sugars is associated with a high energy intake, and with long-term conditions such as obesity (Malik et al., 2013; Dong et al., 2015; Public Health England, 2015; SACN, 2015), Type 2 diabetes (Malik et al., 2010; Hu, 2013), and poor dental health (Sheiham and James, 2015; Meier et al., 2017). However, 98% of children in the United Kingdom consume more non-milk extrinsic sugar than the recommended limit (Public Health England, 2018), while only 18% meet the recommended five portions of fruit and vegetables per day (NHS Digital Lifestyles Team, 2019).

Given that the majority of children's sugar intake comes from non-core foods such as soft drinks, biscuits, cakes, and puddings (Public Health England, 2015), replacing these sugary snacks with a piece of fruit could help to redress the existing dietary imbalance. However, early preferences for sweet vs. bitter flavours mean that children prefer energy-dense foods over fruit and vegetables (Birch and Fisher, 1998), with flavour often being the primary driver of children's food choices (Nguyen et al., 2015). Younger children in particular are less likely to choose healthier foods over more palatable, energy-dense options (Ha et al., 2016). Energy-dense foods are often easily accessible, convenient, and highly visible (e.g., through marketing; Swinburn et al., 2011), and children are especially susceptible to the influence of food marketing (Boyland et al., 2016). Some strategies to encourage fruit and vegetable intake can also result in unintended negative consequences; for example, telling children that healthy foods have instrumental value (e.g., carrots help you to see in the dark) can actually decrease perceptions of tastiness and the likelihood of subsequent intake (Maimaran and Fishbach, 2014).

Many interventions to improve the nutritional quality of children's diets are not successful, whilst those that are tend to be resource-intensive, multi-component interventions (Knai et al., 2006; Bourke et al., 2014; Hendrie et al., 2017; Johnson et al., 2018; Hodder et al., 2020), which may not be feasible to implement in all settings or with limited budgets (Ward et al., 2017). Digital behaviour change interventions (DBCIs) can reduce the costs associated with delivering interventions (e.g., time, personnel, and financial), and facilitate accessibility where attending in-person services is difficult or expensive (Murray et al., 2005; Sallinen et al., 2013; Price et al., 2014; Hayes et al., 2017; Sorgente et al., 2017). DBCIs are also a prime platform for delivering content in a gamified way that appeals to children (Chow et al., 2020).

Food-specific inhibition training (FSIT) is an example of a DBCI that aims to gamify the learning of healthier eating habits. Users make motor responses (e.g., key presses or touchscreen taps) in response to stimuli presented on screen (typically healthy foods or neutral images), but refrain when energy-dense foods such as chocolate, sweets, and crisps are presented (Houben and Jansen, 2011; Lawrence et al., 2015). Playing this task leads to reduced intake and choice of energy-dense foods, both amongst adults (Jones et al., 2016; Aulbach et al., 2019) and children (Folkvord et al., 2016; Porter et al., 2018).

Food-specific inhibition training is an example of an intervention that targets "automatic" drivers of eating behaviour. Many health behaviour change interventions focus on education, and do not account for the influence of these "automatic" drivers of behaviour (Marteau et al., 2012; Johnson et al., 2018). However, these processes are crucial for eating behaviour; automatic reward responses to food predict craving and food intake (Lawrence et al., 2012; Boswell and Kober, 2016), particularly when inhibitory control is low, as is likely the case for children given that neural substrates associated with self-control are not mature until early adulthood (Bunge et al., 2002; Keller and Bruce, 2018). It was originally thought that FSIT impacted eating behaviour by strengthening response inhibition in the face of tempting stimuli, however, research with adult participants has found that FSIT effects are more likely to be driven by reductions in the reward appeal (devaluation) of foods paired with response inhibition (Veling et al., 2017b).

Devaluation of food stimuli also occurs after evaluative conditioning, whereby food stimuli are repeatedly paired with images that evoke some kind of emotive or evaluative response (e.g., positive and negative facial expressions), subsequently impacting liking and choice of those items (Hensels and Baines, 2016; Shaw et al., 2016). While it could be argued that FSIT may be a form of evaluative conditioning (i.e., the No-Go cue or the act of not responding could serve as a negative stimulus, leading to devaluation after repeated pairing with certain food stimuli), research has found that devaluation after FSIT results from response inhibition itself rather than evaluative conditioning (Chen et al., 2016).

If both FSIT and evaluative conditioning lead to devaluation of foods and subsequent behaviour change *via* different mechanisms, combining them into one task could have a cumulative impact on food choices. Our past research with children used a version of FSIT containing happy and sad emoji faces as the Go and No-Go signals, respectively (Porter et al., 2018) meaning that this "emotive-FSIT" version of the task arguably also contained an evaluative conditioning element. Whilst FSIT can also reduce children's calorie intake when neutral response signals (e.g., different shapes) are used (Folkvord et al., 2016), it is unknown whether emotive signals can augment FSIT effects. This question is of particular interest given that our team has developed a free FSIT app ("FoodT"[1]) for iOS and Android devices, which uses neutral response signals (green and red circles). This app was developed based on FSIT validated in adults (e.g., Lawrence et al., 2015, 2018) and has not yet been tested with children. If emotive signals are found to be more impactful for child samples, such amendments could be easily implemented into future FSIT paradigms. To explore this, we ran a series of studies to investigate whether this ready-to-use FSIT app (which uses neutral response signals) and the computer-based FSIT used in earlier research (which uses emotive signals) yielded meaningfully different results in FSIT effects on children's food choices.

[1]http://www.exeter.ac.uk/foodt

STUDY 1

Our first study tested whether combining FSIT and evaluative conditioning could enhance healthy-food choices (vs. standard FSIT). We used the same emotive-signal, computer-based task as in Porter et al. (2018) and developed a near-identical version (still computer-based) using neutral signals.[2]

We also aimed to explore whether FSIT effects endure beyond the period immediately post-training. Previous work has tested children's eating behaviour within a single experimental session (Folkvord et al., 2016; Porter et al., 2018), whereas research with adults has found evidence of lasting effects of repeated FSIT sessions (e.g., four or more in a single week) on outcomes over a number of months (Lawrence et al., 2015). In this study, we aimed to investigate whether any FSIT effects on food choices would still be present 1 week later and whether these could be augmented or reinstated with a second FSIT "top-up" session.

Our primary research question was whether combining FSIT with evaluative conditioning (by using emotive response signals) leads to larger training effects (vs. control) compared to FSIT using neutral signals. We hypothesised that children who completed FSIT (emotive or neutral) would choose a greater number of healthy foods in a time-limited, hypothetical choice task than children who completed a control task. Secondary questions included whether FSIT effects on food choice would endure 1 week later, and whether a second top-up FSIT session would augment/reinstate any training effects 1 week later. Ethical approval for this study was granted by the University of Exeter CLES Psychology Ethics Committee (reference 2017/1638).

Materials and Methods

Participants and Design

Participants for this study were children at two schools in the Exeter and East Devon (United Kingdom) areas, whose parents returned the participation consent form. School A was located in a ward where 94.7% of residents are White, 2.8% Asian, 0.4% Black, and the remainder of Mixed or Other ethnic groups. In 2020, the proportion of children eligible for free school meals (FSM) was 9.6% (national average 17.3%; ONS, 2020). School B was located in a ward where 98.8% of residents were White, 0.3% Asian, 0.1% Black, and the remainder of Mixed or Other ethnic groups. In 2020, the proportion of children eligible for FSM was 1.6% (school information collected *via* national and local government websites[3]).

Power calculations were conducted using G*Power 3.1 to find the required sample size to detect an effect size (*f*) of 0.3587 (taken from Study 2 of Porter et al., 2018) at 80% power for a study design with three conditions, three measurement points, and an alpha level of 0.05, yielding a target of 54 participants. This was increased to 90 participants (30 per condition) to insure against attrition over study sessions.

The study had a mixed design, with a between-subjects factor with three levels (FSIT-Emotive vs. FSIT-Neutral vs. Control) and a repeated-measures element (outcomes were measured immediately post-training in session 1, at the start of session 2, and immediately post-training in session 2).

Measures and Materials

Go/No-Go Training Task

This task was programmed using EPrime software and accessed on university-owned laptop computers. Stimuli appeared on the screen one at a time for 1,250 ms, followed by a 1,250 ms inter-trial interval. Participants were required to press the spacebar when the stimulus appeared with a Go-signal but not when the stimulus appeared with a No-Go-signal. In Session 1, the tasks consisted of five blocks of 32 stimuli, while in Session 2, a top-up session of three blocks was used. Accuracy (presented as correct trials out of 32) and reaction time (RT; presented as average response time in milliseconds) feedback was presented after each block.

Active FSIT stimuli were 16 food images identical to those used in earlier research (Study 2, Porter et al., 2018; eight healthy such as apples, blueberries, etc., and eight energy-dense such as chocolate, crisps), while Control-task stimuli were 16 games-equipment images (eight sports, eight technology). Stimuli were presented twice per block. In the FSIT-Emotive task, Go-signals were happy-face emojis and No-Go-signals were sad-face emojis. In the FSIT-Neutral and Control tasks, Go-signals were green "Go" signs and No-Go-signals were red "Stop" signs. Each stimulus was presented with two variants of the relevant signal type to encourage stimulus-response learning over stimulus-signal learning (Best et al., 2016; Bowditch et al., 2016). There were three variations of each signal type (i.e., three of each of Emotive-Go, Emotive-No-Go, Neutral-Go, and Neutral-No-Go).

Hypothetical Food-Choice Task

Food choices were measured immediately post-training in Session 1, at the start of Session 2, and immediately post-training in Session 2. This task was hosted on a university server and accessed *via* the web browser. About 16 food images (eight healthy, eight energy-dense) were presented on the screen in a grid. Six of the healthy-food images and six of the energy-dense food images were different images of the same food types shown in the active FSIT tasks (e.g., apple, chocolate bar), with the rest being novel foods that did not appear in the FSIT tasks. Some images were those used by Porter et al. (2018), with extra image sets being created with photos found online or photographed by the first author. Images presented approximately one portion of food. Three image sets were created so that different images could be shown at each of the three measurement points (these were was counterbalanced across participants).

[2]For pragmatic reasons associated with access to university laptops with EPrime software, a further (harder) variant of the task was developed using an online server and tested simultaneously in a separate sample of children. The results regarding this variant are not reported here but will appear in the lead author's upcoming thesis.

[3]https://get-information-schools.service.gov.uk/ and https://www.devon.gov.uk/factsandfigures

Children clicked on the eight foods they wanted most within a 60-s time limit. A time limit was imposed based on findings that FSIT effects disappear when longer time-periods are allowed for deliberation (Veling et al., 2017a). If children did not select eight foods within the time limit, the researcher offered them a second attempt. The number of healthy-foods chosen was recorded as the outcome variable (as children were only allowed to choose eight foods, this was directly proportional to the number of energy-dense foods chosen). Children were asked to pretend that these were real foods they could eat, to motivate ecologically valid choices.[4] Children were able to modify their choices as many times as they wanted to within the time limit.

Procedure

Letters were sent to parents, containing a brief study description and a consent form. Only children whose parents consented were invited to participate. Children took part in groups of 4–15 at a time. Group sizes were dependent on the requirements of the schools. Groups were mixed with regards to FSIT condition.

For session 1, groups of children were taken from the classroom to an activity area where the laptops were set up. Instruction sheets showed the specific response signals children should attend to (i.e., happy/sad faces or Go/Stop signs) and the experimenter delivered verbal instructions to aid understanding. Once children had been instructed to begin, the experimenter observed children's performance to ensure they understood the task and provided additional instructions and support for children who were struggling with the task. As each child reached the end of the Go/No-Go task, the experimenter opened the instruction page for the first food-choice task (Food Choice 1) for each child and asked them to wait at the instruction screen (no foods visible). When all children were ready, the experimenter again delivered verbal instructions to accompany those present on screen, emphasising the time limit and that they should pretend that they were choosing real foods to eat.

After a week-long interval, Session 2 began with a food-choice task (Food Choice 2a) followed by a "top-up" of the same Go/No-Go training task as before, and then a final food-choice task (Food Choice 2b). Before each task, children were given brief verbal instructions to refresh their memory.

Data Preparation and Analysis

Planned exclusion criteria included overall accuracy on the Go/No-Go task below 60%, No-Go accuracy below 50%, and average RTs beyond three SDs of the mean for that condition. Additional exclusions were made when Go/No-Go data were lost due to technical errors, researcher errors caused a deviation from the planned procedure (these included accidentally failing to counterbalance food choice image-sets, or presenting children with the wrong Go/No-Go task in the second session) and for child absence or requests to drop-out.

Repeated-measures ANOVAs investigated the effect of Condition on Go trial RTs, Go trial omission errors and No-Go trial commission errors across blocks. Models were analysed separately for each session. Where Mauchly's test for sphericity was significant, corrections were used (Greenhouse-Geisser when epsilon <0.75, Huynh-Feldt otherwise). All pairwise comparisons were Bonferroni corrected.

An ANOVA was used to investigate the effect of Condition on the number of healthy-foods chosen in Food Choice 1. This analysis was one-tailed as it was a direct replication of the analyses conducted by Porter et al. (2018). Unadjusted planned comparisons between each FSIT group vs. the Control group were conducted (replicating earlier findings, as before). Bayes factors for these two planned comparisons were calculated using an online calculator (Dienes, 2014). For each comparison, the inputs to this calculator consisted of the mean difference between conditions, the standard error of this difference, and a prior based on all previous studies with children conducted by our research group and calculated using another calculator provided by Dienes and colleagues (prior = 0.8569); both the Bayes factor calculator and the prior calculator can be found online.[5] A repeated-measures ANOVA investigated healthy-food choices across the three measurement-points. All analyses were conducted in SPSS v26. The full dataset is available at https://doi.org/10.24378/exe.3303.

Results

Preliminary Analyses

Before exclusions, 112 children (59 female) aged 5–10 years ($M = 7.93$, $SD = 1.84$; age and gender information were missing for two children) were enrolled. Eight children were excluded from session 1 (absence on experiment days = 5, drop-out = 2, data loss = 1), with no further exclusions made on the basis of poor Go/No-Go task performance, resulting in a sample of 104 children (57 female) aged 5–10 years ($M = 7.93$, $SD = 1.83$). A further 11 children were excluded from session 2 (absence on experiment days = 6, experimenter error = 3, low Go/No-Go task accuracy = 2), resulting in a sample of 93 children (52 female) aged 5–10 years ($M = 7.73$, $SD = 1.81$) for these analyses. The minimum target sample size of 30 per condition was met in both sessions (see **Table 1** below).

One participant had missing data for Go RTs in the first block of Session 1 due to not making any correct Go responses in this block (the participant completed the task with 100% Go accuracy for the remaining blocks, meaning that they passed the accuracy inclusion criteria). This missing value was filled in with the mean for the participant's age group and condition at Block 1, Session 1.

Go/No-Go Task Performance Analyses

In Session 1, RTs got significantly faster across blocks ($F_{3.538, 357.341} = 27.98$, $p < 0.001$, $n^2_p = 0.217$; Huynh-Feldt corrected; **Figure 1**),

[4]This differs from the procedure in Porter et al. (2018) where children were told they would be given one of their choices to motivate ecologically valid choices. This was not possible in the current study due to group-testing, and the logistical issues involved in transporting required amounts of equipment and food *via* public transport.

[5]http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/Bayes.htm

TABLE 1 | Sample characteristics for each condition at each session.

	FSIT-emotive	FSIT-neutral	Control
Session 1 – n	34	35	35
Age – M (SD)	8.04 (1.88)	7.96 (1.81)	7.79 (1.86)
Gender – % female	52.9%	60.0%	51.4%
Session 2 – n	30	32	31
Age – M (SD)	7.82 (1.88)	7.78 (1.79)	7.60 (1.83)
Gender – % female	53.3%	62.5%	51.6%

with no significant differences between conditions (p = 0.297). In Session 2, the Block × Condition interaction was significant ($F_{4,180}$ = 3.64, p = 0.007, n^2_p = 0.075; **Figure 1**), with RTs getting faster over time in the Active-Emotive group ($F_{2,89}$ = 3.51, p = 0.034, n^2_p = 0.073), getting slower in the Control group ($F_{2,89}$ = 4.30, p = 0.017, n^2_p = 0.088) and remaining stable in the Active-Neutral group (p = 0.146).

Commission error rates improved significantly across blocks in Session 1 ($F_{3.231,326.328}$ = 4.48, p = 0.003, n^2_p = 0.042; Huynh-Feldt corrected). Unexpectedly, there was a main effect of Condition ($F_{2,101}$ = 5.67, p = 0.005, n^2_p = 0.101) with the FSIT-Emotive group showing significantly higher error rates (M = 0.109, SE = 0.012) compared to the FSIT-Neutral (M = 0.064, SE = 0.011, p = 0.019) and Control groups (M = 0.060, SE = 0.011, p = 0.009; **Figure 1**). In Session 2, commission error rates varied significantly across blocks ($F_{2,180}$ = 3.93, p = 0.021, n^2_p = 0.042). There was a significant effect of Condition ($F_{2,90}$ = 3.10, p = 0.050, n^2_p = 0.064), however, no pairwise-comparisons were significant.

Food Choices

The main effect of Condition was not significant, and healthy-food choices did not significantly differ between children in the FSIT-Emotive (M = 3.77, SE = 0.35), FSIT-Neutral (M = 3.91, SE = 0.36), and Control groups (M = 3.27, SE = 0.36) at Food Choice 1 (immediately after the first training; all values of p > 0.210). Bayes factors for the pairwise-comparisons sat between 1/3 and 3 (FSIT-Emotive BF = 1.15, FSIT-Neutral BF = 1.80), meaning that the evidence was not sufficiently conclusive to support either the null or alternative hypothesis.

Healthy-food choices decreased significantly over time ($F_{1.702,144.639}$ = 3.29, p = 0.048, n^2_p = 0.037; HF corrected; Linear Contrast $F_{1,85}$ = 4.42, p = 0.038; see **Figure 2**). Neither the effect of Condition nor the Time × Condition interaction was significant. Missing values were deleted listwise, meaning that different mean values for Food Choice 1 are presented in **Figure 2** compared to those reported above, due to session 2 exclusions.

Discussion

This study aimed to investigate whether combining evaluative conditioning and FSIT would encourage healthier choices among children compared to standard FSIT alone. We compared a task that used happy and sad faces as Go and No-Go signals, respectively (FSIT-Emotive condition) and a task that used neutral (green Go and red No-Go) signals (FSIT-Neutral condition) against a non-food Control task, measuring children's food choices in a time-limited, hypothetical choice task at three time points. Our hypothesis of higher healthy-food choice in the FSIT tasks vs. Control was not confirmed; unexpectedly, we failed to replicate the significant training effects previously observed (Porter et al., 2018), despite the FSIT-Emotive task being identical to that used in the earlier research. Instead, there were no significant differences between groups at any time-point, and healthy-food choices decreased significantly over time with no evidence of this trend differing between groups.

Due to the non-significant results of this study, we were unable to determine whether evaluative conditioning can enhance FSIT effects on food choices. There are a number of differences between this study and the earlier study by Porter et al. (2018) that could help to explain the discrepancy in results. Firstly, in the earlier study, children were told that they would receive one of their food choices at the end of the day, to motivate ecologically valid choices. This was not possible in the present study for practical reasons. Children were encouraged to imagine that these were real foods that they would eat, but this may not have been enough, and future studies should aim to use real food outcomes to ensure ecological validity.

In addition, the food-choice tasks in the present study were timed by the computer and although children were not alerted to this feature, they were able to modify their choices as many times as they wanted to within the 60-s window. Comparatively, the earlier study involved researchers working one-on-one with children for this task, meaning that children could be prevented from changing their choices or deliberating for too long. Past research with a similar response training task has found that effects on food choices are eliminated when adult participants are given more time to make their choices (Veling et al., 2017a). These results could indicate that a similar effect occurs with children. Future studies should explore whether FSIT effects on food choices are impacted by the amount of time permitted for food choices.

Alternatively, it could be that group-testing in this study impacted children's attention and engagement with the FSIT task (e.g., due to distraction by other children). The FSIT-Emotive task had a significantly higher no-go commission error rate than the other two tasks, with a mean of 0.109. The mean commission error rate for the same task in the earlier study was 0.063 (where children were tested individually, or in smaller groups of a maximum of four with two researchers present; Porter et al., 2018). A meta-analysis of studies with adult participants found that accuracy on inhibition trials is a crucial predictor of training effects on outcomes (Jones et al., 2016). Therefore, poorer task performance in the current study may have minimised training effects and resulted in the non-significant effects observed here. The FSIT-emotive task may have been impacted more than the other tasks due to the highly-similar Go and No-Go signals (i.e., yellow circles with small variations in facial expression, compared to potentially more easily-discriminable green and red signs). Future studies should ensure that children can concentrate and engage with the FSIT task.

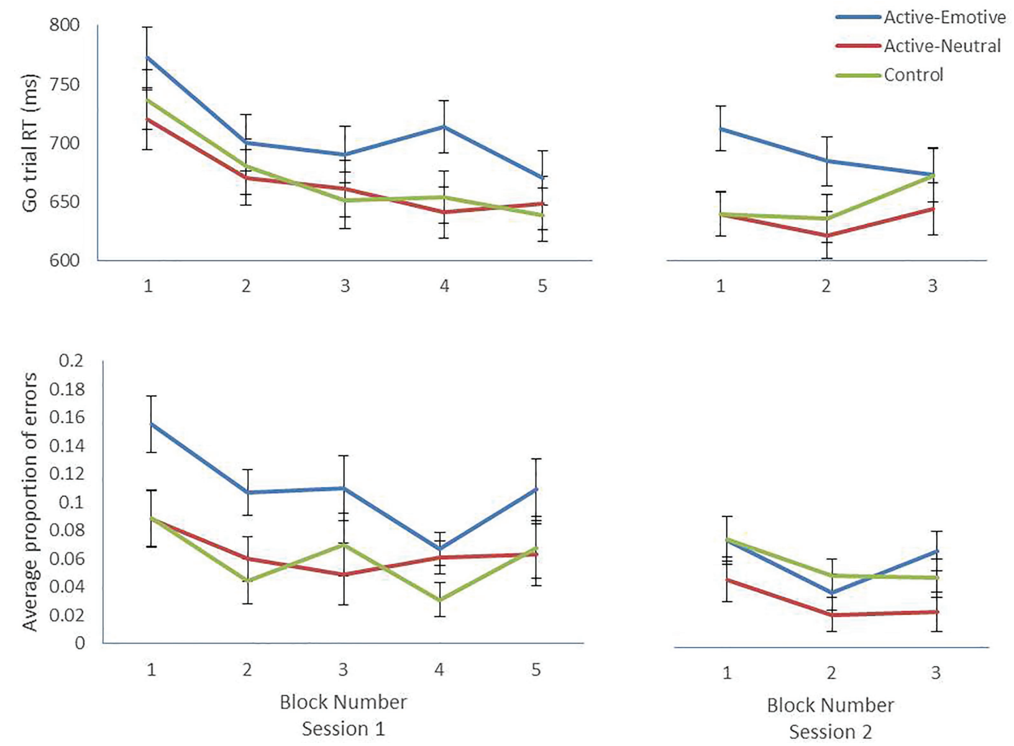

FIGURE 1 | Mean and SE per block for Go trial Reaction Times and proportion of No-Go trial commission errors for each condition across blocks. Lower RTs/error rates indicate better performance.

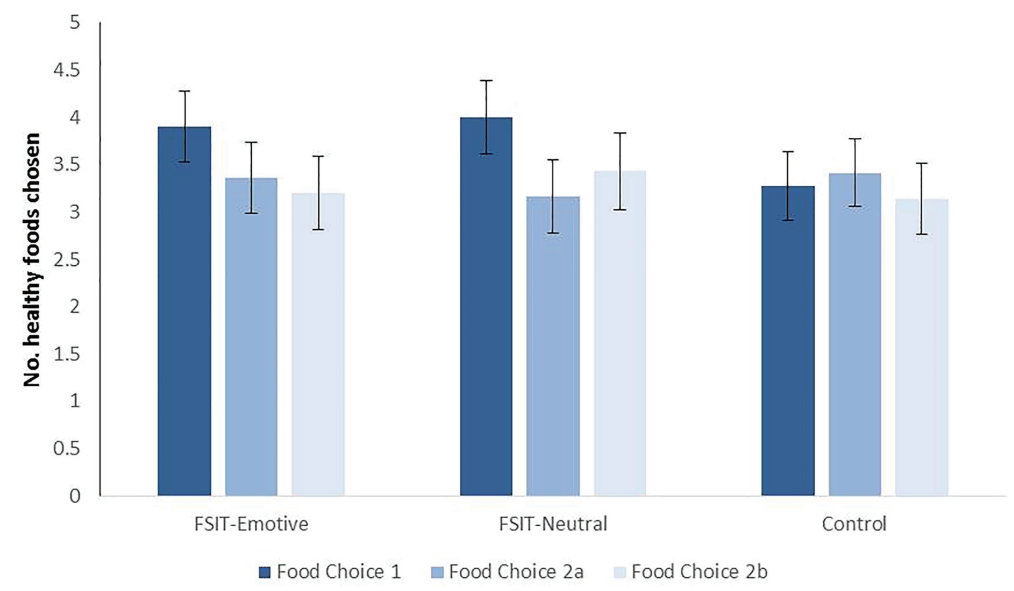

FIGURE 2 | Mean number of healthy-foods chosen at each time-point for each condition, with SE. Food Choice 1 occurred immediately post-training in Session 1, 2a occurred 1 week later before the top-up training and 2b occurred immediately after the top-up training.

STUDY 2

In Study 2, we implemented the methodological recommendations of Study 1 (i.e., using real food rewards to improve ecological validity of outcome measures; implementing FSIT individually in a quieter, less distracting environment) to compare the FSIT-emotive task against the neutral FSIT task included in the FoodT app. Children worked with the experimenter one-on-one to create a more controlled testing environment, and when taking part in the time-limited hypothetical food-choice task, children were told that they would receive one of their choices at the end of the study. Real-food choices were also measured. Thirdly, a baseline measure of hypothetical food choices was taken to help understand (i) whether groups were well matched in their healthy-food choices at the outset, and (ii) whether any changes occurred within groups from pre to post-training. Finally, the hypothetical food-choice task was changed to a card-based game (as in Porter et al., 2018), rather than the computer-based task used in Study 1. These methodological changes brought the method of Study 2 more closely in line with the methods used in Porter et al. (2018).

As described earlier, FoodT is a FSIT app that uses neutral response signals (red and green circles, similar to the colour-based signals of the FSIT-neutral task of Study 1) that was developed based on FSIT tasks that had been validated in adult samples (e.g., Lawrence et al., 2015). Preliminary work with adults using FoodT at home has revealed reduced self-reported snacking and greater self-reported weight loss, although the effect is smaller than that observed with web-based training accessed *via* laptop or desktop computers (Lawrence et al., 2018). FoodT has not yet been tested for its efficacy at changing children's eating behaviours. We decided to test this app directly (rather than reusing the FSIT-neutral task in Study 1) as FoodT is a ready-to-use app that could be delivered immediately to families with children if there is evidence of its effectiveness. Unpublished feasibility studies conducted by our research group have shown that families prefer touchscreen-compatible tasks, which accords with wider trends showing increases in children's use of touchscreen devices such as tablets (Ofcom, 2020). While it would not be possible to isolate the effects of emotive vs. neutral signals alone due to other differential features between the two tasks (e.g., touchscreen vs. keyboard response, the use of "filler" stimuli in FoodT, clearer point scoring system in FoodT; see **Table 2** below), it would at least be possible to understand whether FoodT produces comparable results to the computer-based task tested successfully in earlier research (Porter et al., 2018). If not, this would indicate that further development and optimisation of the app may be needed.

An additional aim was to pilot a measure of food liking that could be used to investigate whether food devaluation occurs after children complete FSIT. No research has yet investigated the mechanisms of FSIT with children, and this study aimed to make the first steps towards testing the devaluation hypothesis (Veling et al., 2017b) with this population. A further outcome measure tested here was whether children's first choice in the hypothetical food-choice task was more likely to be a healthy food after FSIT compared to control.

Our primary research question was whether the computer-based FSIT task used in our earlier studies (Porter et al., 2018) leads to a larger training effect (vs. control) compared to app-based FSIT. We hypothesised that children who completed FSIT (computer or app) would choose a greater number of healthy foods in a time-limited, hypothetical food-choice task than children who completed a control task. Our secondary research questions were (i) whether children who completed FSIT (computer or app) would rate their liking for energy-dense foods as lower compared to children in the control group, and (ii) whether children would be more likely to choose a healthy food as their first choice in the time-limited hypothetical food-choice task. This study was pre-registered at https://osf.io/2v7hg/. Ethical approval was granted by the University of Exeter CLES Psychology Ethics Committee (reference eCLESPsy000031 v4.1).

TABLE 2 | Differences between the food-specific inhibition training (FSIT)-computer and FSIT-app tasks.

	FSIT app	FSIT computer	Control
Delivery mode	iPad (FoodT)	Laptop (EPrime)	Laptop (EPrime)
Number of blocks	6	5	5
Trials per block	32	32	32
Critical trials per block	16	32	0
Trial length (inter-trial interval)	1,500 ms (500 ms)	1,250 ms (1,000 ms)	1,250 ms (1,000 ms)
Go trial stimuli	Healthy food (e.g., fruit)	Healthy food (e.g., fruit)	Sports-equipment (e.g., goggles, balls)
No-Go trial stimuli	Energy-dense food (e.g., chocolate, crisps)	Energy-dense food (e.g., chocolate, crisps)	Technology (e.g., TVs, games consoles)
Filler stimuli	Yes (clothes, flowers, stationery)	No	No
Response signals	Green vs. red circles	Happy vs. sad emoticons	Happy vs. sad emoticons
Signal delay	Yes (100 ms)	None	None
Feedback	Trial-by-trial point scoring presented;	End of block feedback only;	End of block feedback only;
	End of block feedback	Accuracy: score/32	Accuracy: score/32
	Accuracy: %	Speed: seconds	Speed: seconds
	Speed: milliseconds		

Materials and Methods

Participants and Design

This study had a mixed design with a three-level between-subjects factor (FSIT-app vs. FSIT-computer vs. Control) and a within-subjects repeated outcome assessment. Two outcome measures were assessed at baseline and post-training (the number of healthy foods chosen in the hypothetical food-choice task, and food-liking ratings), while real-food choice was measured at the end of the study only.

A power analysis conducted using G*Power 3.1.9.2 revealed that a sample of 192 participants would be required to achieve 80% power with an alpha level of 0.05 and a medium effect size (f = 0.25).[6] As the main hypothesis involved comparing

[6]A meta-analysis of studies performed by our research group with child participants yielded a medium effect size of d = 0.446, which translates as f = 0.223. Some of the studies included in this meta-analysis involved group-testing studies, and as noted in Study 1, it was observed that group-work studies produced smaller effect sizes than individual-testing studies. As the current study used an individual-testing methodology, the standard medium effect size of f = 0.25 was used as a closer estimate of the true effect size for this method type.

each FSIT group to the Control group, the power analysis was conducted for an ANCOVA with two groups and one covariate, with the resulting sample size (n = 128) then being multiplied by 1.5 to achieve the correct sample size for a design with two FSIT groups to be compared against a Control group (n = 192).

Three primary schools in London were approached to participate in the study, with all three responding and consenting. School A had 9.2% of pupils eligible for FSM (national average = 17.3%; ONS, 2020), and was located in the borough of Brent, where in 2018 32.6% of residents were Asian, 31.1% were White, 18.9% were Black and the remainder were of Mixed or Other ethnicity. School B had 15.6% of pupils eligible for FSM, and was located in the borough of Southwark where in 2018, 61.0% of residents were White, 19.5% were Black, 5.2% were Asian, and the remainder were of Mixed or Other ethnicity. School C had 27.8% of pupils eligible for FSM and was located in the borough of Lambeth, where 52.4% of residents were White, 23.2% were Black, 8.5% were Asian, and the remainder were of Mixed or Other ethnicity. Data on schools was obtained from national and local government websites.[7]

Measures and Materials

Go/No-Go Training Task

As in Study 1, all tasks consisted of stimuli appearing on screen, one-by-one, accompanied by a Go or a No-Go signal. The FSIT-Computer and Control tasks were both programmed using EPrime and delivered *via* laptop, and consisted of five blocks of 32 stimuli presentations as in earlier studies. The FSIT-app task was delivered on an Apple iPad and consisted of six blocks of 32 stimuli presentations (two separate games of FoodT, which consists of three blocks per game). This ensured roughly equivalent gameplay time (approximately 5 min) across conditions due to the slightly faster pace of the FSIT-app task.

The FSIT-computer task was adapted from Study 1 to contain the same eight healthy-food images (Go trials) and the same eight energy-dense food images (No-Go/trials) as the FSIT-app task. These images appeared twice per block in the FSIT-computer task (as in previous studies) but only once per block in the FSIT-app task as this task also presented participants with eight "filler" stimuli (i.e., flowers, clothing, and stationery), which were each presented twice per block, once as a Go stimulus and once as a No-Go stimulus. The Control task contained eight sports-equipment images (Go trials) and eight technology images (No-Go trials), all presented twice per block.

In the FSIT-app task, the Go signal was a green ring encircling the stimulus and the No-Go signal was a red ring encircling the stimulus. These rings appeared 100 ms after stimulus onset and remained on screen for the duration of the stimulus. In the FSIT-computer and Control tasks, the Go signal was a happy emoticon and the No-Go signal was a sad emoticon that appeared at the same time as the stimulus and remained on screen for the duration (as before, three different exemplars of each signal type were used in the two computer-based tasks, with each stimulus being presented with two variants to encourage Stimulus-Response learning over Stimulus-Signal learning; Best et al., 2016).

There were a number of further differences between the FSIT-app task and the two computer-based tasks; a summary of the differences between the tasks is presented below in **Table 2**. As noted in the introduction to this study, we chose specifically to compare the FSIT-app task against a version of FSIT that has previously been found to impact children's food choices (e.g., see Porter et al., 2018). For this reason, and to maintain consistency with the task in Study 1, the FSIT-computer task was not reprogrammed to accommodate these differences.

Hypothetical Food-Choice Task

Following the methods of Porter et al. (2018), children were shown 12 food-image cards (six healthy, six energy-dense), of which they could choose six. Four of each food type were different exemplars of foods presented in training and two were novel, untrained foods. To motivate ecologically valid choices, children were informed that they should choose foods that they really wanted, as they would be getting one of these foods at the end of the experiment. They were also informed that they would be given 30 s to complete the task as research has shown that FSIT effects disappear when more time is given for deliberation over choices (Veling et al., 2017a). If children completed their choices within 30 s, the researcher ended the task, preventing any further changes to selections. The researcher informed children that time was running out as the 30 s limit approached.

Images were printed on paper, laminated, and cut into sets of cards. Two different image sets were developed which were counterbalanced among participants from pre- to post-training. The number of healthy foods chosen was the primary outcome measure. The first food that children chose was also recorded as a novel secondary outcome measure. Whilst the images included in the choice tasks were judged to be equally attractive across categories (i.e., healthy and energy-dense) by the research team, they were not systematically matched for palatability and attractiveness as no data currently exists regarding children's ratings of food stimuli. However, the food rating task described below made a first attempt at piloting a measure to obtain this information from children.

Food-Liking Rating Task

Children were shown 12 images of food (six healthy, six energy-dense), one at a time. Four of each food type were different exemplars of foods presented in training, whilst two were novel, untrained foods. Images in the liking rating task were different to those presented in the hypothetical food-choice task. Children were asked to rate each food on a 100-point visual analogue scale (VAS) ranging from "Not at all yummy" all the way up to "Very yummy". The number ratings were not visible on the scale, but a visual aid was available in the form of increasing numbers of stars above the line as it approached the "Very yummy" end (visually, this resembled a "wedge" made up of stars that hovered above the length of the line; see **Figure 3**).

[7]Resources consulted = https://get-information-schools.service.gov.uk/ and https://data.london.gov.uk/dataset/ethnic-groups-borough.

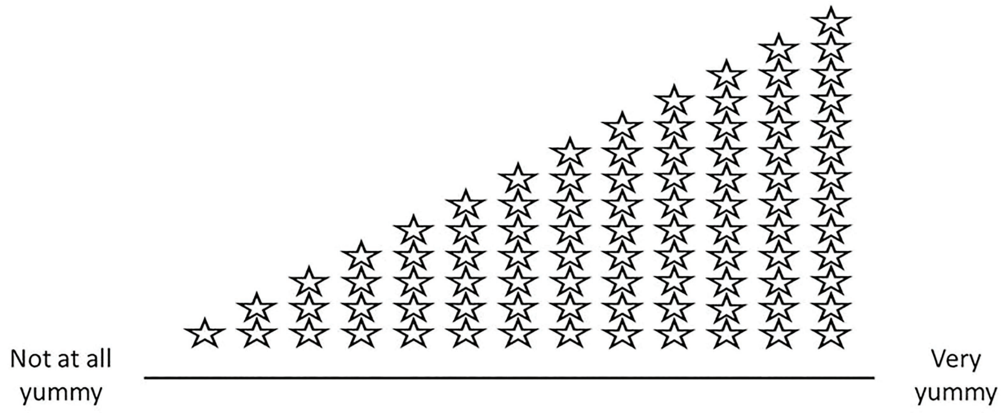

FIGURE 3 | Visual analogue scale used to rate food-liking.

Children were discouraged from counting the stars and were advised to use the visual aid as a rough guide to prevent them from remembering their rating for a given food from one session to the next (for the same reason, previously tested measures using a smaller number of categories to indicate liking were not appropriate for this study). Children pointed to the location on the line that they would rate the food, and the experimenter marked a line with a pen to show where the child's finger had landed. Later, these marks were measured for their location along the line, and converted into a value out of 100. Images were printed on paper, laminated, and cut into sets of cards. The same images were rated at pre- and post-training. Again, whilst chosen images across categories were judged to be equally attractive by the research team, they were not systematically matched for palatability and attractiveness as no data currently exists regarding children's ratings of food stimuli. However, this task makes a first attempt at piloting a measure to obtain this information from children.

Hunger Scale

The five-point hunger scale developed by (Bennett and Blissett, 2014) was used. This depicts a series of teddy bears with increasing amounts of "food" in their tummies, and ranges from "very hungry" to "very full", with an option of "just right" in the middle. Hunger was measured at the start of the second session (i.e., the training session) only, as previous work has suggested that hunger levels may influence the efficacy of the training task (Veling et al., 2013). Lower scores indicated greater hunger, while higher scores indicated increasing fullness.

Real-Food-Choice Task

Children were offered a selection of snacks from which they could choose one to take home as a participation reward. The options included fruit (apple, orange, and small bunch of green grapes) and energy-dense snacks (medium-sized Kinder chocolate bar, Nairn's gluten-free chocolate chip biscuits, and Walker's baked crisps). An example of each food was placed on a paper plate, (the actual foods that children would be given were kept in staffroom refrigerators or in a cool bag) and these example options were kept covered by a tea towel until the real-food-choice task began. Children chose one option (this choice was noted as an outcome measure) and were subsequently also allowed an extra choice of one piece of fruit (to ensure all children went home with at least one piece of fruit). No time limit was imposed on this task. Children's choices were placed in paper bags, stapled closed with a debrief letter for parents attached, and handed to teachers at the end of the day.

Debrief and Awareness Assessment

Children were asked a series of questions to assess their awareness of the aims of the project: (i) what they thought the games they had played were about, (ii) why they thought they had played them, (iii) if they could remember which pictures (Control) or foods (FSIT) they had to press during the computer/iPad game, and finally (iv) if they thought that the computer/iPad game might have changed which foods they wanted. Children's answers were coded as aware/unaware for the following: (i) awareness of contingencies, (ii) awareness of healthy eating purpose, and (iii) awareness of task effects on food choices.

Procedure

Letters were sent home to parents, containing a brief description of the study, and a consent form. Only children whose parents consented to participation were invited to take part. All children worked with the researcher individually. In the first session, children were asked if they assented to playing a few quick games about their favourite foods. Children completed the baseline hypothetical food-choice task and food-liking rating task before returning to the classroom. Session 1 lasted for approximately 5 min.

The second session took place during the following school week. Children were again asked if they assented to participating. The second session began with the hunger rating scale, before the Go/No-Go training task. Children then completed the hypothetical food-choice task and the food-liking rating task.

The order of these tasks remained fixed due to food choices being our primary outcome measure. Finally, the experimenter presented children with the real-food-choice task, and asked children to choose one item to take home as a thank you for taking part. After their choices had been made, children were asked the awareness questions and were debriefed before returning to the classroom.

Data Preparation and Analyses

Planned exclusion criteria included overall accuracy on the Go/No-Go task below 60%, No-Go accuracy below 50%, and average RTs beyond three SDs of the condition group mean.

To check whether the food pictures presented in the liking rating task were well matched, repeated-measures ANOVAs were conducted with a two (food type: healthy vs. energy-dense) by two (included in FSIT tasks vs. novel) design. This analysis was conducted as a preliminary check considering that, as noted above, stimuli were not systematically matched for palatability and attractiveness as no data currently exists regarding children's ratings of food stimuli.

Repeated-measures ANOVAs were used to investigate reaction times on Go trials and No-Go commission errors across blocks. For the FSIT-app condition (for which six blocks of training were completed), only the first five blocks were entered into analyses so that comparisons could be made across conditions. Where the assumption of sphericity was violated, corrections were used (Greenhouse-Geisser where epsilon < 0.75, Huynh-Feldt otherwise). The data from the FSIT-app condition was also analysed in repeated-measures ANOVAS to see whether reaction times and error rates across blocks differed for food stimuli (which were presented with constant stimulus-response associations) vs. filler stimuli (50/50 stimulus-response associations). This allows us to differentiate between performance improvements based on general task practice vs. those based on learning specific stimulus-response (go or no-go) associations (e.g., Lawrence et al., 2015).

The effect of training group on hypothetical food choices was explored using an ANCOVA model, with baseline choices entered as a covariate and post-training choices as the outcome measure. Pairwise comparisons were conducted to investigate differences between the three groups (these were unadjusted as they replicated earlier findings). Bayes factors for each FSIT vs. Control comparison were calculated using the method and calculator described in Study 1. Paired samples *t*-tests were conducted for each condition separately to test the change in number of healthy foods chosen between the two measurement points. Binary logistic regression models were analysed to test whether children in the two FSIT groups (compared to the Control group) were more likely to choose (i) a healthy food as their first choice in the hypothetical food-choice task, and (ii) a healthy food as their real food participation reward.

Food-liking ratings were analysed with repeated-measures ANOVAs, including the within-subjects factors of food health status (healthy vs. energy-dense) and time (baseline vs. post-training), with condition as a between-subjects factor. We had also planned to include a within-subjects factor indicating whether foods had been included in the FSIT tasks (included vs. novel), however, baseline analyses indicated that included vs. novel foods were not well matched and could not therefore serve as an appropriate comparison (see below). All analyses were conducted in SPSS v26 and the dataset is available at https://doi.org/10.24378/exe.3303.

Results

Preliminary Analyses

In total, 219 children (115 female) aged 4–10 years (M = 6.64, SD = 1.80) were randomised to the FSIT App (n = 72), FSIT Computer (n = 73), and Control (n = 74) groups. Thirteen were excluded due to either low Go/No-Go task performance accuracy (i.e., lower than 60%; n = 8) or absence from school during the second session (n = 5). The data from 206 children (106 female) aged 4–10 years (M = 6.77, SD = 1.76) were retained.

The three training groups (FSIT-app, FSIT-computer, and Control) were well balanced with regards to age, gender, baseline food choices, baseline ratings for each of the four food types (healthy trained, healthy novel, energy-dense trained, and energy-dense novel), and hunger during the training session (**Table 3**).

Baseline Food Ratings

At baseline, a significant effect of health status was found ($F_{1,203}$ = 45.17, p < 0.001, n^2_p = 0.182), with healthy foods being rated as liked less than energy-dense foods. Foods that were included in the training were liked more than the novel foods ($F_{1,203}$ = 21.19, p < 0.001, n^2_p = 0.095), suggesting that the novel stimuli chosen in this study were not well matched (no exposure to the training task had occurred at this point). Due to these unintended baseline differences in liking for foods included in the training vs. novel foods, subsequent analyses only focused on those foods that had been included in the training, as the novel foods could not be used for comparison.

TABLE 3 | Group demographic characteristics and baseline outcome measures.

	App (n = 70)	Computer (n = 69)	Control (n = 67)
Age	6.99 (1.80)	6.62 (1.71)	6.69 (1.79)
Gender – *n* female (%)	37 (52.9)	30 (43.5)	39 (58.21)
Healthy-food choices	2.54 (1.21)	2.87 (1.45)	2.57 (1.29)
Healthy trained rating	72.60 (18.41)	71.68 (20.62)	69.14 (21.30)
Healthy novel rating	58.68 (27.70)	54.71 (31.34)	57.44 (30.76)
Energy-dense trained rating	74.18 (19.11)	77.30 (18.42)	71.10 (21.79)
Energy-dense novel rating	79.72 (20.61)	77.88 (21.99)	75.11 (21.87)
Hunger	2.57 (1.27)	3.04 (1.39)	2.85 (1.47)

For gender, frequencies of female participants are noted with percentage of group in brackets. All other variables are described in terms of mean averages, with SDs in brackets.

Training Performance

Reaction times got significantly quicker over blocks ($F_{3.28,659.282} = 42.03$, $p < 0.001$, $n^2_p = 0.173$). A significant effect of condition was found ($F_{2,201} = 34.29$, $p < 0.001$, $n^2_p = 0.254$) with slower RTs for participants in the FSIT-app condition ($M = 884.93$, $SE = 16.83$) compared to participants in both the FSIT-computer ($M = 703.79$, $SE = 16.83$, $p < 0.001$) and control ($M = 726.19$, $SE = 17.20$, $p < 0.001$) groups. A significant interaction between block and condition ($F_{6.56,659.282} = 3.08$, $p = 0.004$, $n^2_p = 0.030$) was also observed, with simple effects analyses revealing that improvements in RTs over blocks were strongest for the FSIT-app group ($F_{4,198} = 18.42$, $p < 0.001$, $n^2_p = 0.271$), followed by the FSIT-computer group ($F_{4,198} = 7.22$, $p < 0.001$, $n^2_p = 0.127$) and finally the control group ($F_{4,198} = 3.88$, $p = 0.005$, $n^2_p = 0.073$).

Commission errors decreased over blocks ($F_{3.650,733.550} = 11.426$, $p < 0.001$, $n^2_p = 0.054$), and a significant effect of condition ($F_{2,200} = 11.41$, $p < 0.001$, $n^2_p = 0.100$) revealed lower error rates in the FSIT-app group ($M = 0.031$, $SE = 0.007$) compared to the FSIT-computer ($M = 0.067$, $SE = 0.007$, $p = 0.001$) and control ($M = 0.072$, $SE = 0.007$, $p < 0.001$) groups. No significant interaction was observed for this analysis.

In analyses on FSIT-app data only, there was no evidence of an effect of Stimulus Type (food vs. filler) on RTs, nor was there evidence of an interaction between Stimulus Type and Block for RTs (both $p < 0.200$). Commission errors were significantly higher for filler stimuli ($M = 0.055$, $SE = 0.007$) than for energy-dense food stimuli ($M = 0.028$, $SE = 0.005$; $F_{1,68} = 33.22$, $p < 0.001$, $n^2_p = 0.328$), suggesting participants learned food-No-Go associations as expected. No interaction was found between block and stimulus type for commission errors.

Food Choices

Post-training healthy-food choices differed significantly between conditions ($F_{2,202} = 5.74$, $p = 0.004$, $n^2_p = 0.054$) with the highest healthy-food choice in the FSIT-computer group ($M = 2.78$, $SE = 0.16$) followed by the FSIT-app group ($M = 2.42$, $SE = 0.16$) and finally the control group ($M = 2.02$, $SE = 0.16$). Planned pairwise comparisons revealed that the only significant difference existed between the FSIT-computer group and the Control group ($p = 0.001$), with the comparison between the FSIT-app and Control groups failing to pass the significance threshold ($p = 0.077$). There was no significant difference between either of the two FSIT groups either ($p = 0.103$). Bayes factors show that the data indicates strong support for a difference between the control group and the FSIT-computer task (BF = 210.98) but that the data are inconclusive for the FSIT-app task (BF = 1.80).

Paired sample *t*-tests revealed that the effect of condition was primarily driven by a decrease in healthy-food choice in the Control condition across time-points (**Figure 4**). Comparing baseline food choices to post-training food choices revealed no evidence of change in the FSIT-app ($p = 0.334$) or FSIT-computer ($p = 1.000$) groups, but a significant effect of time was found in the Control group ($t_{66} = 3.56$, $p = 0.001$) with choices at post-training ($M = 1.99$, $SD = 1.32$) being significantly lower than those at baseline ($M = 2.57$, $SD = 1.29$).

Binary logistic regression revealed that compared to the Control group, participants in the FSIT-computer group were no more likely to select a healthy food as their first choice in the post-training hypothetical choice task ($p = 0.052$) and nor were those in the FSIT-app group ($p = 0.653$).

Across the entire sample, only 14.8% of children chose a healthy food in the real choice reward task and when examining the effect of condition on real-food choices, there was no significant effect of completing either the FSIT-app or FSIT-computer training compared to the Control task (both $p > 0.400$).

Food-Liking Ratings

These analyses were conducted for trained foods only, due to the finding that trained foods and novel foods were not well matched at baseline. Healthy foods were rated slightly lower ($M = 70.95$, $SE = 1.38$) than energy-dense foods ($M = 74.78$, $SE = 1.25$, $F_{1,197} = 4.66$, $p = 0.032$, $n^2_p = 0.023$) but no further significant main effects or interactions were observed. For healthy foods, a slight decrease in liking was observed for the FSIT-app group and the Control group, whereas a slight increase was observed in the FSIT-computer group (**Figure 5**). The opposite patterns were observed for unhealthy items, with liking ratings decreasing slightly in the FSIT-computer group and increasing slightly in the FSIT-app and Control group. However, none of these differences or changes reached significance (all $p > 0.130$).

Effect of Awareness

One-hundred-and-eighty-six children in the sample were interviewed at the end of their involvement with the project (some children were not interviewed either due to time constraints or due to difficulties maintaining attention i.e., for very young children). The majority of children were aware of task contingencies ($n = 152$) but awareness of the healthy-eating aims of the study and task effects were much lower ($n = 62$ and 39, respectively). Chi-squared tests revealed that there were no significant differences between groups for any of the awareness measures (all $p > 0.480$). In addition, adding these variables to the ANCOVA investigating the effect of training on food choices revealed that none were predictive of food choices (all $p > 0.290$), while the effect of condition remained significant ($p = 0.004$).

Discussion

In this study, we tested a FSIT-app against the FSIT-computer task, we have used in previous research (Porter et al., 2018). We hypothesised that children playing the two FSIT tasks (app or computer) would choose a greater number of healthy foods compared to children playing the Control task. We were also interested in whether there would be any preliminary evidence for differences in effect sizes of these respective FSIT tasks (when each was compared to the Control task). Our findings partially support our hypothesis; children in

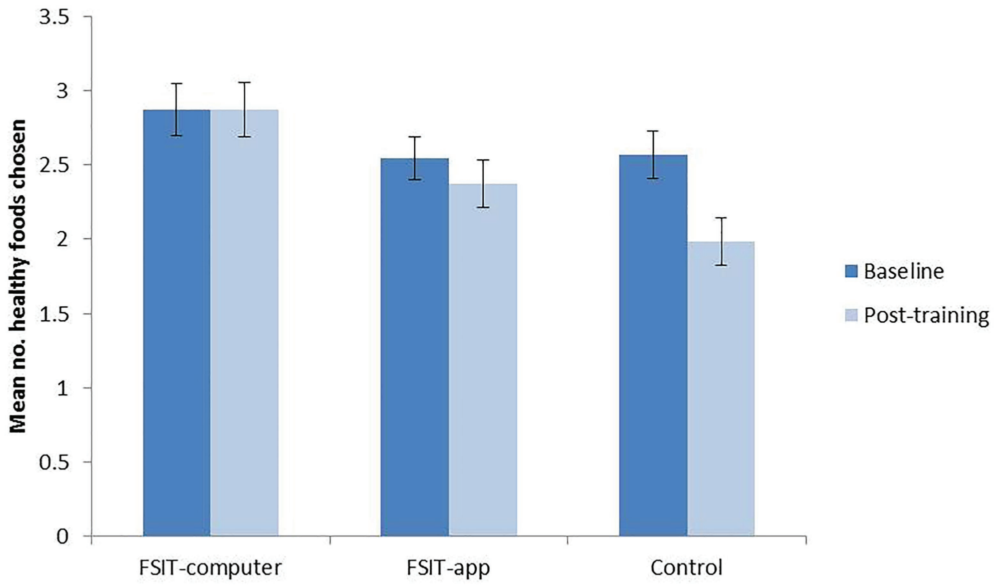

FIGURE 4 | Mean number of healthy foods chosen at baseline and post-training within each condition; error bars show SE.

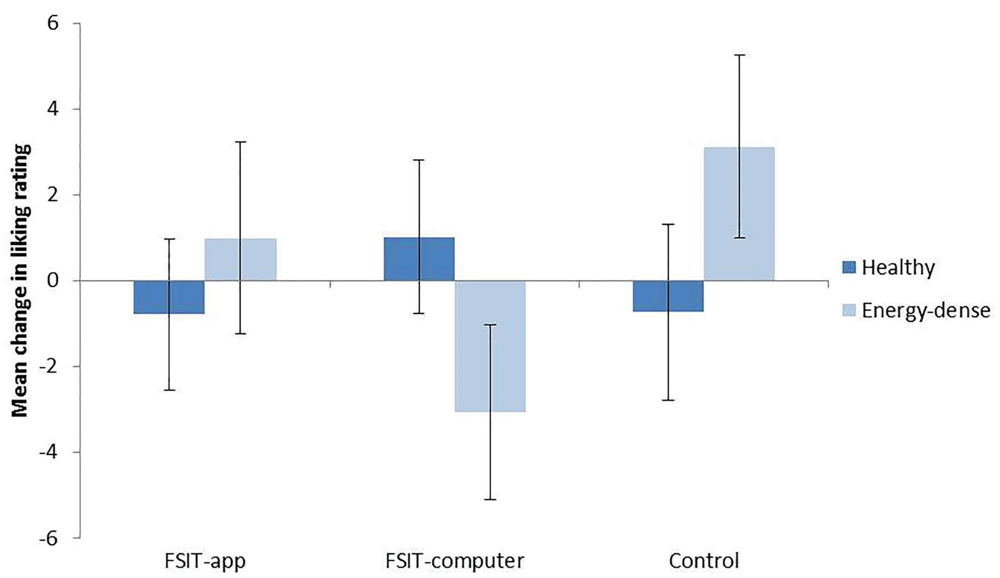

FIGURE 5 | Mean change (plus SE) from baseline to post-training in food-liking ratings for healthy foods and energy-dense foods.

the FSIT-computer group chose a significantly greater number of healthy foods in the post-training hypothetical food-choice task. In addition, within-group analyses showed that healthy-food choices in the control group decreased over time, whereas they remained stable in the two FSIT groups. This suggests that FSIT can have a beneficial effect on healthy eating behaviours. Whilst there was a trend for children in the FSIT-app group to choose a greater number of healthy foods than children who had played the control task, this difference was not significant. The within-group analyses showed that the FSIT-app group also appeared to be protected from the decline in healthy-food choices observed in the Control group; however, the lack of significant differences at post-training means that no definitive conclusions can be drawn regarding the effects of this task on food choices.

There was no evidence that either of the FSIT tasks had any effect on real-food choices. Previous research has found that FSIT can impact children's food choice and eating behaviours when faced with real foods; Folkvord et al. (2016) found that children who had played FSIT ate less than children who had played control training when they were given free access to sweets and chocolate, and Porter et al. (2018) found that children who had played FSIT chose a greater number of fruit items (relative to energy-dense foods) to go into their snack bags compared to children who had played control training. It is possible that the present non-significant effects are due to wash-out of training effects in the current study, as the real-food-choice task came at the very end of the experiment after the hypothetical food-choice task and the food-liking rating task. In addition, the real-food-choice task (in which children were allowed a single food choice) may not have been sensitive enough to detect differences between groups compared to those used by other studies (e.g., calorie intake in Folkvord et al., 2016 and a task where children were allowed three items in Porter et al., 2018). Thus, our real-food choice measure depended on training effects being of an "all or nothing" nature, whereas FSIT effects might be more subtle than this [e.g., the children who played FSIT in the study by Folkvord et al. (2016) consumed 34% fewer calories than their peers in the control group]. Children were also allowed more time to deliberate over their choices in this task than they were in the time-limited, hypothetical food-choice task. Work with adults has shown that the effects of response training paradigms can be highly dependent on impulsive choice contexts (Veling et al., 2017a), which provides another potential explanation for these non-significant effects.

A new measure of food devaluation for use with children was piloted in this study. Devaluation of foods associated with response inhibition has been observed in previous studies with adults (Veling et al., 2017b). On the whole, children were able to complete the task, indicating its suitability for use with younger samples. However, there were no significant differences between groups on change in liking ratings for either healthy or energy-dense foods. This may be because this study was powered to detect between-groups differences in food choices but not in children's food ratings. It is also possible that using VAs with child participants is not a particularly sensitive method for assessing food devaluation; histograms of children's food ratings revealed that some children were only selecting extreme values for their ratings of the food stimuli, which would preclude the detection of subtle changes in food-liking. Nevertheless, it is interesting that the means showed a subtle trend for devaluation in the FSIT-computer group only (which was also the only group to show significantly higher healthy-food choice at post-training), and future research could aim to probe this in more adequately powered studies to determine whether food devaluation plays a role in FSIT effects on children's food choices. Alternatively, other measures for food-liking could be explored such as a measure of instrumental responding to obtain food items. This outcome has been found to reduce for energy-dense foods after FSIT (Houben and Giesen, 2018), and the measurement task has also been validated in samples of children as young as 4 years old (Savell et al., 2020).

GENERAL DISCUSSION

The studies presented here aimed to explore the effectiveness of different variants of FSIT as a healthy eating tool for primary school aged children. Study 1 found no significant effects of FSIT on food choice behaviour at all. A key difference between this study and positive earlier studies (Folkvord et al., 2016; Porter et al., 2018) was that children participated in groups (mixed by condition) rather than one-on-one. Anecdotally, the group-testing sessions were noisier and more distracting – children would talk during the task despite efforts to keep the room quiet, and they could also turn around and see that their peers were playing a different version of the task than themselves. This is reflected in the data – examining children's performance data on the emotive-FSIT task (i.e., the only version of FSIT that we had tested beforehand, and with success) showed that commission error rates were unexpectedly high. Children may also have been influenced by each other during the food-choice task itself – some items were clearly very popular, and some children would exclaim in delight upon finding them in the choice task. Children are influenced by the food preferences of their peers (Birch, 1980; DeJesus et al., 2018) and this social endorsement by peers may have overridden FSIT effects on food choices.

In comparison, children in Study 2 participated on a one-on-one basis, as in our own earlier research and that of others (Folkvord et al., 2016). This time, a significant effect of training was observed once more for the FSIT-computer task, which is the same task that has been successfully tested in earlier research. Unlike in Study 1, children's task performance did not appear to be negatively impacted in this study. This suggests that low commission error rates during FSIT may be important for subsequent training effects on food choices, which dovetails with meta-analyses of studies in adult participants, where it was found that successful stopping on inhibition trials was necessary for FSIT to have an impact on eating behaviour (Jones et al., 2016). To explore this, we conducted an exploratory correlation on the data collected in Study 2, which indicated that changes in commission errors were negatively correlated with changes in healthy-food choice ($R = -0.223$, $p = 0.009$) – in other words, improvements in inhibition to energy-dense foods in the FSIT training tasks were associated with increases in healthy-food choices.

These findings suggest that lower commission error rates lead to stronger FSIT effects on eating behaviour. However, in Study 2, FSIT-computer training appeared to be more effective than FSIT-app training, despite the computer task having significantly higher commission error rates than the app task. This could be due to differences in commission error measurement sensitivity as a result of the response mode (touchscreen taps vs. keyboard press). The computer task left little room for error (i.e., because children's hands were resting on computer keys, meaning that even very tiny movements can result in a "press") and was thus a highly-sensitive measure of commission errors. Comparatively, for the app task, the resting position of children's hands was further away from the response apparatus (it is not possible to play the FSIT-app task with the hand resting on the screen). The greater distance between hand and device may then lead to the recording of artificially low error rates (i.e., because there is more time to correct errors on the hand's comparatively long journey towards a touch screen). Future research could explore this possibility, and could also investigate whether these task differences impact children's engagement with FSIT. For example, the increased challenge of computer-based tasks may engage children's attention and motivation, and compel them to improve their scores and focus on learning the rules of the game. However if the game is less challenging (i.e., because motor responses can be corrected at relative leisure), then there may be less drive to improve performance. The findings of these studies together indicate that such motivation and attention may be key for FSIT effects on eating behaviour.

Altogether, the results of these studies suggest that high task performance is required for FSIT to have an impact on eating behaviour outcomes, and that this may be achieved by implementing training in a controlled and quiet environment. One potential alternative explanation for the difference between studies is that individual testing results in demand characteristics, with children more likely to try and please the experimenter when they are working on a one-on-one basis. In Study 2, we found no significant differences between groups regarding awareness of the study aims, task contingencies, or task effects on food choices/liking. Awareness of the healthy-eating aims and expected task effects were low, although awareness of contingencies within the task was high. Children in the control group who were considered "aware" of the study's aims and task contingencies described how they needed to press for the "healthy" activity images (sports), and not for the "unhealthy" activity images (technology). This suggests that the control task could also have driven any demand characteristics within the sample, rather than this being limited to the active group only.

However, if children were simply choosing foods based on what they believed the experimenter wanted them to choose, healthy-food selection rates would surely be much higher than they are and similar across all conditions. In reality, very few children chose a high number of healthy foods (and barely any selected a healthy food as their real choice), further suggesting that demand characteristics were not driving these results. Both studies found a decline in healthy eating behaviour across time – this occurred in all groups in Study 1, and in the Control group only in Study 2. Turton et al. (2018) who also observed a decline in the healthiness of participants' eating behaviour over experimental sessions, suggested that such patterns may be due to participants becoming more familiar with the experimental environment and becoming more relaxed in their eating behaviours. Relatedly, children being offered a snack of their choice in the middle of the school day (Study 2 only) would have been a departure from their usual routine, and may have been seen as a rare chance for them to indulge in a "treat". In this sense, children may have been in a more disinhibited state than they would normally when choosing which foods to eat. Understanding the wider context of children's eating behaviours (e.g., whether they had already eaten fruit that day, how often they were allowed energy-dense foods at school and at home etc.) would help to better contextualise these findings.

While the finding of a decline over time departs from previous findings (i.e., Porter et al., 2018 found an increase in healthy-food choice in the FSIT group and no change in healthy-food choice in the control group), this could be due to children in the current study choosing a higher percentage of healthy foods at baseline. An earlier study by our research group (Porter et al., 2018) saw healthy choices rise significantly in the FSIT group from 36 to 52%, whereas in the present study, they were higher at baseline (42–48%) but remained stable to post-training (40–48%). Meanwhile, healthy choices in the earlier study's two control groups remained stable from baseline (29–36%) to post-training (32–39%) whereas in the present study, baseline choices in the Control group were higher (43%) but then significantly declined to a more comparable 33% at post-training. This suggests that the starting point for children's food choices could be key for determining whether FSIT has an augmentative effect (i.e., increases healthy-food choice) or a protective effect (i.e., guards against a decline in healthy-food choice); when healthy-food choices are low at baseline then FSIT has the potential to increase them but when healthy-food choices are high at baseline, FSIT can maintain this behaviour.

These studies have a number of strengths; firstly, they provide further support for the use of FSIT as a healthy eating intervention for use with children. While it could be argued that the consistent stimulus-response associations (which are important for FSIT's efficacy) reinforce potentially harmful and rigid narratives about which foods "should" and "should not" be eaten, it is notable that the effects of FSIT on behaviour are much more subtle than this – after FSIT children choose a slightly higher number of healthy foods (Porter et al., 2018) and consume a slightly smaller amount of energy-dense foods (Folkvord et al., 2016), however, they do not completely stop choosing or eating these foods. Similarly, work with adults has shown that FSIT leads to subtle reductions in liking of energy-dense foods (e.g., Veling et al., 2017b), which could help people achieve a more balanced diet without needing to entirely cut out their favourite energy-dense foods. A further strength is that Study 2 also piloted a FSIT app with children for the first time and provides preliminary, tentative evidence that this app may be able to support healthy eating habits in children (i.e., by protecting against the observed decline in healthy behaviours over time). As FSIT can be delivered as a DBCI directly to users' devices (such as *via* the FoodT app), this intervention can be used immediately and for free by families. A further advantage is that the flexibility that DBCIs afford users means that recommendations for usage based on the findings of this study (i.e., to preferably play the app in a quiet environment) can be implemented in a way that suits them. The smaller effect size for this app (in comparison to computer-based FSIT) suggests that further research needs to be conducted to identify the reasons for this, and potential developments to optimise app-based training should be identified. A further strength of this study is that a food-liking rating scale was successfully piloted which could be used in future research to pursue the question of whether the stimulus devaluation contributes to FSIT effects on children's eating behaviour as well as adults'.

Nevertheless, a number of limitations should also be noted. Most notably, the question of whether evaluative conditioning can bring additional benefits to FSIT paradigms has not been fully answered. In Study 1 (in which we could directly compare neutral and emotive No-Go signals), no training effects were observed. In Study 2 (in which training effects were observed), the two FSIT tasks differed in a number of ways beyond the response signals used, and therefore the relative contribution of these various factors cannot be teased apart. For example, a further potentially crucial difference between the app and computer tasks is the proportion of critical "food-response" trials per block – in the app this comes to 50% of all trials (plus 50% "filler" trials) whereas in the FSIT-computer task, 100% of trials encouraged a food-response association. Therefore, the level of exposure to stimulus-response associations was lower in the FSIT-app group compared to the FSIT-computer group, which may have impacted the efficacy of this task variant. Earlier research with children (Folkvord et al., 2016; Porter et al., 2018) has found significant, positive effects of FSIT using tasks that do not contain these fillers, suggesting that simpler tasks with a higher proportion of food-response trials may be most effective for children. Future research should aim to test the influence of these various factors (including the use of emotive vs. neutral response signals) in tasks that more closely control for other differences. A second limitation is that the researcher who delivered the intervention, recorded the outcome measures and performed the statistical analysis was not blinded to condition allocation. Finally, current results do not help to answer the question of how long any FSIT effects on food choices might last for, and whether effects can be reinforced by repeated training sessions. A more longitudinal design, such as that used by Study 1, would help to explore this question.

Future research should aim to investigate whether repeated use of FSIT at home can have a significant impact on real-life eating behaviour, as has been found to be the case with adult participants. While the outcome measures used here are useful for gathering preliminary evidence on FSIT effects within a controlled environment, their ecological validity is questionable. For example, the hypothetical food-choice task (when implemented as in Study 2) does not allow children to change their choices after they have made their initial selections. It is questionable whether this is truly representative of children's daily feeding decisions compared to tasks in which they are allowed (at least some) time to deliberate over their choice and select an alternative if they change their minds. Work with adults has suggested that the effect of response training paradigms may be limited to choices made under time-pressure. While this could be a further explanation for the lack of effects in the real-food-choice task, it also has clear implications for the applied value of this paradigm as a healthy eating intervention. Folkvord et al. (2016) found an effect of FSIT on calorie intake without time pressure, however, no studies have yet investigated the impacts of FSIT on children's real life eating behaviour outside of an experimental setting.

CONCLUSION

To conclude, the studies presented here provide some further support for the efficacy of FSIT as a healthy eating tool for children. Accuracy on energy-dense food No-Go trials appears to be important for FSIT effects on eating behaviour, and conditions that reduce children's attention or motivation (such as noisy, distracting environments) may subsequently reduce training effects on food choices. Future research should explore whether app-based versions of FSIT can be optimised (i.e., by increasing the level of challenge) to increase the efficacy of this delivery mode, and whether FSIT effects on food choices can translate into real life eating behaviour over longer time periods.

DATA AVAILABILITY STATEMENT

The research data and analysis code supporting this publication are openly available from the University of Exeter's institutional repository at: https://doi.org/10.24378/exe.3303.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Exeter CLES Psychology Ethics Committee. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

LP: conceptualisation, methodology, software, investigation, data curation, formal analysis, and writing. FG: conceptualisation, writing (review and editing), and supervision. KW: conceptualisation (Study 2), writing (review and editing), and supervision (Study 2). FV: conceptualisation (Study 1), methodology (Study 1), writing (review and editing), and supervision (Study 1). NL: conceptualisation, methodology, formal analysis, writing (review and editing), and supervision. All authors contributed to the article and approved the submitted version.

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Developmental Changes in Food Perception and Preference

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Food choices are a key determinant of dietary intake, with brain regions, such as the mesolimbic and prefrontal cortex maturing at differential rates into adulthood. More needs to be understood about developmental changes in healthy and unhealthy food perceptions and preference. We investigated how food perceptions and preference vary as a function of age and how food attributes (taste and health) impact age-related changes. One hundred thirty-nine participants (8–23 years, 60 females) completed computerized tasks to rate high-calorie and low-calorie food cues for taste, health, and liking (preference), followed by 100 binary food choices based on each participant's ratings. Dietary self-control was considered successful when the healthier (vs. tastier) food was chosen. Self-control success ratio was the proportion of success trials over total number of choices. Beta-weights for health (β-health) and taste (β-taste) were calculated as each attribute's influence on food preference. Adiposity measurements included BMI z-score and waist-to-height ratio (WHtR). High-calorie foods were rated more tasty and less healthy with increasing age. Older participants liked high-calorie foods more (vs. younger participants), and β-taste was associated with age. Significant age-by-WHtR interactions were observed for health and taste ratings of high-calorie foods, β-taste, and marginally for preference of high-calorie foods. Stratifying by WHtR (high, low), we found age-related increases in taste and preference ratings of high-calorie foods in the high WHtR group alone. In contrast, age-related decreases in health ratings of high-calorie foods were significant in the low WHtR group alone. Age and β-taste were significantly associated in the high WHtR group and only marginally significant with low WHtR. Although participants rated low-calorie foods as less tasty and less healthy with increasing age, there was no association between age and preference for low-calorie foods. Participants made faster food choices with increasing age regardless of WHtR, with a significant age-by-WHtR interaction on reaction time (RT). There were no age-related effects in self-control success ratio and β-health. These results suggest that individual differences in age and central adiposity play an important role in preference for high-calorie foods, and a higher importance of food tastiness in food choice may contribute to greater preference for high-calorie foods with increasing age.

Keywords: eating behavior, food choice, dietary self-control, pediatric obesity, children, adolescents

INTRODUCTION

Every day, we make a series of dietary decisions that determine energy intake (van Meer et al., 2016; Beckerman et al., 2017). Over time, if more energy is consumed than expended, a positive energy balance is created that acts as a driver of obesity (Blundell and Cooling, 2000). The central regulation of food intake involves a delicate balance between top-down regulation from the prefrontal cortex (key region for cognitive control) and bottom-up regulation from limbic reward pathways (Lowe et al., 2020). However, during adolescence—a time of rapid brain maturation—the prefrontal cortex develops at an imbalanced, slower pace than the limbic system creating an increased risk for impaired behavioral regulation (Casey et al., 2000; Lowe et al., 2020). This is particularly relevant when adolescents are faced with appetitive cues (Somerville and Casey, 2010; Bruce et al., 2011), as well as given what is now known about continued neurodevelopment into the third decade of life (Sawyer et al., 2018). Food cues target susceptible emotions and cognitive brain functions, and can trigger automatic/habitual behaviors, particularly in children and adolescents (Berthoud, 2012; Ames et al., 2014). This knowledge can be exploited by the food industry, leading to ubiquitous food cues in our current obesogenic environment for the purposes of neuromarketing (Berthoud, 2012; Belfort-DeAguiar and Seo, 2018).

Age-related effects on the central regulation of eating have been shown in studies where younger individuals exhibit greater food craving for unhealthy foods compared to older individuals, decreased brain signal change in the prefrontal regions, and fewer connections between prefrontal-limbic regions implicated in regulation of eating (Giuliani and Pfeifer, 2015; Silvers et al., 2015; van Meer et al., 2017, 2019). Compared to adults, adolescents have been found to exhibit greater striatal sensitivity to food stimuli (Galván and McGlennen, 2013), and children exhibit greater differences between those with obesity and those with healthy weight in their response to food cues in the left insula (Morys et al., 2020).

In addition to the imbalanced development of the prefrontal cortex and limbic system, adolescents could also develop less healthy eating behaviors with increasing independence (Bassett et al., 2008; Vaitkeviciute et al., 2015). Adolescent eating habits are motivated by multiple factors including hunger and food cravings, time, convenience and availability, among many others, and they are motivated more by food preferences and food appeal, including taste, than by nutritional knowledge or perceived health benefits (Neumark-Sztainer et al., 1999; Fitzgerald et al., 2010; Lai Yeung, 2010; Naeeni et al., 2014). Food choices in adolescents are characterized by a high consumption of calorie-dense foods and low consumption of nutrient-dense foods, such as vegetables and fruits compared to children (Lytle et al., 2000; Smithers et al., 2000; Hackett et al., 2002; Mannino et al., 2004). As children get older, their dietary quality tends to decline (Smithers et al., 2000; Hackett et al., 2002), as shown in a study that compared the diet of 9–10 year old children to that of 11–12 year old children in the United Kingdom and found that the older children ate less fruits and vegetables than the younger ones (Hackett et al., 2002), as well as a National Diet and Nutrition Survey in the United Kingdom in children 4–18 years which found that potassium, magnesium and calcium intakes, as well as vitamin A levels, were lower in the older children (Smithers et al., 2000). A cohort study with third, fifth and eighth graders in Minnesota found that fruit consumption fell by 41% between the third and the eighth grades while vegetable consumption fell by 25% (Lytle et al., 2000). A study of 24-h dietary recalls in Non-Hispanic White girls ages 5, 7, and 9 years in Pennsylvania found that at age 9, significantly fewer girls were meeting the recommendations for dairy, fruit and vegetable servings than at age 5 (Mannino et al., 2004). Based on rodent studies, calorie-dense diets could alter the functional and structural maturation of the prefrontal cortex, and lead to cognitive and behavioral changes including anxiety-like behaviors, and impaired memory and decision-making (Reichelt et al., 2015, 2016, 2019; Baker and Reichelt, 2016). These alterations could have concerning long-term neurological effects in adolescents given increased neuroplasticity at this age (Lowe et al., 2020).

The observed connections between brain development and dietary intake during adolescence present an opportunity for behavioral research in food decision-making. Dietary decision-making involves integration of basic food attributes, such as tastiness, and abstract attributes, such as healthiness. Food tastiness is reliably weighted in decisions, and is a primary driver of food choices in youth 8–14 years old, as studied with a computerized food ratings and subsequent food choice (4-point scale "strong no" to "strong yes") task (Bruce et al., 2016; Lim et al., 2016); subjects' taste ratings predicted their food choice. Similarly, youth between the ages of 10–17 years were studied with a button-press food choice task where subjects indicated whether they wanted to eat a food by pressing "yes" or "no" (van Meer et al., 2017, 2019); subjects made their choices based on food tastiness. Food tastiness has also been shown to be a stronger predictor of food preference in older youth compared to younger youth (van Meer et al., 2019; Pearce et al., 2020). Pearce et al. (2020) studied children 7–11 years old and asked them to choose the food they preferred to eat using the computer mouse. Considering food healthiness in food decisions requires effort and is therefore unreliably weighted in decisions (Sullivan et al., 2015). In contrast to youth, however, in young adults both food tastiness and healthiness appear to contribute to food choices, even though taste still plays a more dominant role than health (Sullivan et al., 2015; Lim et al., 2018). Finally, healthy food choices require greater dietary self-control in older youth compared to younger youth, shown in a study of youth 8–13 years of age who used a computer mouse to indicate whether they wanted to eat healthy or unhealthy foods (yes or no) (Ha et al., 2016). In this study, the area under the curve (AUC) for the computer mouse actual trajectory compared to the ideal trajectory (i.e., a straight line from the start point to the selected response) was used to represent a child's cognitive efforts to shift a decision toward the selected response, despite being initially attracted to the unselected response (Ha et al., 2016). The difference score in AUC for Yes and No curves was calculated between AUC (No choice)—AUC (Yes choice) for healthy vs. unhealthy food cues, and the AUC difference score for unhealthy foods was significantly larger than that for healthy foods, and this was most pronounced in the older children (Ha et al., 2016). Taken together, it has been shown that there is an increase in calorie-dense food consumption with increasing age, in which tastiness of food is the main determinant. In contrast, observations have been mixed in terms of effects of age on healthy food consumption and preference. We aimed to clarify whether perceptions and preferences for high-calorie and low-calorie foods vary as a function of age, and further investigate how specific food attributes (i.e., taste and health) impact these age-related changes in young individuals between 8 and 23 years old. We hypothesized that there would be an age-related increase in preference for high-calorie food items, which may be driven by the tastiness of food, with stronger integration into dietary decisions with increasing age. We did not have a clear hypothesis concerning age effects on preferences for low-calorie foods and dietary self-control given inconsistent findings in the literature. Hypotheses were generated prior to data analysis.

MATERIALS AND METHODS

Study Participants

This was a cross-sectional study of 139 individuals between 8 and 23 years old (14.5 ± 0.42 years; 57% male). Race was reported as 79.9% Caucasian, 11.6% Asian, 2.3% African-American, and 6.2% more than one race. For ethnicity 57.4% (74/129) were Hispanic or Latino. A subset of participants had both brain structural data and food choices behavioral data, for which we published their Self-Control Success Ratio variable data (Kim et al., 2020). Data were collected for the purpose of examining how individual differences in age and adiposity influence food choices in youth, as an *a priori* research question. At the time of initiating this study and its design in 2015, there were not any similar food choices studies in youth available in the literature to utilize as a basis for power calculation. Thus, sample size was largely driven by feasibility and resources. Our data collection ended due to the Covid-19 pandemic.

In this study we included participants from age 8 to 23 years old. We included children starting at 8 years so that they would be able to understand and follow the instructions to complete the computer food ratings and food choice task, which were written at a third-grade level. Subjects 19–23 years old were included given recent proposals that the definition of adolescence be expanded to 24 years old to reflect continued neurodevelopment into the third decade of life (Sawyer et al., 2018), and given that there is a growing consensus that the age ranges studied need to span late childhood to early adulthood to assess the entire developmental period of adolescence (Foulkes and Blakemore, 2018). Participants were recruited from the pediatric endocrinology and general pediatric clinics at Children's Hospital Los Angeles (CHLA), as well as the University of Southern California (USC) and Los Angeles community. Participants were directly approached with flyers when attending clinics or responded to flyers posted around the greater Los Angeles metro area, through previous participation in another USC research study, as well as approached at community outreach events. They were asked to participate in a study about food choices in youth. Brain imaging scans were added during the later phase of the study, and 71 participants with both brain MRI and behavioral food choices data were published in Kim et al. (2020). Inclusion criteria included: age 8–23 years, English as primary language, and being otherwise healthy. Exclusion criteria included: systemic illness, developmental delay, behavioral disorders, learning disabilities, use of psychotropic medications, and prior participation in a weight-management program. All subjects were able to read and speak English to be able to understand and respond to the computer task prompts. Parents were either Spanish- or English-speaking. Written informed consent from parents and age-appropriate assent from children were obtained. The protocol was approved by the Institutional Review Board of CHLA and USC (CHLA-15-00007 and HS-16-00978).

Parents or subjects older than 18 years old filled out a demographic questionnaire. The height and weight of all participants were measured using a stadiometer and a calibrated digital scale, respectively. Body mass index (BMI) was calculated (kg/m^2) and BMI z-score (BMI-z) was determined based on the U.S Center for Disease Control normative data[1]. Participants aged 20 and older had BMI-z calculated for 20 years of age. Waist circumference (n = 136) was measured at the midpoint between the iliac crest and lower costal margin in the midaxillary line, and waist-to-height ratio (WHtR) was calculated. Average BMI-z (SE) was 0.93 ± 0.09 and WHtR was 0.52 ± 0.01.

Computer-Based Behavioral Task

The computer-based food choice task was based on a previously published platform used to study dietary decision-making (Sullivan et al., 2015) and modified for our youth cohort with input from a pediatric dietitian and child psychologist, as previously published (Kim et al., 2020). The task consisted of a Food Ratings component and a Food Choices component, both of which were programmed in MATLAB (version 2014a, Natick, MA) with PsychophysicsToolbox (version 3)2. Instructions were designed to be at a 3rd grade reading level and were read

[1] https://www.cdc.gov/growthcharts/clinical_charts.htm

aloud to participants who were younger than 18 years old in order to standardize for literacy. Participants completed the task in a fasted state of at least 4 h, to account for a potential desensitization to food cues in a sated state (van Meer et al., 2016). Parents were requested to wait in a separate room to control for confounding effects.

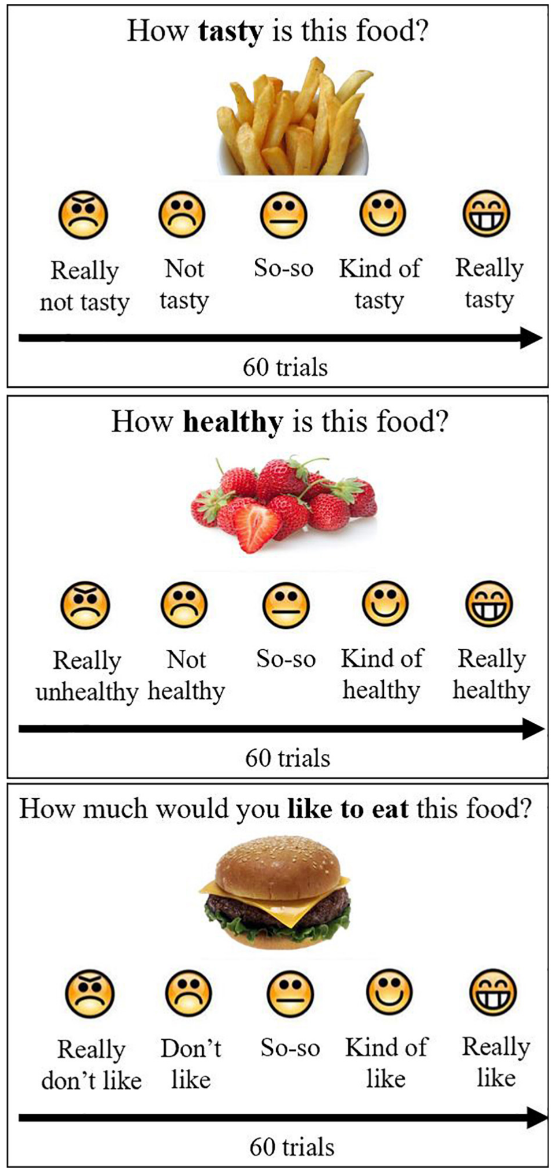

FIGURE 1 | Food ratings. Participants rated 60 foods on taste, health and preference, using a 5-point scale with emoticons and words, by pushing buttons on the keyboard. Block and stimulus order were randomized across participants.

Food Ratings

Participants were shown 30 high-calorie and 30 low-calorie food cues and were asked to rate the cues according to tastiness ("How tasty is this food?"), healthiness ("How healthy is this food?"), and preference or liking ("How much would you like to eat this food?") (**Figure 1**). Block and cues order were randomized across participants. The food cue stimuli were leveraged from prior validated studies (Page et al., 2011; Blechert et al., 2014; Sullivan et al., 2015) and were matched between calorie groups for red/green/blue color proportion, size, brightness, contrast and normalized complexity so that the groups only differed by their caloric density (kcal/100 g). Caloric density for each food cue was obtained from the USDA Food Data Central[2] and for food cues of a mixed composition was determined based on a weighted average. Food cues were selected to be foods that were familiar and appealing to a pilot group of youth. For each of the 60 cues, participants indicated their ratings (taste, health, and preference) for each food attribute on a 5-point verbal and visual Likert scale. Participants rated food tastiness as (1) really not tasty, (2) not tasty, (3) so-so, (4) kind of tasty, and (5) very tasty. Participants rated food healthiness as (1) really unhealthy, (2) not healthy, (3) so-so, (4) kind of healthy, and (5) really healthy. Participants rated preference as (1) really don't like, (2) don't like, (3) so-so, (4) kind of like, and (5) really like.

Based on participants' rating of the 60 food cues, a linear regression model was created for each participant to measure how well the health rating or taste rating predicted their preference rating for food cues. A beta weight for health (β-health) and for taste (β-taste) were determined for each participant from the 60 trials to quantify the relative influence given to each attribute in determining preference for a food cue.

Food-Choice Mouse-Tracking

The ratings were then used to construct 100 binary pairs of food cues for the participant to choose between in the food-choice mouse-tracking task (Sullivan et al., 2015; Ha et al., 2016; Lim et al., 2018). Of these 100 pairs, 75 pairs were designed to be challenge trials, wherein one of the food cues had a higher taste rating but lower health rating than the other. This task involved the participants choosing which of two food cues they would rather eat (**Figure 2**). Participants were reminded to "try to keep it healthy" and were told that one of their decisions would be actualized once they had completed the task. Further details on trial structure have been previously published in a subgroup of participants with brain imaging (Kim et al., 2020).

Each participant's reaction time, the time between the presentation of the food cues and when they indicated their choice, was also calculated. A self-control success ratio, the proportion of challenge trials in which the subject chose the healthier food cue over the tastier one, was calculated for each participant.

For each subject's mean trajectory, a multiple linear regression was constructed to predict how differences in taste ratings and health ratings between the two food cues influenced the angle of the mouse from the start point. These models were then used to find the Significance Time for health and taste per participant, defined as the time at which the respective attribute (health or taste) emerged and remained as a significant predictor of the participant's final choice. The Significance Time was reported

[2]https://fdc.nal.usda.gov/

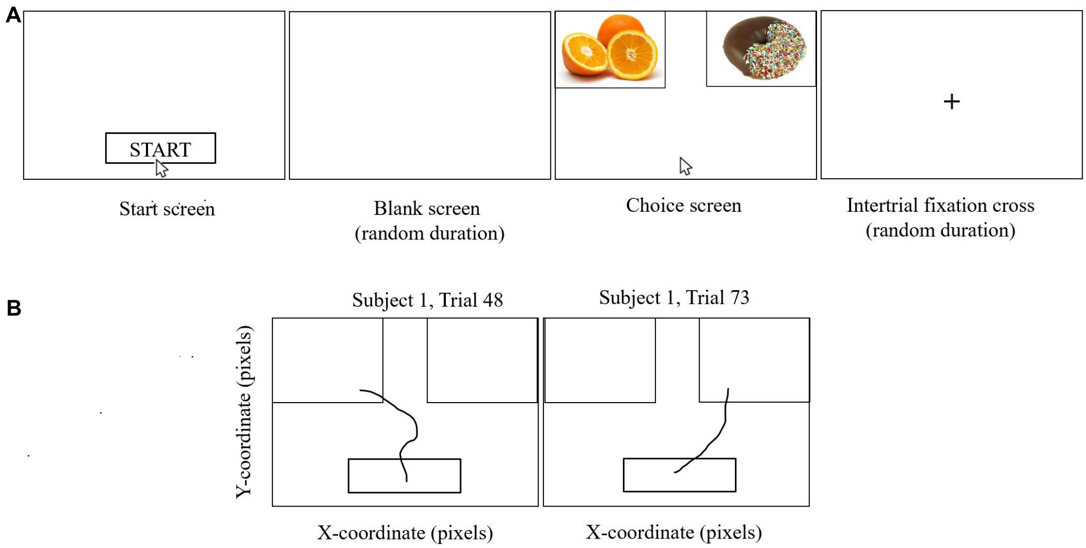

FIGURE 2 | Food-choice mouse-tracking. Participants were asked to choose the food item they would like to eat. They completed several practice trials prior to starting the task. As shown in **(A)**, participants clicked on the Start button, after which there was a blank screen of random duration (200–500 ms), and then the cursor would reappear in the bottom center of the screen and the food cues appeared on the screen, one at the left upper corner and one at the right upper corner of the screen. Participants moved the computer mouse to select a response and each mouse trajectory was recorded. Once the computer mouse entered the box containing the food cue, the trial ended, without the need to click. Trajectories were not visible to the participant. Trials were separated by a fixation cross of random duration (400–700 ms). One hundred binary choices were presented to each participant based on their individual ratings for taste and health from the food ratings task. Two representative mouse paths for Subject 1 are shown in **(B)** for trials on which the left-hand food item and the right-hand food item, respectively, were selected.

as the normalized time window (t = 1 to t = 101) at which a one-sided t-test first reported the coefficient of the particular attribute in a multiple linear regression as significantly greater than 0. The individual Significance Times were corrected by first normalizing the particular multiple linear regression coefficient of the attribute to be a proportion of its final value, and then fitting these normalized coefficients to a logistic regression; the time window at which that regression first has a non-zero value is the corrected individual Significance Time.

This recorded trajectory was analyzed to calculate the maximal deviation (MD), the furthest point of the mouse's actual trajectory from the ideal trajectory (i.e., a straight line from the start point to the final mouse point), and the AUC, the space between the actual and ideal trajectories of the mouse's path. MD represents how close a participant was to making a different decision while AUC is a measure of the cognitive effort with which the participants made decisions. The greater the AUC and MD, the greater the cognitive effort engaged to make a decision (Ha et al., 2016).

Statistical Analysis

Statistical analyses were conducted using SPSS (version 27.0, Armonk, NY: IBM Corp.). Linear regressions were used to examine relationships between age and food ratings. Food ratings included taste, health and preference of high-calorie and low-calorie food cues. We additionally examined relationships between age and β-taste and β-health using linear regressions.

Mouse-tracking related variables included AUC for successful self-control trials, AUC for failed self-control trials, MD for successful self-control trials, and MD for failed self-control trials. As well, Significance Time for taste and for health. Relationships between age and self-control success ratio were investigated using linear regressions. We used linear regressions to investigate relationships between age and mouse-tracking related variables. We also examined age-related effects on reaction time during food choice using linear regressions.

Sex and WHtR were included as covariates in all the age-related models. For all the age-related models, age variable was transformed using a square-root transformation given the non-uniform distribution of age; we also explored if the quadratic model would fit the data better than the linear model of age-related effects on food ratings and food-choice mouse-tracking data. F change scores were compared between quadratic models (age + age^2) and linear models (age). We found that F change score was not significant for all the comparisons between quadratic models and linear models, suggesting that linear models fitted data better than quadratic models in age-related effects on food ratings and food choice data.

We further examined age-by-adiposity interactions on food ratings and food-choice mouse-tracking data using linear regressions controlling for sex. We focused on WHtR as the primary adiposity measurement given it has a more pronounced effect on brain regions related to food choice than BMI-z (Kim et al., 2020; Ronan et al., 2020). When age-by-WHtR interaction was significant, we further investigated effects of age on food ratings and food-choice mouse-tracking data in high and low WHtR groups (based on the median split for WHtR of 0.51 for producing equal sample size for high and low WHtR groups) separately. Clinically, a WHtR $\geq$ 0.5 is considered to be a marker of central obesity and higher metabolic risk (McCarthy and Ashwell, 2006; Mehta, 2015).

A p-value of < 0.05 was considered to be significant for all statistical tests.

RESULTS

Food Ratings

Across participants, the average rating ± SE of high-calorie foods in terms of tastiness was 3.52 ± 0.07, healthiness was 1.82 ± 0.04, and overall preference (i.e., liking) was 3.40 ± 0.07. The average rating of low-calorie foods in terms of tastiness was 3.73 ± 0.06, healthiness was 4.42 ± 0.04 and overall liking was 3.70 ± 0.06. Repeated measures of ANOVA on food ratings with two-within subject factors (calorie: high- vs. low-calorie food cues; attribute: health vs. taste) controlled for age, sex and WHtR revealed a significant main effect of calorie [$F_{(1,132)} = 16.35$, $p < 0.001$, partial eta squared = 0.11], such that low-calorie foods were rated higher than high-calorie foods (mean difference ± SE: 1.41 ± 0.07, $p < 0.001$). There was no significant main effect of attribute [$F_{(1,132)} = 0.003$, $p = 0.96$, partial eta squared = 0]. There was a significant interaction of calorie and attribute [$F_{(1,132)} = 6.37$, $p = 0.013$, partial eta squared = 0.046]. *Post-hoc* paired t-tests revealed that participants rated low-calorie foods more tasty (mean difference ± SE: 0.21 ± 0.10, $p = 0.046$) and healthier (mean difference ± SE: 2.60 ± 0.07, $p < 0.001$) than high-calorie foods. One-way ANOVA on food preference controlled for age, sex and WHtR revealed a significant main effect of calorie [$F_{(1,132)} = 5.39$, $p = 0.022$, partial eta squared = 0.039], such that participants liked low-calorie foods more than high-calorie foods (mean difference ± SE: 0.29 ± 0.10, $p = 0.004$).

Food-Choice Mouse-Tracking Data

The average RT for food choices made was 1.63 ± 0.03 s. The average self-control success ratio for all participants was 33.55 ± 2.11%. Consistent with prior studies, we found that reaction time was longer during successful self-control trials than failed self-control trials (mean difference ± SE: 0.14 ± 0.04 s, $p = 0.001$). AUC and MD for successful self-control trials were larger than failed self-control trials (AUC mean difference ± SE: 1.88 ± 0.54, $p = 0.001$; MD mean difference ± SE: 0.05 ± 0.01, $p < 0.001$) suggesting that greater cognitive effort was engaged during successful self-control choices than failed self-control choices.

Across participants, the average Significance Time for taste was 899.20 ± 34.50 milliseconds (ms), and the average Significance Time for health was 1043.59 ± 33.11 ms. We also found that the Significance Times for taste were earlier than Significance Times for health (mean difference ± SE: −144.39 ± 43.88 ms, $p = 0.001$), suggesting that the taste attribute is processed earlier than health attribute in food choice.

Effects of Age (Table 1)

To investigate age-related effects on food perceptions and food preference, we modeled relationships between age and task-related variables while controlling for sex and WHtR (**Table 1**).

Effects of Age on Food Ratings

High-calorie foods were rated as more tasty (β = 0.49, $SE = 0.11$, $p < 0.001$, partial eta squared = 0.12) and less healthy (β = −0.14, $SE = 0.07$, $p = 0.03$, partial eta squared = 0.04) with increasing age. As well, older participants indicated greater overall preference for high-calorie food cues (β = 0.33, $SE = 0.11$, $p = 0.004$, partial eta squared = 0.06) than the younger participants.

Although participants rated low-calorie foods as less tasty (β = −0.17, $SE = 0.09$, $p = 0.07$, partial eta squared = 0.03) and less healthy (β = −0.14, $SE = 0.07$, $p = 0.04$, partial eta squared = 0.03) with increasing age, there was no significant association between age and preference for low-calorie food cues (β = −0.13, $SE = 0.09$, $p = 0.18$, partial eta squared = 0.01).

Older age was associated with an increased influence of taste attribute (i.e., β-taste) on food preference (β = 0.10, $SE = 0.03$, $p = 0.002$, partial eta squared = 0.07), suggesting that the taste attribute may contribute to the age-related increases in preference for high-calorie foods. There was no significant relationship between age and β-health (β = −0.01, $SE = 0.03$, $p = 0.67$, partial eta squared = 0.001).

Effects of Age on Food-Choice Mouse-Tracking Data

Participants made faster food choices with increasing age (β = −0.21, $SE = 0.05$, $p < 0.001$, partial eta squared = 0.10). There was no significant association between age and self-control success ratio (β = −0.02, $SE = 0.04$, $p = 0.51$, partial eta squared = 0.003), neither were there significant associations between age and mouse-tracking related variables (AUC: β = 0.65, $SE = 0.98$, $p = 0.51$, partial eta squared = 0.003; MD: β = −0.007, $SE = 0.02$, $p = 0.68$, partial eta squared = 0.001; Significance Time for taste: β = −1.43, $SE = 3.35$, $p = 0.67$, partial eta squared = 0.002; Significance Time for health: β = 4.20, $SE = 3.20$, $p = 0.19$, partial eta squared = 0.02).

Interactions of Age and WHtR (Table 1)

We further examined age-by-WHtR interactions on food ratings and food-choice mouse-tracking data controlling for sex.

WHtR, Age, and Food Ratings

There was a significant interaction of age-by-WHtR on taste (β = 0.30, $SE = 0.14$, $p = 0.034$, partial eta squared = 0.03) and health (β = −0.24, $SE = 0.08$, $p = 0.003$, partial eta squared = 0.06) ratings for high-calorie foods, and a marginally significant interaction for preference ratings (β = 0.26, $SE = 0.14$, $p = 0.06$, partial eta squared = 0.03) for high-calorie foods (**Figure 3**). When we stratified participants into high and low WHtR groups, we found that age-related increases in taste ratings (β = 0.62, $SE = 0.16$, $p < 0.001$, partial eta squared = 0.20) and preference (β = 0.44, $SE = 0.15$, $p = 0.006$, partial eta squared = 0.11) for high-calorie food cues were significant in the high WHtR group, but not in the low WHtR group (taste ratings: β = 0.28, $SE = 0.17$, $p = 0.11$, partial eta squared = 0.04; preference ratings: β = 0.15, $SE = 0.17$, $p = 0.40$, partial eta squared = 0.01). In contrast, age-related decreases in health ratings of high-calorie foods were

TABLE 1 | Summary of results for age-related effects on food ratings and food choice.

		Beta	SE	P	Effect size (partial eta squared)
Age	Taste ratings for high-calorie foods	0.49	0.11	**<0.001***	0.12
	Health ratings for high-calorie foods	−0.14	0.07	**0.03**	0.04
	Preference for high-calorie foods	0.33	0.11	**0.004**	0.06
	Taste ratings for low-calorie foods	−0.17	0.09	0.07	0.03
	Health ratings for low-calorie foods	−0.14	0.07	**0.04**	0.03
	Preference for low-calorie foods	−0.13	0.09	0.18	0.01
	β-taste	0.10	0.03	**0.002**	0.07
	β-health	−0.01	0.03	0.67	0.001
	Self-control success ratio	−0.02	0.04	0.51	0.003
	Reaction time	−0.21	0.05	**<0.001**	0.10
	Area under curve (AUC)	0.65	0.98	0.51	0.003
	Maximum deviation (MD)	−0.007	0.02	0.68	0.001
	Significance Time for taste	−1.43	3.35	0.67	0.002
	Significance Time for health	4.20	3.20	0.19	0.02
Interaction of age and waist-to-height ratio (WHtR)	Taste ratings for high-calorie foods	0.30	0.14	**0.03**	0.03
	Health ratings for high-calorie foods	−0.24	0.08	**0.003**	0.06
	Preference for high-calorie foods	0.26	0.14	0.06	0.03
	Taste ratings for low-calorie foods	−0.14	0.11	0.21	0.01
	Health ratings for low-calorie foods	−0.14	0.08	0.07	0.02
	Preference for low-calorie foods	−0.09	0.11	0.43	0.005
	β-taste	0.10	0.04	**0.01**	0.05
	β-health	−0.03	0.03	0.38	0.006
	Self-control success ratio	−0.02	0.04	0.57	0.002
	Reaction time	−0.15	0.07	**0.02**	0.04
	Area under curve (AUC)	2.51	1.16	**0.03**	0.03
	Maximum deviation (MD)	0.02	0.02	0.29	0.009
	Significance Time for taste	1.71	3.98	0.67	0.002
	Significance Time for health	3.09	3.76	0.41	0.006

**Results highlighted in bold indicate significant findings at* $p < 0.05$.

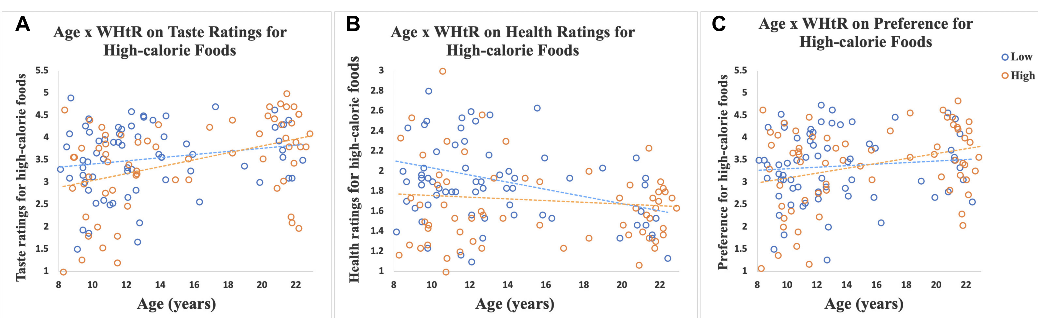

FIGURE 3 | Scatterplots show ratings of 30 high-calorie and 30 low-calorie food cues by age, classified by WHtR status (categorized as high or low based on a median split for WHtR of 0.51). Data for participants with low WHtR are shown in blue circles and those with high WHtR are shown in orange circles. **(A)** Scatterplot shows the significant interaction of age-by-WHtR on taste ratings for high-calorie foods; age-related increases in taste ratings for high-calorie foods were significant in the high WHtR group but not in the low WHtR group. **(B)** Scatterplot shows the significant interaction of age-by-WHtR on health ratings; age-related decreases in health ratings for high-calorie foods were significant in the low WHtR group but not in the high WHtR group. **(C)** Scatterplot shows the marginally significant interaction of age-by-WHtR on preference ratings; age-related increases in preference for high-calorie foods were significant in the high WHtR group but not in the low WHtR group.

significant in the low WHtR group ($\beta = -0.26$, $SE = 0.10$, $p = 0.01$, partial eta squared = 0.09), but not in the high WHtR group ($\beta = -0.06$, $SE = 0.09$, $p = 0.54$, partial eta squared = 0.006).

A significant age-by-WHtR interaction was observed on β-taste ($\beta = 0.10$, $SE = 0.04$, $p = 0.01$, partial eta squared = 0.05). When data were stratified into high and low WHtR groups a

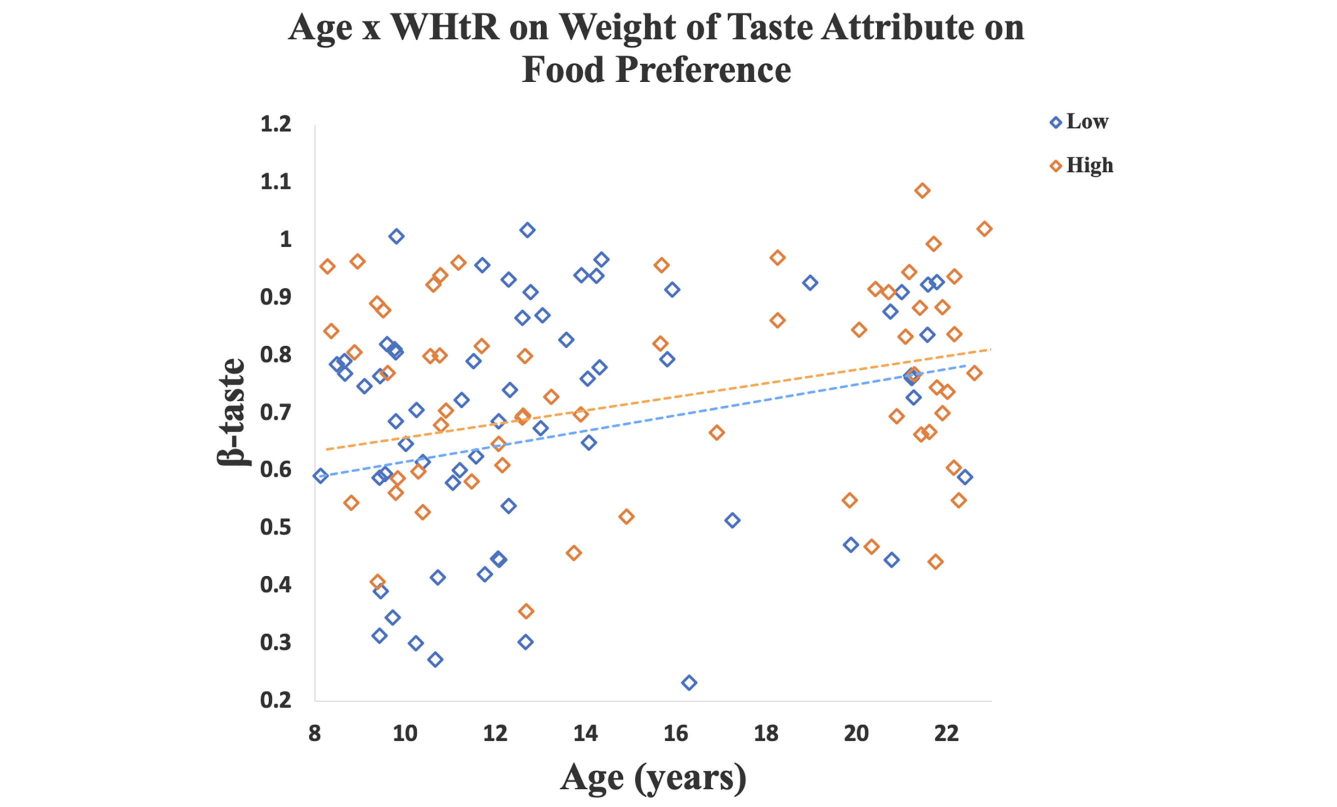

FIGURE 4 | A linear regression model was created for each participant to measure how well the taste ratings predicted their preference for a specific food cue (i.e., β-weight). Scatterplot shows that older age was associated with a higher β-taste. Relationship between age and β-taste was significant in the high WHtR group, and marginally significant in the low WHtR group. Data for participants with low WHtR are shown in blue diamonds and those with high WHtR are shown in orange diamonds.

significant association between age and β-taste was observed in the high WHtR group (β = 0.09, *SE* = 0.04, $p = 0.02$, partial eta squared = 0.08), and a marginally significant relationship between age and β-taste was found in the low WHtR group (β = 0.10, *SE* = 0.05, $p = 0.06$, partial eta squared = 0.05) (**Figure 4**).

We did not find significant age-by-WHtR interactions on taste (β = −0.14, *SE* = 0.11, $p = 0.21$, partial eta squared = 0.01), health (β = −0.14, *SE* = 0.08, $p = 0.07$, partial eta squared = 0.02) and preference ratings (β = −0.09, *SE* = 0.11, $p = 0.43$, partial eta squared = 0.005) for low-calorie foods as well as β-health (β = −0.03, *SE* = 0.03, $p = 0.38$, partial eta squared = 0.006).

WHtR, Age, and Food-Choice

A significant age-by-WHtR interaction was observed on reaction time (β = −0.15, *SE* = 0.07, $p = 0.02$, partial eta squared = 0.04), such that both the high (β = −0.23, *SE* = 0.07, $p = 0.003$, partial eta squared = 0.13) and low (β = −0.20, *SE* = 0.09, $p = 0.02$, partial eta squared = 0.08) WHtR groups exhibited a faster reaction time with increasing age. There was a significant age-by-WHtR interaction on AUC (β = 2.51, *SE* = 1.16, $p = 0.03$, partial eta squared = 0.03). When data were stratified into high and low WHtR groups, we found no significant relationships between age and AUC in both high (β = 1.28, *SE* = 1.42, $p = 0.37$, partial eta squared = 0.01) and low WHtR (β = 0.31, *SE* = 1.40, $p = 0.83$, partial eta squared = 0.001) groups.

We did not observe significant age-by-WHtR interaction on self-control success ratio (β = −0.02, *SE* = 0.04, $p = 0.57$, partial eta squared = 0.002), MD (β = 0.02, *SE* = 0.02, $p = 0.29$, partial eta squared = 0.009), Significance Time for taste (β = 1.71, *SE* = 3.98, $p = 0.67$, partial eta squared = 0.002), and Significance Time for health (β = 3.09, *SE* = 3.76, $p = 0.41$, partial eta squared = 0.006).

DISCUSSION

We examined food perceptions and preferences for high-calorie and low-calorie foods in participants between 8 and 23 years old. The main finding of this study was that there was an age-related increase in preference for high-calorie food cues, particularly in those individuals with a higher WHtR. As well, we found higher taste ratings for high-calorie food cues and an increased effect of taste attribute on food preference with increasing age, especially in those with high WHtR. In contrast, health ratings for high-calorie foods declined with increasing age, particularly in those with low WHtR. Both high and low WHtR groups made faster food choices with increasing age. These findings suggest that individual differences in age and central adiposity play a more important role in preference for high-calorie foods than low-calorie foods, and that the tastiness of food may contribute to age-related increases in preference for high-calorie foods.

Consistent with other studies that demonstrate increased consumption of calorie-dense foods in adolescents (Lytle et al., 2000; Smithers et al., 2000; Hackett et al., 2002; Nielsen et al., 2002; Mannino et al., 2004; Al-Hazzaa et al., 2011), we showed an age-related increase in preference for high-calorie foods. This pattern could be explained by the differential development of the prefrontal cortex and limbic reward regions, with slower development of the prefrontal cortex, in adolescence resulting in an increased drive for rewarding behaviors (e.g., consumption of highly palatable, calorie-dense foods) and reduced cognitive regulation (Somerville and Casey, 2010; Van Leijenhorst et al., 2010; Peeters et al., 2017). We further demonstrated that age-related increases in preference for high-calorie foods were significant in individuals with a higher WHtR, but not a lower WHtR. We studied WHtR given that it is a marker of central obesity that is more directly associated with cardio-metabolic risk factors than BMI (Schneider et al., 2011; Jiang et al., 2018). We had previously reported WHtR to be related to structural brain morphology, with a negative association with prefrontal cortex thickness, and a positive association with volume of the central nucleus region of the amygdala; both regions jointly influence food choice (Kim et al., 2020). Adolescents with higher body fat vs. lower body fat have shown greater brain reward responses to food commercials, suggesting that young individuals with higher adiposity may be more responsive to appetitive food rewards (Rapuano et al., 2016). Our results further suggested that older youth with higher central adiposity are most susceptible to overconsumption of calorie-dense foods.

Our study adds to the current literature by assessing how taste and health attributes affect age-related changes in food preferences within an age-range that represents the most inclusive definition of adolescence based on neurodevelopment (Sawyer et al., 2018). With increasing age, there was a greater influence of taste attribute on food preference, suggesting that taste attribute contributes to increased preference for high-calorie foods with increasing age. These results are in line with prior studies showing that taste attribute was a stronger predictor of food preference in older vs. younger youth (van Meer et al., 2019; Pearce et al., 2020). We additionally showed an interaction of age and WHtR on β-taste, such that the group with high WHtR demonstrated a greater positive relationship between age and β-taste compared with the low WHtR group. It has been demonstrated that children with obesity, relative to children with healthy-weight, demonstrated greater responses to sweet taste (vs. water) in the insula and amygdala, regions implicated in taste processing and emotion signaling (Boutelle et al., 2015). These results suggested that youth with higher adiposity may have heightened sensitivity to appetitive taste. Our data further suggested that the association between taste and adiposity may be greater in older than younger youth. We additionally observed that older youth compared with younger ones reported higher taste ratings but lower health ratings for high-calorie foods. The former was driven by having a higher WHtR and the latter was driven by having a lower WHtR. Older youth with higher central adiposity may be most susceptible to excessive consumption of high-calorie foods that are highly palatable. It has been shown that health literacy increases with age, whereas nutritional awareness does not change as consistently with age (Naeeni et al., 2014); it has also been reported that health literacy is inversely associated with obesity in adolescents (Lam and Yang, 2014), which is consistent with our findings, with participants with low WHtR showing decreased health ratings for high-calorie foods as a function of age. This suggests it may be particularly beneficial to focus on health literacy and nutritional awareness in youth with higher abdominal obesity.

We did not find an association between age and dietary self-control, as measured by the self-control success ratio. We found the average MD was higher for choices with successful self-control than those with failed self-control, and the average AUC was also higher for successful self-control trials compared with failed self-control trials. This is consistent with increased cognitive effort when exerting self-control, yet there were no significant age-related effects on MD or AUC. While some studies showed increased cognitive effort and associated prefrontal cortex engagement during food choice or reduced craving for appetitive food cues as a function of age (Silvers et al., 2015; Ha et al., 2016; van Meer et al., 2017, 2019), we and others did not see significant age effects on dietary self-control (Pearce et al., 2020). It is generally accepted that dietary self-control is contingent on the function of the prefrontal cortex. With continued development of the prefrontal cortex into early 20s, however, dietary self-control may be still compromised in youth in the early 20s. Future studies including mapping of prefrontal cortex development and dietary self-control among individuals with a wide age-range spanning from childhood to adulthood are merited to understand the developmental trajectory of dietary self-control and prefrontal cortex development.

The strengths of the study include a sample that varied across a broad age-range, spanning the most recent definition of adolescence in terms of neurodevelopment. We used a well-designed computer task, that allows us to quantify how specific food attributes are integrated in food decision-making. There are several limitations to consider as well, including that it was a cross-sectional study, and thus causality cannot be inferred. Future longitudinal study of participants would be helpful to understand the relationships between age and preference for high- and low-calorie foods. It was challenging to recruit participants between 16 and 18 years old; future studies would benefit from enriching this specific age-range and investigate developmental trajectory of food choice behavior in the full spectrum of age. Power analysis was not performed prior to data collection, thus some null results (e.g., age effects on dietary self-control and preferences for low-calorie foods) could be due to lack of power. As well, positive results need to be interpreted with caution given there might be a possibility of type 1 error induced false positive results. There are also inherent limitations in all laboratory food choices research, as they may differ from real-life choices. Finally, future correlation of behavioral task results with brain imaging data would be useful in further understanding neurobiological underpinnings of developmental trajectory of food decision-making.

We conclude that our results are consistent with other studies that demonstrate age-related increases in consumption of calorie-dense foods in youth, in particular in those with central obesity, and suggest that age and adiposity may be more relevant to preference for high-calorie foods. Interventions targeting youth at an early age could therefore be beneficial to helping reduce consumption of high-calorie foods over time.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board of CHLA and USC (CHLA-15-00007 and HS-16-00978). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MSG, MK, and SLu took responsibility for the integrity of the data in the study and the accuracy of the data analysis, and drafted the manuscript. SLu contributed to statistical analysis. MK, MH, and SLu provided administrative, technical, or material support, supervised the work, and obtained funding. All authors contributed to acquisition, analysis, or interpretation of data and critical revision of the manuscript for important intellectual content.

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Decision-Making Processes Related to Perseveration Are Indirectly Associated With Weight Status in Children Through Laboratory-Assessed Energy Intake

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Decision-making contributes to what and how much we consume, and deficits in decision-making have been associated with increased weight status in children. Nevertheless, the relationships between cognitive and affective processes underlying decision-making (i.e., decision-making processes) and laboratory food intake are unclear. We used data from a four-session, within-subjects laboratory study to investigate the relationships between decision-making processes, food intake, and weight status in 70 children 7-to-11-years-old. Decision-making was assessed with the Hungry Donkey Task (HDT), a child-friendly task where children make selections with unknown reward outcomes. Food intake was measured with three paradigms: (1) a standard *ad libitum* meal, (2) an eating in the absence of hunger (EAH) protocol, and (3) a palatable buffet meal. Individual differences related to decision-making processes during the HDT were quantified with a reinforcement learning model. Path analyses were used to test whether decision-making processes that contribute to children's (a) expected value of a choice and (b) tendency to perseverate (i.e., repeatedly make the same choice) were indirectly associated with weight status through their effects on intake (kcal). Results revealed that increases in the tendency to perseverate after a gain outcome were positively associated with intake at all three paradigms and indirectly associated with higher weight status through intake at both the standard and buffet meals. Increases in the tendency to perseverate after a loss outcome were positively associated with EAH, but only in children whose tendency to perseverate persistedacross trials. Results suggest that decision-making processes that shape children's tendencies to repeat a behavior (i.e., perseverate) are related to laboratory energy intake across multiple eating paradigms. Children who are more likely to repeat a choice after a positive outcome have a tendency to eat more at laboratory meals. If this generalizes to contexts outside the laboratory, these children may be susceptible to obesity. By using a reinforcement learning model not previously applied to the study of eating behaviors, this study elucidated potential determinants of excess energy intake in children, which may be useful for the development of childhood obesity interventions.

Keywords: childhood obesity, decision-making, eating behavior, Hungry Donkey Task, children

INTRODUCTION

Approximately 18% of children in the United States have obesity, and an additional 16% meet the criteria for overweight (Skinner et al., 2018). These statistics are concerning given the associations between childhood obesity and adverse physical and psychosocial health outcomes (Reilly, 2005). Behavioral interventions to reduce energy intake can produce beneficial weight-loss results (Jelalian, 1999; Epstein et al., 2001), however, they are not effective for all children and lack long-term efficacy (Mead et al., 2017). One reason for this may be a lack of understanding of food-related decision-making in middle childhood (i.e., 6-to-12 years-old), a period where children gain autonomy over food-related decisions (Ogden and Roy-Stanley, 2020). In particular, while research has examined the decision-making mechanisms underlying *what* foods children select (Lim et al., 2016; van Meer et al., 2017; Ha et al., 2020; Ogden and Roy-Stanley, 2020; Pearce et al., 2020), the mechanisms underlying *how much* children consume are unclear. To close this gap, this study aims to identify decision-making processes that are associated with increased energy intake and weight status in middle childhood.

Decision-making is a multi-stage process that involves the assessment of options, the selection of an action, and the evaluation of an outcome (Ernst and Paulus, 2005). This is applicable to food-related decisions that impact overall energy intake (Rangel, 2013). For example, when food is available, a decision to eat may occur when the estimated value of eating is greater than the estimated value of not eating (Rangel and Hare, 2010). Following a decision to eat, the consequences of taking a bite (e.g., taste, physiological changes) are evaluated and can influence subsequent value assessments. In general, decision-making is supported by affective and cognitive processes (Ernst and Paulus, 2005) referred to as decision-making processes; however, the decision-making processes that underlie food-related decision-making in middle childhood are unknown. The protracted development of prefrontal cortex in childhood and adolescence (Casey et al., 2008) supports improvements in executive functioning (e.g., inhibitory control, working memory, and cognitive flexibility; Anderson, 2002; Davidson et al., 2006; Buttelmann and Karbach, 2017), which may improve future-oriented decision-making (Steinbeis et al., 2016); however, children in this stage make less future-oriented decisions compared to both adolescents and adults (Crone and van der Molen, 2004). Given the unique stage of cognitive development and increasing autonomy over food-related decisions, identifying the decision-making processes that relate to energy intake in middle childhood is warranted.

One approach to studying decision-making is to have children complete tasks that assess choice behaviors in response to uncertain outcomes. One such task is the Hungry Donkey Task (HDT; Crone and van der Molen, 2004), the child-friendly version of the Iowa Gambling task (IGT; Bechara et al., 1994) where children are instructed to accumulate as many rewards as possible ("apples" for the hungry donkey) by choosing from options with different reward and punishment probabilities. Cross-sectional analyses indicate that performance on these tasks (i.e., the proportion of advantageous versus disadvantageous choices) is negatively associated with weight status in children (Verdejo-García et al., 2010; Verbeken et al., 2014; Groppe and Elsner, 2017; Lensing and Elsner, 2017), although performance has not been related to self-reported measures of overeating (Macchi et al., 2017) or food approach behavior (Groppe and Elsner, 2014). Examining the decision-making processes that underlie HDT performance may provide a more nuanced understanding of the mechanisms that underlie energy intake and weight status in children.

To isolate decision-making processes, computational models can be applied to behavioral data from decision-making tasks (e.g., Busemeyer and Stout, 2002; Worthy et al., 2013b). Using this approach on the present data, Roberts et al. (In prep) revealed that children's decisions on the HDT were best characterized by the Value-Plus-Perseveration (VPP) reinforcement learning model (Worthy et al., 2013b). The VPP model allows for the examination of individual-level decision-making processes that impact children's (a) estimated expected value of a decision and (b) their tendency to perseverate (repeat) a decision (Worthy et al., 2013b). In the context of food-related decision-making, the concepts of expected value and perseveration are theoretically relevant. For example, a child might take a bite of ice cream because the expected value of taking a bite is greater than the expected value of an alternative option (e.g., not taking a bite) and/or because they previously took a bite and have a tendency to repeat selections associated with positive outcomes (e.g., the ice cream tasted good). Thus, we hypothesized that decision-making processes (i.e., VPP model parameters) related to expected value and perseveration would be directly associated with children's laboratory energy intake and indirectly associated with children's weight status through energy intake.

As decision-making and eating behaviors may differ across contexts, we captured food-related decisions by measuring energy intake during three different paradigms: (1) a standard meal, designed to examine intake at a typical meal, (2) an eating in the absence of hunger (EAH) protocol designed to elicit disinhibited intake of snack foods when children are not hungry

(Fisher and Birch, 1999), and (3) a buffet meal designed to elicit overeating in a meal context. Using separate path models for each eating context, we assessed: (1) the associations between decision-making processes and children's energy intake; and (2) the indirect associations between decision-making processes and child weight status through energy intake. Hypotheses for these analyses are detailed in the methods (see section "Path Analyses"). These analyses have the potential to elucidate the decision-making processes underlying children's food-intake decisions and childhood obesity.

MATERIALS AND METHODS

Data for these analyses were drawn from a larger, cross-sectional study on the associations between decision-making, eating behavior, and weight status in children (NCT02855398). Data were collected between April 2015 and September 2016 in State College, Pennsylvania. The study was approved by the Pennsylvania State University Institutional Review Board (IRB approval number: 674).

Participants

Seventy children participated in the primary study. Data for the HDT, standard meal, and EAH protocol were available for all 70 children, however, only 69 children completed the buffet meal because one child was lost to follow-up. Participants were recruited through flyers and postings on popular websites. Children were eligible for the study if they were 7-to-11-years-old and did not have underweight (i.e., BMI-for-age <5%), pre-existing food allergies and/or dietary restrictions, learning disabilities, psychiatric/neurological conditions, a family history of psychiatric conditions, and were not currently using medications known to affect neural function or appetite. Due to the use of functional magnetic resonance imaging (MRI) in the primary study, children were also excluded if they were left-handed, had impaired or uncorrected vision, or had common MRI contraindications (e.g., metal in body and/or mouth). Lastly, adopted children were not included due to potentially unknown familial medical history. The sample was balanced by sex (n = 34 male; n = 36 female) and weight status (n = 35 healthy weight: $<85^{th}$ %tile BMI-for-age; n = 35 overweight/obesity: $\geq 85^{th}$% BMI-for-age; Cole et al., 2000). Children exhibited a wide range of BMI-z values (–1.25 to 2.57) and were predominately white (91%) and non-Hispanic (94%; **Table 1**). Parents provided written consent to allow their child to participate and children provided verbal and written assent on the first visit.

Experimental Design and Procedures

As part of the larger study, child-parent dyads attended four laboratory sessions conducted over either lunch (11:00 AM–1:00 PM) or dinner time (4:00–6:30 PM), scheduled approximately one week apart. Session times (i.e., lunch or dinner) were consistent within families and, to the extent possible, counterbalanced across families. The order of the first three sessions (A, B, C) was randomly assigned and counterbalanced across families while the fourth session always included the fMRI scan (see Adise et al., 2018, 2019). Session A included a computerized food-choice task (see Pearce et al., 2020) and a delay discounting questionnaire. Session B included the Hungry Donkey Task (HDT) followed by the standard meal and EAH protocol. Session C include an inhibitory control task (see Adise et al., 2021) followed by the buffet meal. The current study included data from the HDT and the three eating paradigms (i.e., the standard meal, EAH protocol, and the buffet meal). Children were asked to fast for at least 3 h prior to each visit so that the standard and buffet meals occurred during a state when children would typically be hungry. No additional instructions were provided to control what children ate prior to the requested fasting period. Children were allowed to consume *ad libitum* during all eating paradigms and were not required to consume any of the foods.

TABLE 1 | Demographic characteristics.

Age in years, Mean (SD); range	9.47 (1.38); 7.04–11.97
Sex, N	34 Male /36 Female
BMI-z, Mean (SD); range	0.92 (0.92); −1.25-2.57
Ethnicity, N	
Not Hispanic	66
Hispanic	4
Race, N	
White	64
Black	3
Asian	2
Other	1
Household income, N	
<$50,000	17
$50–100,000	32
>$100,000	20
Not reported	1
Maternal Education	
<Bachelor's Degree	23
Bachelor's Degree	28
>Bachelor's Degree	19

Measures

Anthropometric Measurements

On the first visit to the laboratory, children's height (to the nearest 0.1cm) and weight (to the nearest 0.1kg) were measured twice by a trained researcher using a standard scale (Detecto model 437, Webb City, MO) and stadiometer (Seca model 202, Chino, CA) while children were in stocking feet and light clothing. Children's average height and weight across the two measurements, along with sex and age, were used to calculate BMI (kg/m^2) z-score (BMI-z) based on the Centers for Disease Control and Prevention growth curves (Cole et al., 2000).

Laboratory Eating Paradigms

Before and after each eating paradigm, children rated their fullness level using a validated, age-appropriate, 150 mm visual analog scale (Keller et al., 2006). A rating of 0 mm indicated their stomach felt empty, whereas a rating of 150 mm indicated they felt so full they could not eat any more. After rating pre-meal/EAH fullness and before the start of each eating paradigm, children rated their liking of small samples (<5 g) of each meal component using a 5-point facial hedonic scale (1 = most negative, 5 = most positive). For the EAH protocol, children also indicated their rank-order preference (Birch, 1979) for the food items. Food and drink items were individually weighed to the nearest 0.1g on a scale (Ohaus, Parsippany, NJ) before and after each eating paradigm to compute grams consumed (i.e., difference in pre- and post-meal weight). Grams consumed for each item were used to calculate the energy (kcal) consumed during each paradigm based on information from the nutritional facts panel and/or from standard nutrition databases.[1]

Standard Meal

To examine intake at a typical meal, children were presented with a multi-item meal of common, age-appropriate food items. Food items were selected based on those commonly eaten by children this age from the Continuing Survey of Food Intakes of Individuals (Smiciklas-Wright et al., 2003) and included macaroni and cheese, garlic bread, broccoli, tomatoes, grapes, and water (**Table 2**). Foods were presented on trays with no packaging (**Figure 1A**). Children were told that they had 30 min to eat as much as they wanted and they could ask for extra helpings at any point. A researcher sat with the child during the meal and read a nonfood-related book to serve as a neutral distraction and to avoid the child engaging in conversations about food and/or the meal. Similar methods have been used in other studies with this age group (Keller et al., 2018; Masterson et al., 2019).

Eating in the Absence of Hunger (EAH)

To assess children's disinhibited eating of palatable snacks when not hungry, children were presented with a variety of sweet and savory snacks (**Table 3**) 15 min following the standard meal (Fisher and Birch, 1999). Snack items were presented on trays in separate containers with no packaging (**Figure 1B**). In addition to snack items, children were provided with toys (e.g., coloring, playing cards) and books. Children were left alone in the room for 15 min and told they could play with any of the toys or eat any of the foods while the researcher worked in an adjacent room.

Buffet Meal

To assess children's tendency to overeat from a variety of highly palatable foods approached in a fasted state, children were presented with a palatable buffet meal consisting of savory-fat (e.g., cheese bagel bites), sweet-fat (e.g., chocolate chip cookies) and sweet (e.g., red licorice) food and drink items (**Table 4**). Food items were presented on trays in separate containers with no packaging (**Figure 1C**). Children were told that they had 30 min to eat as much as they want and that they could ask for extra helpings. Similar to the standard meal, a researcher sat with the child during the meal and read a nonfood-related book to serve as a neutral distraction.

Decision-Making Measurements

The Hungry Donkey Task

Decision-making was assessed using the HDT (Crone and van der Molen, 2004). In the HDT, children select from four doors (A, B, C, D) with different gain and loss probabilities in order to win "apples" for a hungry donkey. Children are not informed of the gain and loss probabilities, but they can be inferred throughout the task through feedback received after each selection (Crone and van der Molen, 2004). Doors A and B are associated with a higher gain magnitude (4 apples gained on 100% of trials) and higher loss magnitude (Door A: 0, 8, 10, or 12 apples lost per trial; Door B: 0 or 50 apples lost per trial), whereas doors C and D are associated with a lower gain magnitude (2 apples gained on 100% of trials) and lower loss magnitude (Door C: 0, 1, 2, or 3 apples lost per trial; Door D: 0 or 10 apples lost per trial). Consistently choosing doors A or B would ultimately result in a negative net yield while consistently choosing doors C or D would result in a positive net yield. Thus, doors A and B are considered "disadvantageous" choices, and doors C and D are considered "advantageous" choices (Bechara et al., 1994; Crone and van der Molen, 2004).

The task was presented electronically using E-Prime 2.0 software (Psychology Software Tools, Inc., Pittsburgh, PA, United States). Prior to the task, children were (a) instructed to select doors to win as many apples as possible for the hungry donkey, (b) told that choosing a door would result in one of two outcomes: (1) winning apples, or (2) winning some apples and losing some apples, and (c) told they would play the game several times and could pick different doors any time they wished. Following the instructions, children completed 200 trials of the task. At the start of each trial, children were presented with a selection screen (**Figure 2A**) which displayed: (1) four doors (A, B, C, D) presented horizontally in the center of the screen, (2) an image of a donkey below the doors, and (3) the instructions "Choose the most favourable door!" above the doors. Children chose a door by using one of four keyboard keys (C, V, B, N) that corresponded to each door from left to right. Children had unlimited time to select a door. After each selection, an outcome screen (**Figure 2B**) displayed the numbers of apples gained and lost in the current trial pictorially as green and red apples, respectively, in place of the chosen door and numerically on the right side of the screen. Further, the net total (gained-lost) number of apples won in the task so far was presented numerically in the lower half of the screen, in place of the donkey. To reduce working memory demands of the task, a vertical bar on the right side of the screen displayed the proportion of apples gained (in green) and lost (in red) in the task so far, averaged across all doors. The outcome screen was displayed for 2 s and then the next selection screen appeared.

Value-Plus-Perseveration Model

To assess decision-making processes, the VPP model (Worthy et al., 2013b) was fit to decision-making data from the HDT. The VPP model assumes that the probability of selecting a door during an HDT trial is based on the overall value of that door relative to other doors. In the VPP model, the overall value of a door is the weighted average of two mathematical

[1] http://www.ars.usda.gov/ba/bhnrc/ndl

TABLE 2 | Food items in Standard Meal.

Food	Company, Brand	ED (kcal/g)	Serving size	kcal per serving	Liking Mean (sd)^
Macaroni and Cheese Dinner, Original	Kraft Foods, Inc.	1.05	400 g	420	4.14 (0.84)
Garlic Bread	Pepperidge Farm, Inc	3.44	100 g	344	4.36 (0.83)
Broccoli with sweet cream butter and butter flavoring	Bird's Eye; Land O'Lakes Inc; Molly McButter, B&G Foods Inc.	0.31	180 g	56	3.36 (1.24)
Cherry tomatoes	Wegmans	0.21	100 g	21	2.61 (1.65)
Red Seedless grapes	Wegmans	0.77	200 g	154	4.46 (0.79)
Angel Food Bundt Cake	Sara Lee Desserts, Hillshire Brands Co.	2.31	80 g	185	4.40 (0.77)
Water	Tap, State College	0	1000 g	0	4.34 (0.83)
Total food		1.35	1060 g	1180	3.89 (0.53)
Total food and water		1.15	2060 g	1180	3.95 (0.50)

Table has been adapted from Adise et al. (2018).
^Liking ratings were collected prior to the meal using 5-point smiley face scale (1 = most negative, 5 = most positive).

FIGURE 1 | Trays of food and drinks presented during the three eating paradigms. **(A)** Standard Meal: (left tray) water, angel food cake, grapes, (right tray) broccoli, garlic bread, cherry tomatoes, macaroni and cheese; **(B)** Eating in the Absence of Hunger protocol: (left tray) chocolate kisses, buttered popcorn, nacho-flavored tortilla chips, fruit-flavored candies, chocolate chip cookies, (right tray) pretzels, fudge brownies, potato chips, chocolate candies, cheese crackers; **(C)** Buffet meal: (left tray) fruit-flavored candies, potato chips, donut holes, chocolate chip cookies, cheese bagel bites, strawberry licorice twists, (middle tray) fruit punch, chocolate cupcake, chocolate milk, cheese pizza rolls, strawberry fruit leather, (right tray) mozzarella sticks, gummy candy, fudge brownies, chicken nuggets.

terms: (1) an Expected Value (EV) term and (2) a Perseveration term, summarized below. The relative weight given to each term is determined by the expectancy weighting parameter w ($0 < w < 1$), with values greater than 0.5 ($w > 0.5$) indicating greater weight given to the EV term and values less than 0.5 ($w < 0.5$) indicating greater weight given to the Perseveration term. The likelihood that the door with the highest overall value will be selected is influenced by the response consistency parameter c ($0 < c < 5$), which reflects the tendency to make decisions that align with value computations. Higher values of c indicate a tendency to make selections consistent with computed values, whereas lower values of c indicate more exploratory and random behavior. For a more detailed mathematical explanation of the VPP model, see Worthy et al. (2013b).

The EV term quantifies the expected value of a chosen door after feedback is presented on a given trial by (1) determining the value derived from that trial's outcome (i.e., a trial's utility) and (2) integrating the trial's utility with the previous expected value of the chosen door. A trial's utility is influenced by a feedback sensitivity parameter and a loss aversion parameter. The feedback sensitivity parameter α ($0 < \alpha < 1$) indicates how sensitive a child is to the size of gains and losses; higher values reflect greater sensitivity to outcome magnitude. The loss aversion parameter λ ($0 < \lambda < 5$) indicates sensitivity to losses relative to gains; values greater than 1 ($\lambda > 1$) indicate greater sensitivity to losses relative to gains, values less than 1 ($\lambda < 1$) indicate greater sensitivity to gains relative to losses, and the value 1 ($\lambda = 1$) indicates equal sensitivity to gains and losses. The impact of a trial's utility on the expected value of the chosen door is determined by an updating parameter ø ($0 < ø < 1$), which reflects the influence of the given trial's evaluation relative to the previous expected value of the chosen door. A value of zero ($ø = 0$) indicates expected value is not updated based on the given trial's utility (i.e., expected value of the given trial equals the expected value from the previous trial), whereas a value of one ($ø = 1$) indicates expected value is completely updated (i.e., expected value of the given trial equals the trial's utility). Thus, higher values reflect more weight given to the most recent evaluation (i.e., more updating).

The Perseveration term quantifies a door's tendency to elicit a perseverative response (i.e., perseveration strength) after feedback is presented on a given trial. This term builds on a 'win-stay-lose-shift' heuristic which proposes an individual will repeat an option following a gain, or select a different option following a loss (Worthy and Maddox, 2012; Worthy et al., 2013a). Gain and loss outcomes impact the perseveration strength of the chosen door according to the impact of gain ($-1 < \varepsilon_{pos} < 1$) and loss ($-1 < \varepsilon_{neg} < 1$) on perseveration strength parameters, respectively. Specifically, the perseveration strength for the chosen door will be incrementally increased or decreased by

TABLE 3 | Food items in EAH protocol.

Food	Brand, Company	ED (kcal/gram)	Serving size	kcal per serving	Liking Mean (sd)^
Potato Chips	Lay's, FritoLay	5.64	58 g	327	4.27 (0.74)
Buttered Popcorn	Herr's	5.28	15 g	79	4.10 (0.76)
Tiny Twists Pretzels	Rold Gold, FritoLay	5.89	39 g	230	3.91 (0.83)
Cheese cracker	Ritz	5.37	6 crackers (∼44 g)	236	3.36 (1.22)
Fudge brownies	Little Bites, Entenmann's	4.36	4 brownies (∼51 g)	222	4.63 (0.73)
Chocolate Chip Cookies	Chips A'Hoy!, Mondelez Int'l	4.97	6 cookies (∼66 g)	327	4.49 (0.79)
Fruit-flavored candies	Starbursts.	4.08	66 g	269	4.63 (0.66)
Chocolate candies	M&Ms, Mars Inc	4.86	66 g	321	4.49 (0.79)
Tortilla Chips, Nacho Cheese Flavored	Doritos, FritoLay	5.14	58 g	298	4.37 (0.94)
Chocolate kisses	The Hershey Company	5.37	66 g	354	4.46 (0.85)
Total food		4.89	529 g	2663	4.27 (0.46)

Table has been adapted from Adise et al. (2018).
^Liking ratings were collected prior to the paradigm using a 5-point smiley face scale (1 = most negative, 5 = most positive).

TABLE 4 | Food items in Buffet Meal.

Food	Brand, company	ED (kcal/g)	Serving size	kcal per serving	Liking Mean (sd)^
Cheese bagel bites, three cheese	H.J. Heinz Company	2.28	8 pieces (∼145 g)	331	3.65 (1.04)
Cheese pizza rolls	Totino's, General Mills	2.51	7 pieces (∼85 g)	213	4.17 (1.00)
Chicken nuggets	Tyson Foods Inc	2.99	7 nuggets (∼105 g)	314	4.41 (0.69)
Mozzarella Sticks	Friday's	3.03	4 sticks (∼125 g)	379	4.09 (1.01)
Potato Chips	Lay's, Frito Lay	5.64	28 g	158	4.22 (0.78)
Fudge brownies	Little Bites, Entenmann's	4.36	4 brownies (∼60 g)	262	4.52 (0.80)
Chocolate cupcakes	Hostess	4.71	1 cupcake (∼50 g)	236	4.25 (0.99)
Donut Holes, Vanilla Glazed	Entenmann's	5.07	4 donuts (∼58 g)	295	4.49 (0.76)
Whole-fat chocolate milk	Schneider Valley Farms	0.83	1 cup (∼245 g)	203	4.01 (1.06)
Chocolate Chip Cookies	Chips A'Hoy!, Mondelez Int'l	4.98	4 cookies (∼44 g)	219	4.4 (0.76)
Strawberry licorice twists	Twizzlers, The Hershey Company	3.39	50 g	170	3.65 (1.16)
Strawberry Fruit Leather	Fruit Roll-up, Betty Crocker, General Mills	4.07	2 pieces (∼30 g)	122	4.54 (0.70)
Gummy Candy	Goldbears, Haribo	3.49	105 g	366	4.36 (0.79)
Fruit-flavored candies	Skittles, Mars Inc.	4.04	86 g	357	4.38 (0.93)
Tropical Punch	Kool Aid Bursts, Kraft Foods Inc.	0.09	1 cup (∼235 g)	21	4.03 (0.91)
Total food		3.89	971 g	3412	4.24 (0.42)
Total food and drink		3.43	1451 g	3636	4.21 (0.44)

Table has been adapted from Adise et al. (2018).
^Liking ratings were collected prior to the meal using a 5-point smiley face scale (1 = most negative, 5 = most positive).

ε_{pos} after a gain (net outcome $\geq$ zero) or by ε_{neg} after a loss (net outcome < zero). A positive ε_{pos} value indicates a tendency to perseverate (i.e., select the same door) after a gain, whereas a negative value indicates a tendency to switch to a different door after a gain. Similarly, a positive ε_{neg} value indicates a tendency to perseverate after a loss, whereas a negative value indicates a tendency to switch to a different door after a loss. The perseveration strength for all doors decays each trial according to the perseveration decay parameter k ($0 < k < 1$). Higher values of k indicate less decay in perseveration strength on each subsequent trial (k of 1 = no decay, k of 0 = complete decay).

Behavioral Metrics

Because there is limited work using the VPP model in children, we also wanted to examine how VPP model parameters related to previously used behavioral metrics of IGT/HDT performance. Therefore, three behavioral metrics were computed: (1) "Netscore" was calculated by subtracting the number of times doors A and B (i.e., disadvantageous choices) were chosen from the number of times doors C and D (i.e., advantageous choices) were chosen [Net score = (C + D) – (A + B)]; (2) "win-stay" was calculated as the proportion of trials where the door chosen on the current trial, t, was the same as the door chosen on the previous trial, t-1, given a "win" (net outcome $\geq$ zero) on the previous trial [$WS = p(stay_t | win_{t-1})$]; and (3) "lose-shift" was calculated as the proportion of trials where the door chosen on the current trial differed from the door chosen on the previous trial, given a "loss" (net outcome < 0) on the previous trial ($LS = p(shift_t | loss_{t-1})$). Although a "win" has also been defined as the absence of points lost regardless of net outcome (Beitz et al., 2014), the definitions of "win" and "loss" used here align with the definitions of "gain" and "loss" in the VPP model (see section "Value-Plus-Perseveration Model"). These definitions are consistent with those previously

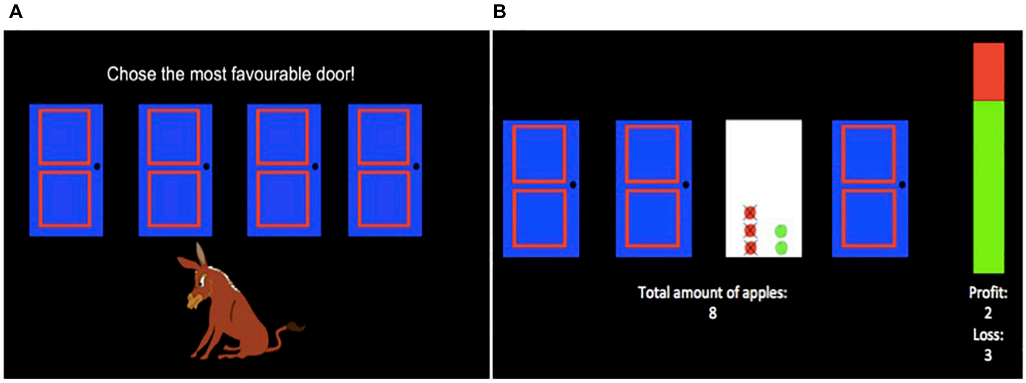

FIGURE 2 | Hungry Donkey Task. During each trial of the task, children were presented with a selection screen **(A)**. During the selection screen, children selected one door by using one of four keyboard keys (C, V, B, N) that corresponded to each door from left to right. Following a selection, children were presented with an outcome screen **(B)**. The number of apples won and lost during that trial were displayed in the frame of the selected door as green and red apples, respectively, and numerically as "profit" and "loss" values under the vertical bar. The vertical bar provided global feedback about the ratio of apples won (green) and lost (red) in the game so far, and the net total amount of apples won in the game so far was indicated under the doors.

used to assess win-stay and lose-shift strategies in children (Cassotti et al., 2011).

Statistical Analyses

Statistical analyses were conducted in R ≥ 3.4 (R Core Team, 2021) and the VPP model was fit using a Bayesian framework[2] with the hBayesDM package (Ahn et al., 2017). Child-specific VPP model parameter point estimates were used for all analyses. Path analyses were conducted using the Lavaan package 0.6–8 (Rosseel, 2012). The significance threshold was set to 0.05. Analysis code is available through the Open Science Framework.[3]

Descriptive Statistics

Mean and standard deviation were calculated for pre-meal fullness ratings and intake, which exhibited approximately normal distributions (assessed *via* skewness and kurtosis). Due to non-normal distributions of several decision-making variables, median and percentile measures (25th, 75th) were calculated for VPP model parameters and behavioral metrics. For normally distributed outcomes (e.g., intake and pre-meal fullness), Pearson correlations and two-sample *t*-tests were used to test associations with child age and sex, respectively. Spearman rank order correlations were used to test associations amongst decision-making variables, and between decision-making variables and continuous characteristics (i.e., BMI-z, age, and pre-meal fullness). Mann-Whitney-Wilcoxon and Kruskal-Wallis tests were used to test associations between decision-making variables and categorical child characteristics (i.e., sex, maternal education, and household income). The Benjamini-Hochberg procedure was used to adjust for multiple comparisons (Benjamini and Hochberg, 1995) such that adjustment was applied for: (1) all pair-wise associations between the eight VPP model parameters (28 tests); (2) associations between VPP model parameters and each behavioral metric (8 tests per behavioral metric); and (3) associations between participant characteristics and each VPP model parameter (6 tests per VPP model parameter).

Path Analyses

We used path analyses to test our hypotheses that decision-making processes related to expected value and perseveration would be associated with weight status through their effects on energy intake. Hypotheses were developed based on theoretical relationships between VPP model parameters and intake-related processes (**Table 5**). Because expected value and perseveration are two conceptually different aspects of decision-making, separate path models were used to test hypotheses related to each, referred to as the "expected value (EV)" and "perseveration" models, respectively. Further, separate path models were used to test hypotheses related to each eating paradigm, resulting in a total of six models.

For the EV models, we hypothesized that two parameters would relate to intake at all three eating paradigms, while one parameter would only relate to EAH and buffet meal intake, as these two paradigms contain a variety of highly palatable foods and are designed to elicit overeating. For all three eating paradigms, we hypothesized that children who update expected value less (i.e., lower ø) would eat more because they may modify the perceived value of eating in response to within-meal decreases in pleasantness (Rolls et al., 1984) or increases in satiation (Yeomans, 2000) to a smaller degree. Further, we hypothesized that children who are less sensitive to the amount gained or lost (i.e., lower α) would eat more because they may be less sensitive to within-meal decreases in food pleasantness. Lastly, for EAH and the buffet meal only, we hypothesized that children who are less loss averse (i.e., lower λ) would eat more because they may be less impacted by negative consequences from overeating [e.g., physical discomfort (Bernstein and Santos, 2018)].

For the perseveration models, we once again hypothesized that two parameters would relate to intake at all three eating

[2]Two chains with 5000 iterations each (including a 1000 warmup phase that was discarded) were used.

[3]osf.io/mwqz9/

paradigms, while one parameter would only relate to EAH and buffet meal intake. We hypothesized that children whose tendency to perseverate decays more slowly (i.e., greater k) would eat more because their motivation to eat may be sustained longer throughout the meal. Further, we hypothesized that children with greater increases in perseveration strength following gains (i.e., greater ε_{pos}) would eat more because they may be more reinforced by rewarding experiences with food (Temple et al., 2008; Epstein et al., 2015). Lastly, for EAH and the buffet meal, we hypothesized that children with greater increases in perseveration strength following losses (i.e., greater ε_{neg}) would eat more because they may overeat despite negative consequences (Moore et al., 2017).

For EV and perseveration models, we tested whether updating and perseveration decay, respectively, moderated the associations between other hypothesized parameters and intake. This is because in the VPP model, updating modifies the effects of other parameters related to expected value, and perseveration decay modifies the effects of other parameters related to perseveration strength. If the moderation was not significant, it was not included in the final path model. Additionally, for each eating paradigm, we hypothesized that intake would be positively associated with BMI-z and that VPP model parameters would be indirectly associated with BMI-z through intake. Specifically, we hypothesized that expected value parameters [i.e., updating (α), loss aversion (λ), and feedback sensitivity ($\o$)] would be negatively associated with BMI-z through reduced intake, while perseveration parameters [i.e., the impact of gain (ε_{pos}) and loss (ε_{neg}) on perseveration strength, and perseveration decay (k)] would be positively associated with BMI-z through increased intake.

Variables with skewness > |2| and kurtosis > |7| were considered to have distributions exceeding acceptable non-normality for path analyses with this sample size (West et al., 1995). Therefore, the loss aversion parameter (skew = 2.88, kurtosis = 11.36) was log transformed for path analyses (log transformed skew = 0.23, kurtosis = 2.20). To facilitate the interpretation of relationships across VPP parameters, all parameters were normalized (mean = 0, SD = 1). Meal intake (kcal) was scaled by a factor of 100 to make the scale more closely match the scale of the other parameters. Models were estimated using maximum likelihood estimation and robust standard errors. Initial and final models met the recommended sample size to number of free parameters ratio of >10:1 by Bentler and Chou (1987), ranging from 11.5:1 to 35:1. Models had good fit (**Supplementary Table 1**) according to the following measures and recommendations by Hooper et al. (2008): Satorra-Bentler (SB) scaled $\chi 2$ test statistic ($p > 0.05$; Satorra and Bentler, 1988, 1994), robust root mean square error of approximation <0.07; Brosseau-Liard et al., 2012), robust comparative fit index (CFI > 0.95; Brosseau-Liard and Savalei, 2014), and the standardized root mean square residual <0.08 (Bentler, 2006). Robust standard errors, SB scaled test statistic, and robust RMSEA/CFI were used to reduce bias resulting from non-normal distributions of decision-making parameters.

Given that meal intake was associated with age and pre-meal fullness, we conducted sensitivity analyses by including age and pre-meal fullness as covariates in each model. In addition, we tested each final model with a reduced sample (n = 64 for standard meal/EAH models, n = 63 for buffet meal models) that excluded three children who did not fully comply with the protocol (e.g., did not fast) and three children who exhibited attentional issues during the HDT (e.g., talked throughout the task). Lastly, because the EAH protocol is designed to assess eating when not hungry, final EAH models were also tested with a reduced sample (n = 57) that excluded thirteen children who rated their pre-EAH fullness as <75% on the visual analog scale, replicating the threshold used in the primary study (Adise et al., 2018).

RESULTS

Descriptive Statistics

Descriptive statistics for decision-making variables, food intake, and pre-meal fullness ratings are presented in **Table 6**. Age was positively associated with buffet meal intake [$r(67) = 0.30$, $p = 0.01$], but not standard meal intake [$r(68) = 0.22$, $p = 0.07$] or EAH [$r(68) = 0.03$, $p = 0.81$]. Intake for the three eating paradigms did not vary by sex (p's > 0.06). Pre-standard meal fullness was negatively associated with standard meal intake [$r(68) = -0.24$, $p < 0.05$], however, pre-EAH and pre-buffet meal fullness were not associated with EAH [$r(68) = 0.06$, $p = 0.62$] or buffet meal intake [$r(67) = -0.02$, $p = 0.86$], respectively. Foods in all three paradigms were generally well-liked (**Tables 2–4**).

Correlation analyses were conducted to examine how decision-making variables related to each other (**Table 7**). All VPP model parameters were associated with at least one other VPP model parameter (-0.56 to 0.39, adjusted p's < 0.05), with the exception of perseveration decay. While loss aversion was negatively associated with other EV parameters (i.e., updating and feedback sensitivity), EV parameters were not associated with perseveration parameters, expectancy weighting, or consistency. In contrast, the impact of gain and loss on perseveration strength were positively correlated with each other and expectancy weighting, but were negatively associated with consistency.

All VPP model parameters were associated with at least one of three behavioral metrics (–0.90 to 0.93, adjusted $p' s < 0.05$), with the exception of perseveration decay (**Table 7**). Conversely, each behavioral metric was associated with at least four of eight VPP model parameters. EV parameters related to processing gain and loss outcomes (i.e., feedback sensitivity, loss aversion) were positively associated with netscore, while perseveration parameters related to processing gain and loss outcomes (i.e., the impact of gain and loss on perseveration strength) were negatively associated with netscore. In line with the 'win-stay-lose-shift' heuristic, the impact of gain on perseveration strength was strongly related to win-stay [$r_s(68) = 0.93$, adjusted $p < 0.001$], while the impact of loss on perseveration strength was strongly related to lose-shift [$r_s(68) = -0.90$, adjusted $p < 0.001$].

Additional analyses conducted to examine how decision-making variables related to participant characteristics revealed that updating, the impact of gain on perseveration strength and win-stay were positively associated with child age (0.35 to 0.49,

TABLE 5 | Summary of hypotheses between VPP model parameters and intake.

VPP model parameters	Potential processes influencing intake	Intake hypotheses#:
Expected value parameters		
Updating (ø)	Degree to which information about hedonics and fullness are updated	Standard meal (–), EAH protocol (–), Buffet meal (–)
Feedback sensitivity (α)	Sensitivity to changes in hedonics	Standard meal (–), EAH protocol (–), Buffet meal (–)
Loss aversion (λ)	Relative impact of negative (e.g., physical discomfort) versus positive (e.g., food) experiences	EAH protocol (–), Buffet meal (–)
Perseveration strength parameters		
Perseveration decay (*k*)	Influence of early-meal motivation to eat on behavior later in the meal	Standard meal (+), EAH protocol (+), Buffet meal (+)
The impact of gain on perseveration strength (ε_{pos})	Impact of food reward on the tendency to take another bite	Standard meal (+), EAH protocol (+), Buffet meal (+)
The impact of loss on perseveration strength (ε_{neg})	Impact of negative experience on the tendency take another bite	Buffet meal (+), EAH protocol (+)

#(+) denotes hypothesized positive association between VPP model parameter and intake; (–) denotes hypothesized negative association between VPP model parameter and intake.

TABLE 6 | Descriptive statistics.

Decision-making variables	25th percentile	Median	75th percentile
VPP Model Parameters#			
Updating, ø	0.05	0.11	0.35
Feedback sensitivity, α	0.30	0.52	0.74
Loss Aversion, λ	0.03	0.10	0.39
Impact of gain on perseveration, ε_{pos}	–3.97	–0.42	2.60
Impact of loss on perseveration, ε_{neg}	–8.18	–6.48	–4.34
Perseveration decay, *k*	0.34	0.46	0.57
Expectancy weighting, *w*	0.78	0.81	0.85
Consistency, *c*	0.93	1.04	1.17
Behavioral Metrics			
Win-stay	0.12	0.30	0.50
Lose-shift	0.84	0.93	0.97
Netscore	–26.50	–6.00	5.50
Laboratory Eating Paradigm	**Mean**	**SD**	**Min - Max**
Standard meal (N = 70)			
Pre-standard meal fullness (mm)	38.4	30.8	0 – 100
Intake (kcal)	643.9	212.3	202.5 – 1130.2
EAH (N = 70)			
Pre-EAH fullness (mm)	125.8	24.7	31 – 150
Intake (kcal)	379.9	205.4	0.8 – 1046.1
Buffet meal (N = 69)			
Pre-buffet meal fullness (mm)	35.5	29.1	0 – 110
Intake (kcal)	1271.3	367.6	474.8 – 2025.4

#Quartile values for VPP model parameters were determined using the distribution of person-specific point estimates (i.e., the average estimate across simulations) for each parameter.

adjusted p's < 0.05), while loss aversion was negatively associated with age [$r_s(68) = -0.40$, *adjusted* $p < 0.01$]. Netscore was higher in girls (*median* = 0.00) compared to boys (*median* = −13.00; $U = 379$, *adjusted* $p = 0.04$). Decision-making variables were not related to BMI-z, maternal education, family income, or pre-standard meal fullness, (adjusted p's > 0.05; **Supplementary Tables 2, 3**).

Path Analyses

Results for the final path models (i.e., models with non-significant moderations excluded for parsimony, see section "Path Analyses" in "Material and Methods") are summarized below. Results for initial models, which contain all tested moderations, are reported in **Supplementary Table 4**. Direct and indirect paths are described using unstandardized coefficients (B) and the standard errors (SE) for these estimates. Because path models include multiple predictors of intake, coefficients for paths directed at intake reflect partial regressions (i.e., associations are controlled for other predictors of intake). In contrast, coefficients for paths directed at BMI-z from intake reflect simple regressions (Grace and Bollen, 2005).

Expected Value Models

Standard Meal

The EV model for the standard meal tested our hypotheses that feedback sensitivity (α) and updating (ø) would be negatively associated with intake at the standard meal and BMI-z through intake. In contrast to hypotheses, neither parameter was associated with intake (p's > 0.12; **Table 8**). Our hypotheses about BMI-z were partially supported in that intake was positively associated with BMI-z, such that a 100kcal increase in intake was associated with a 0.15 increase in BMI-z ($B = 0.15$, $SE = 0.04$, $p < 0.001$). However, there were no indirect associations between EV parameters and BMI-z through standard meal intake (p's > 0.16). The pattern of results was maintained after adjusting for age (**Supplementary Table 5**) and excluding children who were non-compliant ($n = 6$; **Supplementary Table 7**). However, after adjusting for pre-meal fullness, updating was positively associated with intake ($B = 0.55$, $SE = 0.25$, $p = 0.03$) such that intake increased by 55 kcal for every 1 SD increase in updating (**Supplementary Table 6**; **Figure 3**).

EAH

The EV model for the EAH protocol tested our hypotheses that feedback sensitivity (α), updating (ø) and loss aversion (λ) would be negatively associated with EAH and BMI-z through EAH. In contrast to hypotheses, none of the parameters were associated

TABLE 7 | Spearman rank correlation coefficients between decision-making variables.

	1	2	3	4	5	6	7	8
Updating, ø	–							
Feedback sensitivity, α	–0.07	–						
Loss Aversion, λ	–0.42**	–0.56***	–					
Impact of gain on Per., ε_{pos}	**0.29**	0.07	–0.24	–				
Impact of loss on Per., ε_{neg}	–0.07	0.17	–0.09	0.39**	–			
Perseveration decay, *k*	–0.10	–0.17	0.24	–0.04	–0.14	–		
Expectancy weighting, *w*	0.03	–0.11	–0.18	0.31*	0.36*	–0.13	–	
Consistency, *c*	–0.14	–0.09	–0.17	–0.34*	–0.35*	–0.04	0.00	–
Netscore	–0.05	–0.69***	0.72***	–0.27*	–0.42***	0.16	–0.23	–0.09
Win-Stay	0.44***	0.00	–0.33*	0.93***	0.30*	–0.02	0.31*	–0.20
Lose-Shift	0.05	–0.19	0.04	–0.45***	–0.90***	–0.01	–0.30*	0.48***

Bolded value indicates statistical significance ($p < 0.05$) before, but not after, adjustment for multiple comparisons.
**Adjusted $p < 0.05$; **adjusted $p < 0.01$; ***adjusted $p < 0.001$.*

TABLE 8 | Summary of path analyses for the six final models predicting intake from VPP model parameters and BMI-z from intake.

	Perseveration Models%						Expected Value Models^					
	Dependent Variable	**Independent Variable**	**B#**	**SE**	**p**	**r^2**	**Dependent Variable**	**Independent Variable**	**B#**	**SE**	**p**	**r^2**
Standard Meal	Intake	ε_{pos}	0.88	0.20	< 0.001	0.17	Intake	ø	0.44	0.29	0.12	0.06
		k	–0.12	0.22	0.58			α	0.30	0.24	0.21	
	BMI-z	Intake	0.15	0.04	< 0.001	0.11	BMI-z	Intake	0.15	0.04	< 0.001	0.11
EAH	Intake	ε_{pos}	0.40	0.17	0.02	0.25	Intake	ø	0.26	0.37	0.50	0.04
		k	–0.55	0.22	0.01			α	–0.08	0.31	0.80	
		ε_{neg}	–0.45	0.23	0.06			λ (log)	–0.24	0.36	0.51	
		$k{:}\varepsilon_{neg}$	0.89	0.27	0.001							
	BMI-z	Intake	0.08	0.06	0.23	0.03	BMI-z	Intake	0.08	0.06	0.23	0.03
Buffet Meal	Intake	ε_{pos}	1.36	0.38	< 0.001	0.14	Intake	ø	0.47	0.53	0.37	0.06
		k	0.12	0.38	0.76			α	0.18	0.59	0.76	
		ε_{neg}	–0.07	0.47	0.89			λ (log)	–0.52	0.57	0.36	
	BMI-z	Intake	0.07	0.03	0.01	0.09	BMI-z	Intake	0.07	0.03	<0.01	0.09

%Perseveration models contain VPP parameters involved in computing Perseveration Strength (i.e., ε_{pos}, k, ε_{neg}).
^Expected value models contain VPP parameters involved in computing Expected Value (i.e., ø, α, λ).
VPP model parameters were normalized and intake (kcal) was scaled by a factor of 100. #Indicates unstandardized path coefficient.

with EAH (*p*'s > 0.50; **Table 8**). Similarly, there was no association between EAH and BMI-z ($p = 0.23$) or indirect associations between EV parameters and BMI-z through EAH (*p*'s > 0.50). The pattern of results was maintained when adjusting for age and pre-EAH fullness and when excluding children who were non-compliant ($n = 6$) or who indicated they were not completely full after the test meal ($n = 13$; **Supplementary Tables 5–8**).

Buffet Meal

The EV model for the buffet meal tested our hypotheses that feedback sensitivity (α), updating (ø) and loss aversion (λ) would be negatively associated with buffet meal intake and BMI-z through buffet meal intake. In contrast to hypotheses, none of the parameters were associated with buffet intake (*p*'s > 0.36; **Table 8**). As with the standard meal, our hypotheses related to BMI-z were partially supported in that buffet meal intake was positively associated with BMI-z such that a 100kcal increase in intake was associated with a 0.07 increase in BMI-z ($B = 0.07$, $SE = 0.03$, $p = 0.007$. However, there were no indirect associations between EV parameters and BMI-z through buffet meal intake (*p*'s > 0.40). The pattern of results was maintained when adjusting for age and pre- buffet meal fullness and when excluding children who were non-compliant ($n = 6$; **Supplementary Tables 5–7**).

Perseveration Models

Standard Meal

The perseveration model for the standard meal tested our hypotheses that the impact of gain on perseveration strength (ε_{pos}) and perseveration decay (*k*) would be positively associated with standard meal intake and BMI-z through standard meal intake (**Figure 4A**). As hypothesized, the impact of gain on perseveration strength was positively associated with standard meal intake ($B = 0.88$, $SE = 0.20$, $p < 0.001$; **Table 8**) such that a 1 SD increase in ε_{pos} was associated with an 88 kcal increase in standard meal intake (**Figure 5A**). However, perseveration decay was not associated with standard meal intake ($p = 0.58$). As in the EV model, standard meal intake was positively associated with

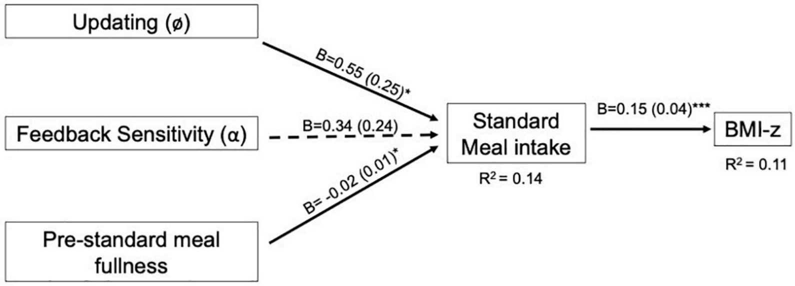

FIGURE 3 | Final expected value model for the standard meal with pre-standard meal fullness covariate. Expected value models include VPP model parameters involved in computing expected value. For path analyses, VPP model parameters were normalized and intake (kcal) was scaled by a factor of 100. Pre-standard meal fullness was rated on a 150 mm visual analog scale prior to the eating paradigm. Arrows indicate paths tested in the final model and are labeled with the unstandardized coefficient (B) and standard error for that path. Dotted lines indicate paths did not reach statistical significance ($p > 0.05$). Solid lines indicate statistically significant paths (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$). Explained variance (R^2) is reported for endogenous variables.

BMI-z such that a 100 kcal increase in intake was associated with 0.15 increase in BMI-z ($B = 0.15$, $SE = 0.04$, $p < 0.001$). Further, ε_{pos} was indirectly associated with BMI-z through standard meal intake such that a 1 SD increase in ε_{pos} was indirectly associated with a 0.13 increase in BMI-z ($B = 0.13$, $SE = 0.05$, $p = 0.005$). Perseveration decay was not indirectly associated with BMI-z through intake ($p = 0.59$). The pattern of results was maintained when adjusting for age and pre-standard meal fullness and when excluding children who were non-complaint ($n = 6$ **Supplementary Tables 5–7**).

EAH

The perseveration model for the EAH protocol tested our hypotheses that the impact of gain (ε_{pos}) and loss (ε_{neg}) on perseveration strength and perseveration decay (k) would be positively associated with EAH and BMI-z through EAH (**Figure 4B**). Further, based on the initial model, the interaction between k and ε_{neg} was included as a predictor of intake. As hypothesized, the impact of gain on perseveration strength was positively associated with EAH ($B = 0.40$, $SE = 0.17$, $p = 0.02$; **Table 8**) such that a 1SD increase in ε_{pos} was associated with a 40 kcal increase in EAH (**Figure 5B**). While we hypothesized independent associations with the impact of loss on perseveration strength and perseveration decay, there was a significant interaction between these parameters indicating that the association between ε_{neg} and EAH was more positive when decay was slower (i.e., at higher values of k; $B = 0.89$, $SE = 0.27$, $p = 0.001$). In children with the fastest perseveration decay (normalized k (i.e., SD) −2.15 to 0.03), greater increases in perseveration strength after a loss (ε_{neg}) were associated with lower EAH, while in children with the slowest perseveration decay [normalized k (i.e., SD) 0.08 to 2.39], greater increases in perseveration strength after a loss (ε_{neg}) were associated with greater EAH (**Figure 6**). As in the EV model, EAH was not associated with BMI-z ($p = 0.23$; **Table 8**) and there were no indirect effects of perseveration parameters on BMI-z through EAH (p's > 0.21). The pattern of results was maintained when adjusting for age and pre-EAH fullness and when excluding children who were non-complaint ($n = 6$; **Supplementary Tables 5–7**). When excluding children with pre-EAH fullness ratings $< 75\%$ ($n = 13$), the pattern of results were similar, however, reduced power caused the association between ε_{pos} and intake to lose significance ($p = 0.07$).

Buffet Meal

The perseveration model for the buffet meal tested our hypotheses that the impact of gain (ε_{pos}) and loss (ε_{neg}) on perseveration strength and perseveration decay (k) would be positively associated buffet meal intake and BMI-z through buffet meal intake (**Figure 4C**). As hypothesized, the impact of gain on perseveration strength (ε_{pos}) was associated with intake ($B = 1.36$, $SE = 0.38$, $p < 0.001$; **Table 8**) such that a 1 SD increase in ε_{pos} was associated with a 136 kcal increase in buffet meal intake (**Figure 5C**). In contrast to hypotheses, neither perseveration decay nor ε_{neg} were associated with buffet intake (p's > 0.76). Our hypotheses about BMI-z were partially supported. As in the EV model, buffet intake was positively associated with BMI-z ($B = 0.07$, $SE = 0.03$, $p = 0.007$). Further, ε_{pos} was indirectly associated with BMI-z through buffet meal intake such that a 1 SD increase in ε_{pos} was indirectly associated with a 0.10 increase in BMI-z ($B = 0.10$, $SE = 0.05$, $p = 0.03$). However, neither the impact of loss on perseveration strength nor perseveration decay were indirectly associated with BMI-z (p's > 0.75). The pattern of results was maintained when adjusting for age and pre-standard meal fullness and when excluding children who were non-complaint ($n = 6$; **Supplementary Tables 5–7**).

DISCUSSION

The current study examined the relationships between decision-making processes, laboratory food intake, and BMI-z in a sample of 7-to-11-year-old children. By using a reinforcement learning model (the VPP model) to quantify decision-making processes during the HDT, we demonstrated that processes related to the tendency to repeatedly choose the same option (i.e., perseverate) were associated with intake across multiple eating paradigms. Children who exhibited greater increases in the tendency to repeat a choice after a gain consumed more from a

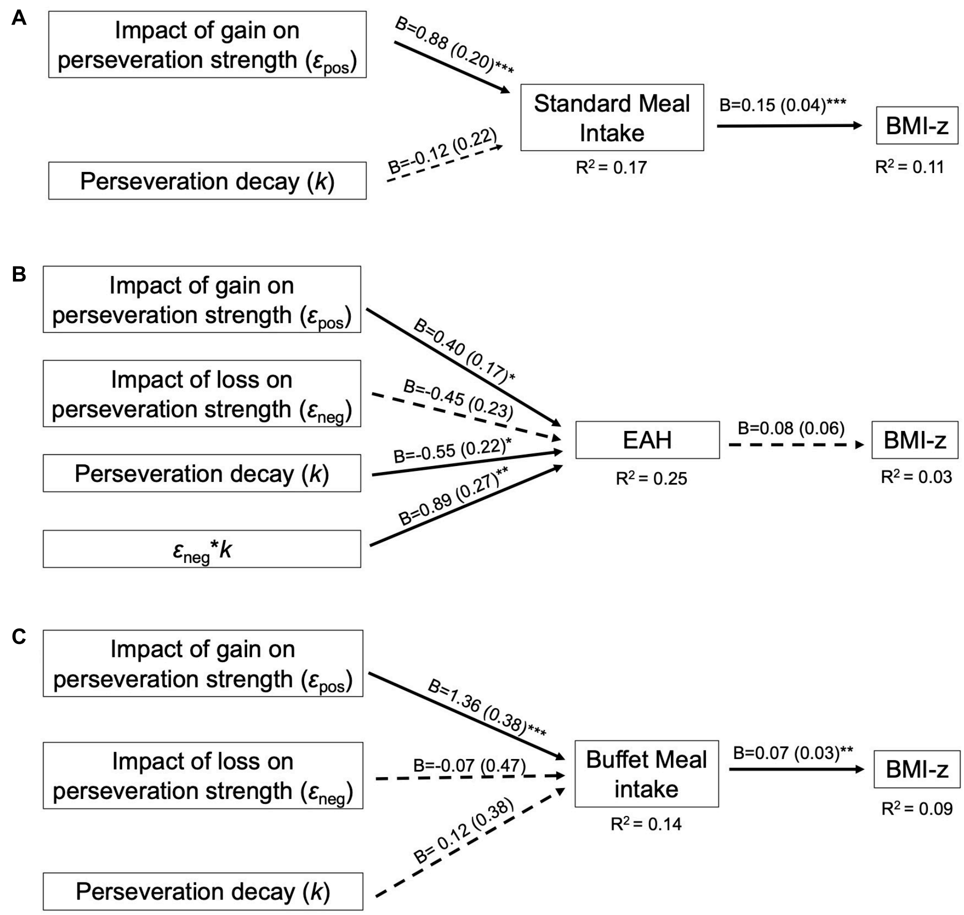

FIGURE 4 | Final perseveration model for the **(A)** Standard Meal, **(B)** Eating in the Absence of Hunger (EAH) protocol, and **(C)** Buffet meal. Perseveration models contain VPP model parameters involved in computing perseveration strength. For path analyses, VPP model parameters were normalized and intake (kcal) was scaled by a factor of 100. Arrows indicate paths tested in the final model and are labeled with the unstandardized parameter estimate (B) and standard error for that path. Dotted lines indicate paths did not reach statistical significance ($p > 0.05$). Solid lines indicate statistically significant paths (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$). Explained variance (R^2) is reported for endogenous variables.

standard meal, a palatable buffet, and from a selection of snacks provided following the standard meal (i.e., an EAH protocol). Moreover, increases in the tendency to repeat a choice after a gain were indirectly associated with greater child weight status through intake at the standard and buffet meals, but not EAH. This study advances the field by demonstrating that decision-making process related to perseveration may be associated with increased weight status in children because they facilitate excess consumption in multiple eating contexts.

Decision-Making Processes and Behavioral Metrics

Given that there has been limited research applying the VPP model to children's decision-making, we assessed the associations between decision-making processes (i.e., VPP model parameters) and three previously used metrics of HDT behavior: netscore, win-stay, and lose-shift. Results revealed that each behavioral metric was significantly associated with at least four of eight VPP model parameters. For example, better performance on the HDT (i.e., higher netscore) was associated with greater feedback sensitivity and updating, and smaller increases in perseveration strength following gain and loss outcomes. These results suggest that VPP model parameters reflect nuanced decision-making processes that underlie traditional behavioral metrics. This demonstrates the utility in applying computational models to understand the decision-making mechanisms that contribute to energy intake and the development of overweight and obesity.

Decision-Making Processes Related to Expected Value, Intake, and Weight Status

Updating of expected value was positively associated with intake during the standard meal when controlling for fullness. This contradicts our hypothesis and suggests that children whose estimation of value was more heavily influenced by recent outcomes (i.e., updated faster) tended to eat more during the

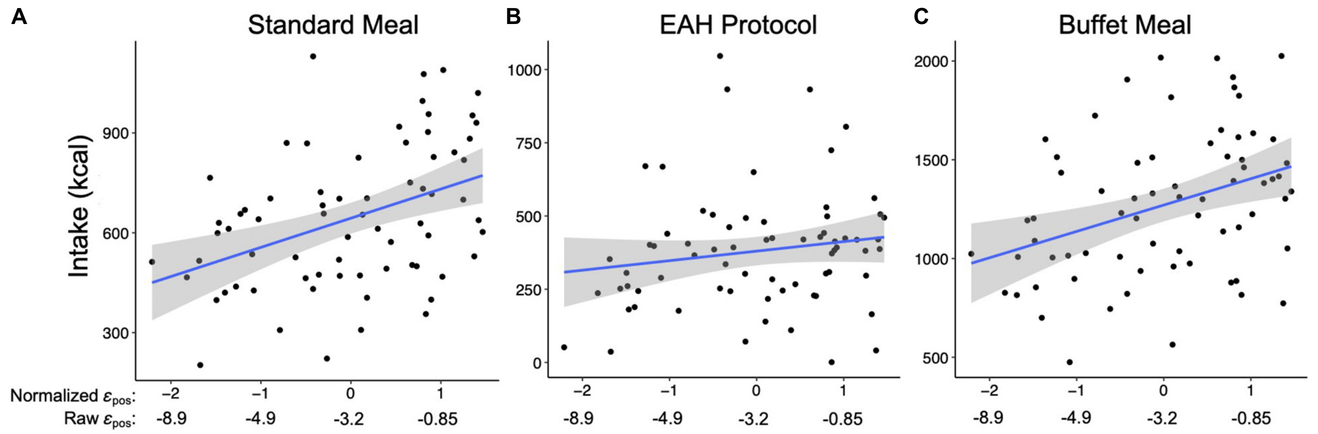

FIGURE 5 | Relationship between the impact of gain on perseveration strength (i.e., ε_{pos}; x-axis) and intake (kcal; y-axis) during the **(A)** Standard meal, **(B)** Eating in the Absence of Hunger (EAH) protocol, and **(C)** Buffet meal. Blue lines reflect the best fit for the linear model between ε_{pos} and intake. Shaded gray regions reflects 95% confidence interval for the line of best fit.

standard meal. Potentially, children who rely more on time-distant information (i.e., update slower) during decision-making better incorporate experiences from prior meals (e.g., how satiating foods were) into their meal choices, and this contributes to reduced intake. However, updating was not related to buffet meal intake or EAH. This suggests that, independent of pre-meal fullness levels, relying more on time-distant information may help children moderate energy intake during moderately palatable meals but not eating contexts with increased variety and palatability. Alternatively, children may have had more experience with the foods in the standard meal than the buffet meal or EAH protocol, and therefore had more relevant prior information to incorporate into decisions made during the standard meal. Although we observed an association between updating and intake at a single meal, there were no indirect effects on weight status; however, this does not rule out the possibility that updating may be associated with long-term energy balance. Support for this comes from work demonstrating that adults who successfully lost weight in a weight-loss intervention relied more on time-distant information during decision-making than adults who were unsuccessful (Koritzky et al., 2015). Thus, relying more on time-distant information during decision-making may contribute to reduced energy intake and have long-term benefits for maintenance of a healthy weight.

Decision-Making Processes Related to Perseveration, Intake, and Weight Status

As hypothesized, the impact of gain on perseveration strength was positively associated with intake at all three eating paradigms and was indirectly associated with BMI-z through standard and buffet meal intakes. These results indicate that children who had greater increases in the tendency to repeat a choice after a gain consumed more energy. Further, indirect associations suggest that greater increases in the tendency to repeat a choice after a gain may contribute to increased weight status by facilitating excess consumption at meals, but not necessarily from snack foods consumed after a meal. Previous research has demonstrated that behavioral responses to rewards correlate with intake and weight status in youth. For example, greater motivation to work for food, as assessed with the reinforcing value of food task, has been positively associated with children's energy intake (Temple et al., 2008; Epstein et al., 2015) and weight gain (Hill et al., 2009). In addition, children with higher drive scores on the Behavioral Approach Scale, indicative of greater reward sensitivity (Dawe and Loxton, 2004), show increased frequency of fast food and sweet drink consumption (De Decker et al., 2016). Thus, our results are consistent with previous research suggesting that altered behavioral responses to rewards may contribute to excess energy intake and obesity. These results provide insight into a decision-making process that may underlie these associations; children who are more likely to repeat behaviors following rewards may be prone to overeating and weight gain.

In addition to the observed associations with the impact of gain on perseveration strength, we observed that the interaction between the impact of loss on perseveration strength and perseveration decay was related to EAH. Children who had greater increases in the tendency to perseverate after a loss ate less during the EAH protocol if their tendency to perseverate decayed quickly but ate more if their tendency to perseverate decayed slowly. This interaction suggests the tendency to eat in the absence of hunger following a negative experience (e.g., physical discomfort) may depend on the persistence of this tendency over time. Further, given that the impact of loss on perseveration strength reflects a process similar to positive punishment (i.e., a decrease in behavior following an aversive outcome; Catania, 1979), the moderation by perseveration decay may explain why prior studies have shown inconsistent relationships between sensitivity to punishment and weight status (Danner et al., 2012; Nazarboland and Fath, 2015; Jonker et al., 2019). Interestingly, neither the impact of loss on perseveration strength or perseveration decay were related to buffet meal intake, suggesting the influence of

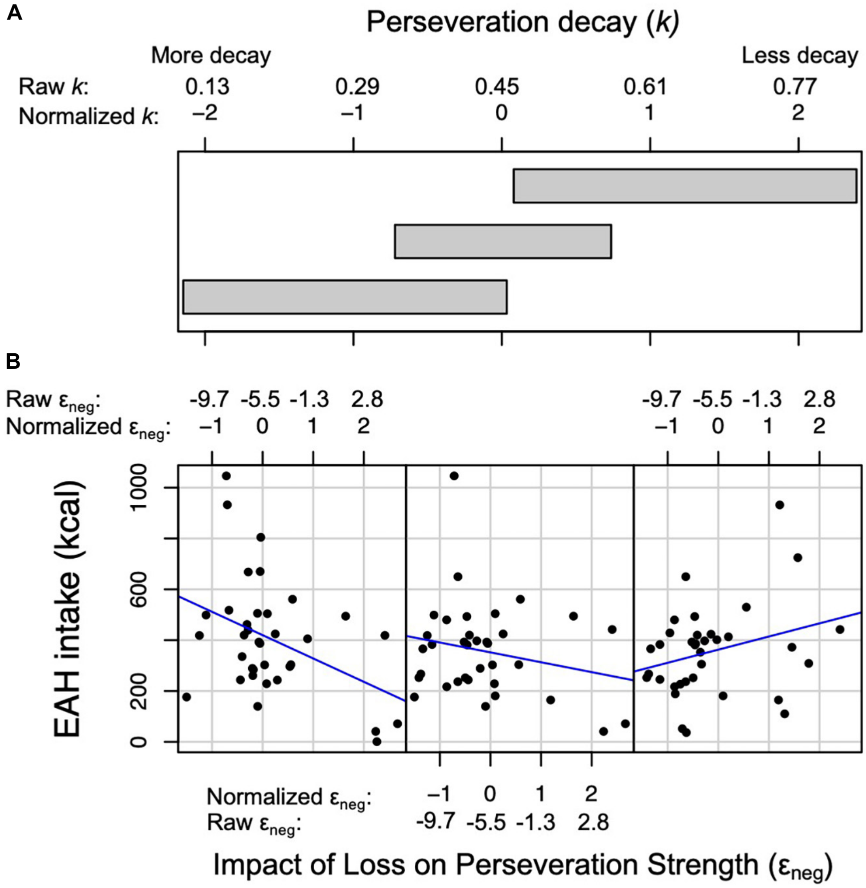

FIGURE 6 | Relationship between the impact of loss on perseveration strength (i.e., ε_{neg}) and intake (kcal) during the Eating in the Absence of Hunger (EAH) protocol at three levels of perseveration decay (i.e., *k*). **(A)** Three overlapping intervals of *k* that correspond to the three scatterplots in panel **(B)**. **(B)** Scatterplots between ε_{neg} (x-axis) and EAH (y-axis). Normalized and raw values of ε_{neg} and *k* are presented. Left scatter plot: at the lower interval of *k* (normalized values: −2.15 to 0.03), the association between ε_{neg} and intake is negative. Middle scatter plot: at the middle interval of *k* (normalized values: −0.72 to 0.74), the association between ε_{neg} and intake is negative, although less negative than the lower interval. Right scatter plot: at the higher interval of *k* (normalized values: 0.08 to 2.39), the association between ε_{neg} and intake is positive.

these decision-making processes on overeating may depend on factors such as physiological status at the start of the meal, types of food served, or the availability of alternative activities (i.e., playing with toys during the EAH protocol). Future studies should examine the long-term implications of these decision-making processes on weight status and test why they may be associated with the tendency to overeat snack foods after a meal but not the tendency to overeat palatable foods within a meal.

Overall, our results suggest that decision-making processes related to perseveration contribute to energy intake and weight status in children. Similarly, previous research has demonstrated positive associations between perseverative behaviors during the Wisconsin Card Sorting Task (WCST) or Door Opening Task and both cross-sectional weight status in children and adolescents (Nederkoorn et al., 2006; Cserjési et al., 2007; Verbeken et al., 2009) and weight re-gain in children following a weight-loss program (Eichen et al., 2018). Further, making more perseverative errors during the WCST has been shown to moderate the relationship between cognitive restraint and *ad libitum* energy intake in adults such that those with high perseverative errors and low restraint ate the most (Graham et al., 2014). In sum, prior research suggests that having a greater tendency to perseverate may contribute to increased energy intake and weight status. Our study builds on this by identifying specific decision-making processes related to perseveration that may underlie these associations.

Limitations and Future Research

There are several limitations to this study that should be highlighted. First, the study was cross-sectional, and although we used path analyses to test directed relationships, these analyses do not allow for assessment of cause and effect (Streiner, 2005). To understand whether decision-making processes impact future weight gain through their effects on intake, longitudinal research is necessary. Second, in our theoretical models, we proposed directed relationships from intake to BMI-z, given that excess energy intake can increase weight status. However, increased weight status also increases energy requirements (Carneiro et al., 2016), so the relationship between intake and weight status may be bidirectional. Further, adiposity can influence cognitive processes (Farruggia and Small, 2019), so BMI-z may also impact decision-making processes. Thus, additional research examining the relationships between these variables is warranted to characterize the causal pathway.

Additional limitations pertain to our sample which was relatively homogeneous, with the majority of children being white and non-Hispanic. To improve the generalizability of these results, similar analyses should be conducted in more diverse cohorts. In addition, the age range of children tested was broad, spanning a period of neurocognitive development that can impact decision-making (Anderson, 2002; Steinbeis and Crone, 2016). While our sample size was too small to test interactions with age, future studies with larger sample sizes should examine whether age in middle childhood moderates the relationship between decision-making processes and food intake, as this will have implications for the development of targeted approaches to reduce excess energy intake.

Lastly, there are several variables that were not assessed in this study that are relevant for future research. First, future research should include an external indicator of neuropsychological maturation, such as parental assessment of child executive functioning. Second, given that affective processes, such as anxiety, relate to both decision-making (Hartley and Phelps, 2012) and eating behaviors (Michels et al., 2012), future research should include assessments of state and trait affect and test whether these processes mediate or moderate the relationships between decision-making processes and food intake. Third, future research should examine how decision-making processes relate to food choices or within-meal eating behaviors (e.g., bite rate) which may mediate the observed relationships with energy intake.

Implications

Despite these limitations, the current study makes contributions to the field. We demonstrated that a reinforcement learning model can be used to estimate decision-making processes that overlap with, but are more nuanced than, traditional decision-making outcomes in children. Further, we demonstrated the feasibility and advantage of using a reinforcement learning model to understand mechanisms underlying children's food intake. By using path analyses to examine the relationships between VPP model parameters, objectivley-assessed intake, and BMI-z, we informed the underlying mechanisms linking decision-making processes to child weight status. In addition, by measuring intake during three different eating paradigms, we demonstrated that some decision-making processes (e.g., the impact of gain on perseveration strength) may contribute to children's intake across various eating contexts, whereas other decision-making processes (e.g., the impact of loss on perseveration strength, perseveration decay) may be context specific. This highlights the need for future studies to identify the contexts most likely to promote overeating among children who vary in decision-making capabilities.

Finally, while additional research is needed to understand the long-term and causal relationships between decision-making processes and child weight status, we speculate on two practical implications related to the finding that increases in the tendency to repeat a choice after a gain were indirectly associated with greater weight status through standard and buffet meal intake. First, children who are more likely to repeat a behavior after a reward may be at higher risk for future weight gain and, therefore, may benefit from early interventions to reduce energy intake. Identifying children who exhibit this decision-making characteristic would be feasible through the administration of the Hungry Donkey Task. Second, intervention approaches to reduce the reinforcing effects of reward outcomes may be beneficial for reducing energy intake across multiple contexts.

CONCLUSION

This study showed that decision-making processes related to perseveration were associated with energy intake in children across a variety of eating contexts. Children who exhibited greater increases in the tendency to repeat a choice after a gain had a tendency to eat more across multiple eating contexts in the laboratory. Further, greater impact of gain on perseveration strength was indirectly associated with increased weight status through its association with greater intake at both the standard and buffet meals. These results suggest that this decision-making process may contribute to increased weight status by increasing intake at both moderately palatable (e.g., standard meal) and highly palatable (e.g., buffet meal) eating occasions. Future studies are needed to examine how decision-making processes impact future weight status and whether interventions that target decision-making processes related to perseveration can mitigate excess energy intake.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: Open Science Framework (OSF.IO/MWQZ9).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Pennsylvania State University Institutional Review Board (IRB approval number: 674). Written informed consent to participate in this study was provided by the participants' legal guardian.

AUTHOR CONTRIBUTIONS

BF wrote the manuscript. BF and AP conceptualized the current project and theoretical model and conducted analyses with the guidance of KK. NR and ZO provided guidance with running and utilizing the reinforcement learning model. NR, SA, CG, and

KK designed the original study with contributions from CW. NR and SA wrote the original grant. SA conducted data collection. All authors contributed feedback, and read and approved the final 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.2021.652595/full#supplementary-material

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Parent Gender Affects the Influence of Parent Emotional Eating and Feeding Practices on Child Emotional Eating

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Extant research supports a direct association between parent's own emotional eating and their child's emotional eating, and demonstrates correlations among parent emotional eating, feeding practices, and child emotional eating. However, the majority of this work focuses on the separate influences of these factors. The current study aims to add to the literature by simultaneously examining the indirect effects of three major parental feeding practices (i.e., emotion regulation, instrumental, and restrictive feeding) in the association between parent emotional eating and child emotional eating, and exploring how these indirect effects vary based on parent gender. Parents (86 fathers, 324 mothers) of an elementary school-age child (M = 8.35, SD = 2.29, range = 5–13) completed an online survey through Qualtrics Panels. Results suggested that restrictive feeding partially accounted for the association between parent and child emotional eating in the combined sample of mothers and fathers. Exploratory analyses revealed that the indirect effects of parental feeding practices in the association between parent emotional eating and child emotional eating varied based on parent gender. Among mothers, restrictive feeding was the only feeding practice that partially accounted for the association between maternal and child emotional eating, whereas all three feeding practices fully accounted for the association between father and child emotional eating. As the bulk of the literature on parent emotional eating and feeding has solely focused on mothers, these findings offer insight into how feeding practices may differentially function in the relation between parent emotional eating and child emotional eating for mothers versus fathers.

Keywords: parent emotional eating, child emotional eating, feeding practices, child eating behavior, parental feeding, parent gender

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INTRODUCTION

Background

Emotional eating is characterized by eating in response to emotions instead of internal hunger cues (Bruch, 1964). Emotional eating is associated with overeating (van Strien et al., 2005), as well as other disordered eating behaviors, including bulimia and binge eating (Ashcroft et al., 2008). Emotional eating is also positively related to disordered eating attitudes such as, weight concern (Barnhart et al., 2021) and body dissatisfaction (Annesi and Mareno, 2015). Both children

(Braet and van Strien, 1997; Webber et al., 2008) and adults (van Strien et al., 2009) who engage in emotional eating are more likely to have a higher body mass index (BMI; usually defined as equal to or over 25), which is a risk factor for chronic diseases (e.g., diabetes; Boles et al., 2017). Further, childhood emotional eating has been shown to predict disordered eating behaviors (e.g., binge eating; Allen et al., 2008) and increased adiposity up to 4 years later (Shriver et al., 2019). While emotional eating can occur in response to both positively and negatively valenced emotions, the majority of the research in this area defines emotional eating as using food to escape or reduce negative emotions (e.g., Arnow et al., 1995). To maintain consistency with the literature, this study focuses on eating in response to negative emotions.

Research suggests that the rates of emotional eating are lower in young children, but increase during middle childhood and adolescence (e.g., Wardle et al., 2001; van Strien and Oosterveld, 2008), with one study reporting that 63% of children ages 5–13 have engaged in emotional eating in their lifetime (Shapiro et al., 2007). The bulk of the research on how children adopt emotional eating practices has focused on the role of mothers and their preschool-aged children (e.g., Wardle et al., 2002; Rodgers et al., 2014). In middle childhood, children often have much more autonomy and less dependence on parents, especially regarding food access (Steinsbekk et al., 2018). Extant work has identified parent eating and feeding practices as correlates of children's emotional eating in middle childhood (Braden et al., 2014), but no study to date has directly disentangled parent eating, feeding, and child eating across different primary caregivers in middle childhood.

Parent and Child Emotional Eating

Some researchers have suggested that child emotional eating is a learned response (van Strien and Oosterveld, 2008; Blissett et al., 2010). Since parents are one of the primary socialization agents for their children, it is not surprising that parenting behaviors are related to child emotional eating. According to psychosomatic theory, child emotional eating is a maladaptive response to negative emotion that results from interactions with caregivers (Bruch, 1973). These caregivers also have a major role in shaping eating behaviors and determining eating environments (e.g., Birch and Fisher, 1998; Anderson and Butcher, 2006; Lindsay et al., 2006; Anzman et al., 2010; Sleddens et al., 2011).

Parents are not only the main providers of food for their child, but they also model eating behaviors (e.g., through their own emotional eating), and affect their child's eating through parenting behaviors such as feeding practices (Ventura and Birch, 2008). For example, numerous studies document a direct association between parent emotional eating and their child's emotional eating (e.g., Snoek et al., 2007; Jahnke and Warschburger, 2008; de Lauzon-Guillain et al., 2009; Elfhag et al., 2010; Kröller et al., 2013; Rodgers et al., 2014). This effect has mostly been explained through modeling: children observe parents eating in response to emotional stimuli and thus may be more likely to do the same when faced with emotional cues (Morrison et al., 2013). Parental feeding behaviors are also consistently associated with children's emotional eating (e.g., Birch and Davison, 2001; Blissett et al., 2010; Rodgers et al., 2013; Braden et al., 2014; Farrow et al., 2015). Although parents are usually well-intentioned, their feeding behaviors can disrupt the child's ability to regulate how they eat in response to physical hunger and satiety cues and lead to unhealthy eating behaviors, including emotional eating (Heatherton and Baumeister, 1991; Birch and Fisher, 1998).

Parental Feeding Practices

Parental feeding practices can also be influenced by parents' own eating behaviors (Sleddens et al., 2010). In a study of parents from the United States and France, researchers found that parent emotional eating behavior was associated with more use of instrumental feeding (de Lauzon-Guillain et al., 2009). However, the majority of this work has been focused on maternal eating and feeding practices. Mothers who engage in emotional eating have been found to report greater use of instrumental (Kröller et al., 2013) and emotional feeding practices (Wardle et al., 2002). As described above, such feeding practices often result in higher levels of child emotional eating. Here, we review the evidence for three types of parental feeding practices that have been linked to child emotional eating: emotion regulation feeding, instrumental feeding, and restrictive feeding.

Emotion Regulation Feeding

Emotion regulation feeding often occurs when parents respond to their child's negative feelings (e.g., boredom, distress) by giving them food (Musher-Eizenman and Holub, 2007). Psychosomatic theory posits that child emotional eating results from children learning to use food to regulate negative emotions when parents repeatedly feed their children while they are upset (Bruch, 1964). Thus, parents who use emotion regulation feeding may be indirectly teaching their children to eat for comfort. Parent emotion regulation feeding has been associated with child emotional eating in numerous cross-sectional (e.g., Jahnke and Warschburger, 2008; Steinsbekk et al., 2018), longitudinal (Rodgers et al., 2013), and experimental studies (Blissett et al., 2010). However, the vast majority of these studies have investigated these processes in preschool-aged children. The few studies that exist on older children do support an association between emotion regulation feeding and emotional eating in children aged 5–12 (see Braden et al., 2014; Tan and Holub, 2015). Because of the increased food autonomy experienced in middle childhood (i.e., the elementary school years), additional investigations as to how parental eating and feeding function to influence child emotional eating in this age range is needed.

Instrumental Feeding

Instrumental feeding occurs when parents use food to regulate their child's desired behavior (i.e., using food as a reward or punishment; Benton, 2004). Similar to emotion regulation feeding, using instrumental feeding can implicitly teach children that food can be used in response to non-nutritional needs (Evers et al., 2010), and inhibit their ability to self-regulate their eating (Musher-Eizenman et al., 2009). Over time, children learn to associate food with external stimulation, such as celebration, rather than hunger. Instrumental feeding is also related to child emotional eating (e.g., Rodgers et al., 2013, 2014; Powell et al., 2017). In particular, longitudinal studies have demonstrated that parent's use of instrumental feeding practices at ages 5–7 significantly predicts child emotional eating (Steinsbekk et al., 2016), and eating in the absence of hunger when experiencing heightened stress (Farrow et al., 2015) several years later.

Restrictive Feeding

Restrictive feeding is a type of controlling feeding practice that occurs when parents limit their child's access to and consumption of food (Fisher and Birch, 1999). Parents may restrict their child's food intake for various reasons, such as restricting food for health or weight reasons (Musher-Eizenman and Holub, 2007), however, much of the research on emotional eating and restrictive feeding has disregarded different motivations for restrictive feeding in studies and focuses on frequency of this behavior instead. Although parents often restrict high-calorie foods, data show that children actually consume more of these foods when access is gained after they have been restricted (Fisher and Birch, 1999). Similar to emotion regulation and instrumental feeding, repeated restrictive feeding may disrupt a child's internal hunger and satiety cues, which in turn can inhibit the child's ability to self-regulate their food consumption (Faith et al., 2004; Jansen et al., 2012). Although there are studies that document a positive association between restrictive feeding and child emotional eating (e.g., Joyce and Zimmer-Gembeck, 2009; Kröller et al., 2013; Williams et al., 2017), other researchers have discovered no significant associations (Blissett et al., 2010). Thus, the relation between restrictive feeding and child emotional eating is less clear compared to emotion regulation or instrumental feeding.

The Role of Parental Feeding in the Relation Between Parent and Child Emotional Eating

The research described above presents meaningful associations among parent emotional eating, feeding practices, and child emotional eating. However, the existing literature in this area suffers from two notable limitations. First, it largely focuses on the separate influences of parents' eating and feeding practices on child emotional eating rather than their simultaneous impact. Thus, it is not clear which feeding practices have the strongest influence in the direct association between parent and child emotional eating. There are only a handful of studies that have compared the indirect effects of various parental feeding practices on the association between parent and child emotional eating. Of the two studies found, one study did not find significant indirect effects of maternal feeding practices in the association between mother-child emotional eating, but did not assess emotion regulation feeding (Kröller et al., 2013). Another study documented significant indirect effects of emotion regulation and instrumental feeding, but excluded restrictive feeding (Rodgers et al., 2014). The present study seeks to reproduce the latter finding and directly compare the indirect effects of emotion regulation feeding, instrumental feeding, *and* restrictive feeding in the relation between parent and child emotional eating in the same model.

Second, the vast majority of work on feeding practices affecting parent-child emotional eating has focused on mothers, despite the fact that evidence exists to suggest that feeding styles vary by parent gender. Studies have documented that, compared to mothers, fathers use more restrictive (Musher-Eizenman et al., 2007) and instrumental (Powell et al., 2017) feeding practices, and report feeling less responsible for feeding (Blissett et al., 2006). Further, the way children respond to parental eating and feeding styles can differ by parent gender (e.g., Johannsen et al., 2006). For example, one study found that child emotional eating is more influenced by emotional eating of mothers than fathers (Snoek et al., 2007). Others have discovered that maternal feeding practices result in higher levels of emotional overeating, whereas paternal feeding practices are more likely to lead to emotional undereating (Haycraft and Blissett, 2012; Wei et al., 2018). Although fathers are increasingly becoming more involved in feeding their children (see Khandpur et al., 2014; Mallan et al., 2014), the overwhelming majority of the extant work on how parent emotional eating and feeding practices affect child emotional eating has focused solely on mothers (e.g., Kröller et al., 2013; Rodgers et al., 2014). While a sizeable body of literature has examined how *child* gender affects child emotional eating and the feeding practices of mothers (e.g., Snoek et al., 2007; van Strien and Bazelier, 2007; Hoffmann et al., 2016), there is limited work on the influence of *parent gender* on the associations among parent emotional eating, feeding practices, and child emotional eating. It is not yet understood how fathers' feeding practices and own emotional eating concurrently influence their child's emotional eating or how these processes differ based on parent gender.

Current Study

Given these gaps in the literature, the purpose of the current study is twofold. First, we aim to simultaneously examine how different parental feeding practices account for variance in the association between parent emotional eating and child emotional eating during middle childhood. Specifically, we will directly compare the indirect effects of parent's use of instrumental, emotion regulation, and restrictive feeding practices, through which parent emotional eating relates to child emotional eating. This is a major gap in the field as many studies have examined only simple associations among these variables instead of a comprehensive model. Second, we aim to add to the literature on parental influences on child emotional eating by exploring how these indirect effects differ based on parent gender as existing research suggests mothers and fathers influence their child's behavior differently. The results of this aim will also inform future interventions or recommendations for parents related to child emotional eating by revealing differences in parent emotional eating and feeding patterns, or lack thereof. These aims will be accomplished by testing a parallel indirect effects model and comparing a multiple group parallel indirect effects model, respectively.

MATERIALS AND METHODS

Sample and Design

This study is part of a larger investigation on parent and child health behaviors and the home and school environments. The sample included independent families in which only one parent (e.g., mother or father) was recruited for each child. Parents (*N* = 410; 79% female) were recruited using an online market research sample aggregator (Qualtrics Panels; see Budd et al., 2020 for more details). To be eligible to participate, individuals had to live in Oregon, have an elementary school-age child, and be able to read in English. Most participants identified as non-Hispanic White (80%), followed by more than one ethnicity (10%), Hispanic (3%), Asian (3%), other (1%), Black (1%), Native American/Alaska Native (<1%), Middle Eastern (<1%), and Pacific Islander (<1%). All other demographics are presented in **Table 1**. Children (49% female) were between the ages of 5–13 years-old (*M* = 8.4 years, *SD* = 2.29). This was a cross-sectional study and all responses were parent-report.

Measures

Parent and child emotional eating were assessed via the self and child emotional eating subscales, respectively, of the Dutch Eating Behavior Questionnaire (DEBQ; van Strien et al., 1986). Both self and child emotional eating subscales included 13 items, assessing eating in response to negative emotions, with a 5-point Likert-type response scale ranging from 1 (seldom) to 5 (very often). Sample items included: "Do you have a desire to eat when you are depressed or discouraged?" and "Do you have a desire to eat when you are feeling lonely?" Item scores were averaged for each subscale to create an average index of frequency of parent and child emotional eating behaviors. Higher scores indicated greater parent-reported emotional eating. Internal consistency was high for parent and child scales; Cronbach's alphas (α) were 0.95 and 0.96, and McDonald's omegas (ω) were 0.95 and 0.96, respectively, for parent and child scales.

TABLE 1 | Parent and child demographics by parent gender.

Variable	Fathers (21%) *n* = 86	Mothers (79%) *n* = 324	Full sample *N* = 410
	n (%)/M (SD)	*N (%)/M (SD)*	*N (%)/M (SD)*
Parent demographics			
Age (years)*			
18–29	7 (8%)	74 (23%)	81 (20%)
30–39	45 (52%)	162 (50%)	207 (50%)
40–49	20 (23%)	64 (20%)	84 (20%)
50–59	9 (10%)	17 (5%)	26 (6%)
Over 60	5 (6%)	7 (2%)	12 (3%)
Child demographics			
Female	35 (41%)	164 (51%)	199 (49%)
Age	8.79 (2.36)*	8.23 (2.26)*	8.35 (2.29)

*n/N, number of observations; M, mean; SD, standard deviation. *significantly different (p < 0.05).*

Parental feeding practices were assessed with the Comprehensive Feeding Practices Questionnaire (CFPQ; Musher-Eizenman and Holub, 2007). The following subscales were included: (1) emotion regulation (3 items); (2) instrumental (3 items); and (3) restriction for weight control (8 items). Parents responded to statements about feeding practices on a 5-point Likert-type scale from 1 (never) to 5 (always). Item scores were summed to create a total index for each subscale. Higher scores indicated greater self-reported use of that feeding practice. Internal reliability for emotion regulation (α = 0.81, ω = 0.81), instrumental (α = 0.70, ω = 0.70), and restrictive (α = 0.86, ω = 0.86) subscales were adequate.

Parent gender was asked directly to participants of the survey (i.e., "With which gender do you identify?"). There were three response options (male, female, and other), although no parents selected "other."

Parent stress, parent negative affect, child gender, and child age were included as covariates. These covariates were selected because previous research suggests they may contribute to variance in the statistical model. Specifically, studies have documented significant associations between child emotional eating and child gender (Braden et al., 2014) and maternal stress (Rodgers et al., 2014), as well as indirect associations with maternal negative affect (Rodgers et al., 2014). Covariates were also included if previous indirect models of parent-child emotional eating included them as controls, such as for child age (e.g., Kröller et al., 2013; Tan and Holub, 2015). Parent stress was assessed with a single subjective rating of stress (i.e., "Overall, how stressed are you?") on a scale from 0 (not stressed at all) to 100 (extremely stressed) in the past month. Parent negative affect was assessed via the trait negative affect subscale on the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988). Responses on the 10-item subscale range from 1 (not at all) to 5 (extremely). A summed score was used for analysis, and internal consistency was good (α = 0.86, ω = 0.86). Child age was chosen from a list (options: 5 through 13 years) and provided in integers. Child gender was assessed with a single item (i.e., "What is the gender of your child?") with three response options (male, female, other), although no parents responded "other."

Analytic Strategy

Reliability metrics, such as Cronbach's alphas were calculated with SPSS version 26, and McDonald's omegas were computed with the OMEGA SPSS macro (Hayes and Coutts, 2020). While Cronbach's alpha is a widely reported measure of internal consistency, McDonald's omega requires fewer statistical assumptions that are difficult to meet (e.g., essential tau-equivalence) and has been recommended as an alternative (see Dunn et al., 2014; Hayes and Coutts, 2020), so both were reported. All subsequent analyses were conducted in R version 4.0.3 (R Core Team, 2019). Study variables were assessed for skew and kurtosis; variables with a skewness or kurtosis over −/+1 were transformed to improve distributions and re-assessed. All feeding practices (i.e., emotion regulation, instrumental, and restrictive) were identified as non-normally distributed. The distributions of these variables were greatly improved by transformation using the transformTukey function in the R package *rcompanion* package (Mangiafico, 2019), which follows the Tukey's Ladder of Powers principle to improve the distribution of skewed variables. The transformed parental feeding variables were used for all statistical analyses and are reported in corresponding tables/figures.

A comparison between fathers and mothers on study variables were analyzed with Welch's *t*-test for continuous variables, and Pearson's chi-squared test for count variables in R. Path models were tested with a series of structural equation models (SEM) with the *lavaan* R package (Rosseel, 2012). There were two participants who did not answer one of the items for the DEBQ. Since both participants had zero variance in their ratings of the remaining items from that scale, their composite scores were calculated using the available items. Thus, there were no missing data in the composite variables that were included in the analysis. All models were tested with full information maximum likelihood estimation with robust standard errors, included all covariates (i.e., parent stress, negative affect, child age, and gender) for all model paths, and specified correlations among all feeding practices. When estimating indirect effects, bias-corrected bootstrapped standard errors and confidence intervals were estimated with the *RMediation* package (Tofighi and MacKinnon, 2011) and 10,000 resamples following the guidelines of MacKinnon (2008) to detect significant indirect effects. To test the indirect effect of the three parental feeding practices (i.e., emotion regulation, instrumental, and restrictive feeding) between parent and child emotional eating, all parental feeding practices were modeled as parallel indirect effects in addition to the direct effect of parent emotional eating to child emotional eating (see **Figure 1**). This allows for the simultaneous evaluation of each parental feeding practice while also accounting for the associations of all feeding practices (Hayes and Rockwood, 2017).

To explore how parent gender moderated the indirect effect of parental feeding practices between parent and child emotional eating, a multiple group structural equation analysis was conducted (see Kline, 2016). In the first step, path coefficients from the above model were freely estimated for both mothers and fathers. Then, path coefficients were constrained to be equal across groups. In the last step, path coefficients and intercepts were constrained to be equal across groups. Tests of model comparisons were then conducted to evaluate which model it the data significantly better. Comparative model fit was assessed with a chi-square difference test. Moderation was determined if the model with freely estimated group parameters fit the data significantly better than the models with constrained parameters. The parallel mediation model was just-identified, therefore, no overall model fit indices were calculated. All reported coefficients are standardized unless otherwise stated, and confidence intervals are reported at the 95% level. The dataset and analysis script are available online - https://osf.io/muzbj/.

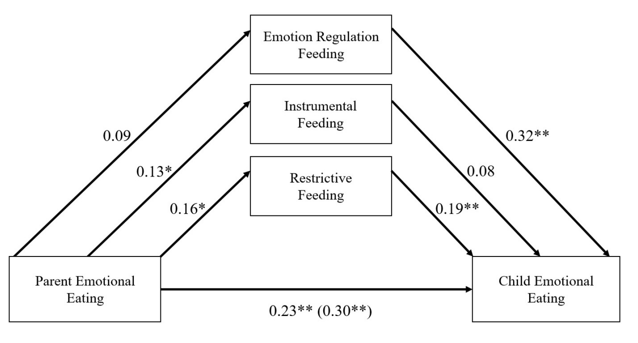

FIGURE 1 | Standardized regression estimates for parallel indirect effects path model with the full sample. *$p < 0.05$, **$p < 0.001$. Covariates included parent stress, parent negative affect, child age, and child gender on all model paths.

RESULTS

Preliminary Analyses

Descriptive statistics for study variables are presented in **Table 2**. Preliminary results from the Welch's *t*-test showed that, compared to mothers ($M = 1.80$, $SD = 0.65$), fathers ($M = 2.04$, $SD = 0.87$) reported significantly greater use of instrumental feeding practices $t(122) = -2.34$, $p < 0.05$. Fathers ($M = 1.94$, $SD = 0.84$) also reported significantly greater use of restrictive feeding practices compared to mothers ($M = 1.56$, $SD = 0.58$), $t(125) = -4.13$, $p < 0.05$. Mothers ($M = 57.40$, $SD = 23.67$) reported significantly higher levels of stress than fathers ($M = 50.74$, $SD = 25.69$), $t(126) = 2.17$, $p < 0.05$. Regarding demographics, fathers ($M = 8.79$, $SD = 2.36$) had slightly older children compared to mothers ($M = 8.23$, $SD = 2.26$), and this difference was statistically significant, $t(130) = -1.98$, $p < 0.05$. The results of Pearson's chi-square test revealed that there were significantly more fathers in the older age range categories than was expected if they were evenly distributed across ages for mothers and fathers, χ^2 (4, $N = 410$) = 13.93, $p < 0.05$. There were no statistically significant differences between fathers and mothers in the remaining study variables (i.e., parent or child emotional eating, emotion regulation feeding, parent negative affect, and child gender).

Parallel Indirect Effects for Full Sample

In regards to aim 1, results from the parallel indirect effects path model are shown in **Figure 1**, and bias-corrected bootstrap results for indirect effects are reported in **Table 3**. The only feeding practice that had a significant indirect effect was restrictive feeding (standardized effect = 0.03). The bootstrapped unstandardized indirect effect was 0.03 [CI (0.01, 0.06), $p < 0.05$]. Parent emotional eating was associated with higher levels of restrictive feeding, $\beta = 0.16$, $p < 0.05$, and higher levels of restrictive feeding were associated with greater parent-reported child emotional eating, $\beta = 0.19$, $p < 0.05$. The direct effect from parent emotional eating to child emotional eating was still significant after accounting for the indirect effect of restrictive feeding [*estimate* = 0.23, $p < 0.001$, CI (0.13, 0.31)], suggesting that the indirect effect of restrictive feeding only partially accounts for the association between parent and child emotional eating. Although no other indirect effects were statistically significant, parent emotional eating was also significantly and positively associated with instrumental feeding ($\beta = 0.13$, $p < 0.05$), and parent emotion regulation feeding was

TABLE 2 | Descriptive statistics for study variables by parent gender.

Variable	Fathers (21%) n = 86	Mothers (79%) n = 324	Full sample N=410	
	M (SD)	*M (SD)*	*M (SD)*	*Range*
Parent emotional eating (DEBQ self-report)	2.46 (0.92)	2.53 (0.80)	2.52 (0.83)	1–5
Child emotional eating (DEBQ parent-report)	1.94 (0.82)	1.93 (0.77)	1.94 (0.78)	1–4.7
Emotion regulation feeding (CFPQ)	1.66 (0.89)	1.47 (0.53)	1.51 (0.63)	1–5
Instrumental feeding (CFPQ)	2.04 (0.87)*	1.80 (0.65)*	1.85 (0.71)	1–5
Restrictive feeding (CFPQ)	1.94 (0.84)*	1.56 (0.58)*	1.64 (0.66)	1–5
Stress (single-item)	50.74 (25.69)*	57.40 (23.67)*	56.01 (24.23)	0–100
Negative affect (PANAS)	2.21 (0.90)	2.22 (0.77)	2.22 (0.80)	1–5

*n/N, number of observations; M, mean; SD, standard deviation; DEBQ, Dutch Eating Behavior Questionnaire; CFPQ, Comprehensive Feeding Practices Questionnaire; PANAS, Positive and Negative Affect Schedule. Range refers to the minimum and maximum observed values. *significantly different (p < 0.05).*

TABLE 3 | Results for parallel indirect effects of parental feeding practices (N = 410).

Feeding practice (CFPQ)	Effect	*SE*	95% CI
Emotion regulation	0.03 (0.03)	0.02	[−0.01, 0.06]
Instrumental	0.01 (0.01)	0.01	[−0.00, 0.03]
Restrictive	0.03 (0.03)	0.01	[0.01, 0.06]

CFPQ, Comprehensive Feeding Practices Questionnaire; SE, standard error; CI, confidence interval. Standardized coefficients are presented for indirect effects. Bias-corrected bootstrapped, unstandardized indirect effects are reported in parentheses. Bootstrapped standard errors and confidence intervals are presented (bootstrap sample = 10,000).

significantly and positively associated with parent-reported child emotional eating, $\beta = 0.32$, $p < 0.001$. Additionally, the total effect of parent emotion eating on child emotional eating was significant [*estimate* = 0.30, $p < 0.001$, CI (0.18, 0.38)].

Moderated Indirect Effects by Parent Gender

The exploratory results for aim 2 indicate that these associations are conditional on parent gender and should be interpreted differently for mothers compared to fathers. Specifically, results for the moderated indirect effect models showed that there were significant differences in indirect effects by parent gender. The test of nested model comparisons (see **Table 4**) revealed that there was a significant decrement in fit when constraining model paths as equal (model 2), indicating that allowing parameters to differ for mothers and fathers (model 1) was a better model ($\chi^2_{diff} = 56.75$, $\Delta df = 12$, $p < 0.001$). There was no significant change in model fit between the model with constrained model paths and intercepts (model 3) compared to constrained model paths only (model 2). An additional chi-square difference test was conducted to directly compare the model with constrained paths and intercepts and the model with freely estimated parameters for mothers and fathers. Results showed that the model with freely estimated parameters fit the data significantly better than the constrained model ($\chi^2_{diff} = 61.47$, $\Delta df = 17$, $p < 0.001$), indicating that both model paths and intercepts should be freely estimated for mothers and fathers.

TABLE 4 | Model comparison results for conditional indirect effects.

Model	*df*	χ^2	χ^2_{diff}	*p*
1. Free parameters	0	0		
2. Constrained paths	12	56.75	56.75	<0.001
3. Constrained paths and intercepts	17	61.47	4.72	0.47

df, degrees of freedom; χ^2, chi-square statistic; χ^2_{diff}, chi-square difference; p, p-value.

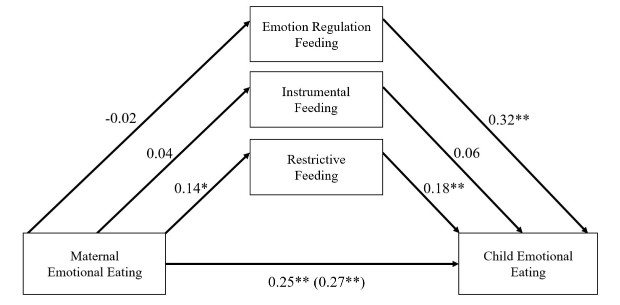

FIGURE 2 | Standardized regression estimates for mother's conditional effects. *$p < 0.05$, **$p < 0.001$. Covariates included parent stress, parent negative affect, child age, and child gender on all model paths.

Estimates from the moderated parallel indirect effects path model are presented separately for mothers (see **Figure 2**) and fathers (see **Figure 3**). All indirect effects are reported in **Table 5**. There was evidence of a moderated indirect effect of feeding practices between parent and child emotional eating for both mothers and fathers. For mothers, the only significant indirect effect was for restrictive feeding (standardized effect = 0.03). The bootstrapped unstandardized indirect effect was 0.02 [CI (<0.01, 0.05), $p < 0.05$]. Mothers who reported greater emotional eating also reported greater use of restrictive feeding practices ($\beta = 0.14$, $p < 0.05$); higher levels of restrictive feeding in mothers was also associated with significantly greater parent-reported child emotional eating ($\beta = 0.18$, $p < 0.001$). The direct effect between maternal and child emotional eating was still significant [*estimate* = 0.25, $p < 0.001$, CI (0.14, 0.33)] suggesting that the indirect effect of restrictive feeding only partially accounts for the association between maternal and child emotional eating. There were no other significant indirect effects for mothers. However, there was a significant, positive association between maternal emotion regulation feeding and parent-reported child emotional eating ($\beta = 0.32$, $p < 0.001$). The total effect of maternal emotion eating on child emotional eating was also significant [*estimate* = 0.27, $p < 0.001$, CI (0.15, 0.36)].

For fathers, there were significant indirect effects for emotion regulation (standardized effect = 0.10), instrumental (standardized effect = 0.08), and restrictive (standardized effect = 0.07) feeding practices. The bootstrapped unstandardized indirect effects were 0.09 [CI (0.01, 0.19), $p < 0.05$], 0.08 [CI

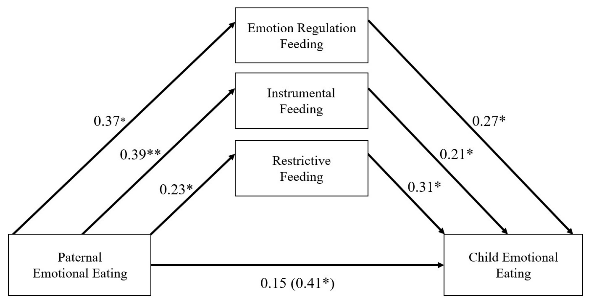

FIGURE 3 | Standardized regression estimates for father's conditional effects. *$p < 0.05$, **$p < 0.001$. Covariates included parent stress, parent negative affect, child age, and child gender on all model paths.

TABLE 5 | Results for conditional indirect effects by parent sex.

	Fathers (*N* = 86)			Mothers (*N* = 324)		
Feeding practice (CFPQ)	**Effect**	***SE***	**95% CI**	**Effect**	***SE***	**95% CI**
Emotion regulation	0.10 (0.09)	0.05	[0.01, 0.19]	−0.01 (−0.01)	0.02	[−0.04, 0.02]
Instrumental	0.08 (0.08)	0.04	[0.01, 0.16]	<0.01 (<0.01)	0.01	[−0.00, 0.01]
Restrictive	0.07 (0.06)	0.04	[0.01, 0.15]	0.03 (0.02)	0.01	[<0.01, 0.05]

CFPQ, Comprehensive Feeding Practices Questionnaire; SE, standard error; CI, confidence interval. Standardized coefficients are reported for indirect effects. Bias-corrected bootstrapped, unstandardized indirect effects are reported in parentheses. Bootstrapped standard errors and confidence intervals are presented (bootstrap sample = 10,000).

(0.01, 0.16), $p < 0.05$], and 0.06 [CI (0.01, 0.15), $p < 0.05$], respectively. Fathers with high levels of emotional eating reported greater use of emotion regulation ($\beta = 0.37$, $p < 0.001$), instrumental ($\beta = 0.39$, $p < 0.001$), and restrictive ($\beta = 0.23$, $p < 0.001$) feeding practices. In turn, greater use of emotion regulation, instrumental, and restrictive feeding practices in fathers was associated with significantly greater parent-reported child emotional eating ($\beta = 0.27$, $\beta = 0.21$, $\beta = 0.31$, respectively, $p < 0.05$). Further, the direct effect for fathers was no longer significant after accounting for these indirect effects [*estimate* = 0.15, $p = 0.17$, CI (−0.06, 0.33)] indicating that these indirect effects through paternal feeding practices fully account for the association between paternal and child emotional eating. The total effect of paternal emotion eating on child emotional eating was statistically significant [*estimate* = 0.41, $p < 0.05$, CI (0.15, 0.57)].

DISCUSSION

Parent-Child Emotional Eating and Feeding Practices in the Full Sample

The current study examined the role of various feeding practices in the association between parent emotional eating and child emotional eating, and explored how the indirect effect of these feeding practices differed according to parent gender. This study builds upon the previous literature by being the first to simultaneously compare the indirect effects of these common parental feeding practices in the association between parent and child emotional eating during middle childhood. Further, results from the current study can be used to inform future parenting interventions aimed at reducing child emotional eating behaviors by documenting important differences between mothers and fathers in the influence of parent emotional eating and feeding practices on child emotional eating.

In the full sample, including both mothers and fathers, results from aim 1 suggest the positive association between parent emotional eating and child emotional eating may be partially explained by higher levels of restrictive feeding, above and beyond the effect of emotion regulation and instrumental feeding practices, which have also been found to relate to both parent and child emotional eating separately (e.g., Rodgers et al., 2014; Powell et al., 2017). However, follow up analyses revealed that results differed by parent gender, suggesting interpretations of the influence of parental feeding practices in the association between parent and child emotional eating should occur separately for mothers and fathers. Specifically, results from exploratory aim 2 showed that the role of parental feeding practices in the association between parent-child emotional eating does vary by parent gender. These results provide initial evidence that there may be different models of how parent emotional eating and feeding influence child emotional eating for mothers and fathers, and highlights the importance of continuing to explore differences in parent-child eating and feeding behaviors by parent gender in future investigations.

Maternal Emotional Eating and Feeding Practices on Child Emotional Eating

The results for mothers are similar to the results from the first aim with the combined sample of mothers and fathers. This is likely because mothers are overrepresented in the full sample which biases the results toward the effects for mothers. Among mothers, greater restriction of children's food intake partially accounted for the positive association between maternal emotional eating and child emotional eating, above and beyond the effect of emotion regulation and instrumental feeding. Mothers who engaged in higher levels of emotional eating were more likely to use restrictive feeding practices; greater restrictive feeding was then positively associated with higher levels of emotional eating in their children. There were no other significant indirect effects of feeding practices in the association between mother-child emotional eating. This is in contrast with previous research suggesting emotion regulation feeding does significantly influence the association between parent and child emotional eating (Rodgers et al., 2014; Tan and Holub, 2015), and studies that document significant associations between instrumental feeding, and maternal emotional eating (Wardle et al., 2002) and child emotional eating (Rodgers et al., 2013, 2014).

These contradictory results could be due to differences in child age among samples. For example, many studies investigating mother-child emotional eating behaviors include mothers of preschool-aged children or younger (e.g., Wardle et al., 2002;

Rodgers et al., 2014), whereas the current study aimed to examine parent emotional eating, feeding practices, and child emotional eating during middle childhood. It may be that parent feeding practices differentially influence the relation between parent and child emotional eating based on the developmental stage of the child. In a study of children ages 2–10 years-old, researchers failed to find a significant indirect effect of restrictive feeding due to a non-significant effect between maternal emotional eating and restrictive feeding practices, however, there was still a significant association between maternal use of restriction and child emotional eating (Kröller et al., 2013). The current sample included parents of school-aged children (ages 5–13) in which there was a significant, positive correlation between maternal emotional eating and restrictive feeding. It is theoretically possible that the association between maternal emotional eating and restrictive feeding strengthens as their children get older, especially if their children are openly engaging in emotional eating. If mothers are repeatedly observing their children overeat in emotional situations, they may be more likely to attempt to restrict their food consumption due to concerns about weight gain. More use of maternal restriction, in turn, can increase children's consumption of restricted foods which are more likely to be energy-dense foods (Fisher and Birch, 1999) and interfere with children's awareness of internal hunger cues (Jansen et al., 2012). This increased preference toward energy-dense foods is also associated with higher levels of emotional eating in children (Nguyen-Michel et al., 2007). More research is necessary to elucidate how different periods of child development and other mechanism influence the association between maternal emotional eating, feeding practices, and child emotional eating. Future studies should aim to explore how these associations differ for children of different ages and reproduce these results in longitudinal studies that can determine the direction of these effects.

Although there was a significant indirect effect of restrictive feeding, greater maternal emotional eating was still directly associated with higher levels of child emotional eating, even after accounting for maternal use of all three feeding practices. This direct effect was not significant for fathers. Numerous studies have documented a direct association between mother and child emotional eating (e.g., Elfhag et al., 2010; Kröller et al., 2013; Rodgers et al., 2014), with one finding that mothers' emotional eating had a stronger influence on child emotional eating compared to fathers' (Snoek et al., 2007). Previous literature suggests that this direct effect from mother to child emotional eating could be explained by modeling (Morrison et al., 2013); children who observe their mothers eating in response to emotional stimuli may do the same when they experience emotional cues themselves. There is evidence to suggest that mothers are more likely to take primary responsibility for feeding their child (Blissett et al., 2006), so it is possible that this effect of maternal modeling is due to mothers spending more time with their child. However, other studies have shown that fathers are now spending more time with their children (Feinberg, 2003) and reporting more responsibility for feeding their child (Mallan et al., 2014) than in the past. Since traditional gender roles and responsibilities have evolved in recent decades (see Bianchi, 2000), mothers may no longer be spending more time with their child or taking primary responsibility for feeding compared to fathers. Thus, there may be alternative factors that can explain the direct effect between mother-child emotional eating that was not present for fathers. In particular, previous research has demonstrated that the direct effect between maternal and child emotional eating may be influenced by maternal psychopathology. Extant studies show that child emotional eating is influenced by maternal anxiety and distress (Kidwell et al., 2017), maternal attachment anxiety (Hardman et al., 2016), and maternal depression, anxiety, and stress (Rodgers et al., 2014). While the current study controlled for maternal negative affect and stress in path models, other aspects of maternal psychopathology may explain the direct effect between maternal and child emotional eating. Further, in the current study, maternal emotion regulation feeding was positively associated with child emotional eating even though the indirect effect was non-significant. Thus, a reciprocal or bidirectional effect is possible, such that mothers use emotion regulation feeding to regulate their child's emotions because they have observed their child using food to cope with their emotions and believe it is an effective coping strategy, instead of or in addition to mothers' own emotional eating driving the use of emotion regulation feeding. Future research in this area should aim to examine mechanisms that could explain the link between mother and child emotional eating (e.g., maternal psychopathology, feeding responsibility), and reproduce this direct effect between maternal and child emotional eating in longitudinal studies with multi-method assessments to fully understand how these processes operate.

Paternal Emotional Eating and Feeding Practices on Child Emotional Eating

In contrast to the results for mothers, there were significant indirect effects between fathers' emotional eating and their child's emotional eating through all three feeding practices. Paternal emotion regulation, instrumental, and restrictive feeding practices fully accounted for the association between father and children emotional eating. Results from the current study show that fathers with higher levels of emotional eating were more likely to report greater use of emotion regulation feeding, which was associated with higher levels of emotional eating in their children. Emotional eating can operate as a successful, although maladaptive, coping mechanism for adults (Spinosa et al., 2019). Thus, fathers who engage in high levels of emotional eating may be more likely to use food to regulate their child's emotional arousal because they believe it is an effective coping strategy and can be used as a simple way to reduce their child's negative emotions immediately. There is some literature to support this indirect effect of emotion regulation feeding between paternal and child emotional eating. In a study of mothers and fathers, researchers reported that emotion regulation feeding practices mediate the association between parent and child emotional eating, but only when children have low self-regulation of eating (Tan and Holub, 2015). Thus, there are likely other factors involved that could further explain the connections among paternal emotional eating, emotion regulation feeding, and child emotional eating. This is a great direction for future research as there are currently limited studies investigating these processes in samples of fathers or examining how these factors differ for mothers compared to fathers in mixed samples.

In the current study, fathers reported significantly greater use of instrumental feeding practices compared to mothers. The results for fathers also demonstrate that the tendency to use food as a means of reinforcing specific children's behaviors (i.e., instrumental feeding) accounts for the association between paternal and child emotional eating. This finding provides initial evidence that using food as a reward or punishment may explain the link between father and child emotional eating. Similar to emotion regulation feeding, fathers who use food to cope with their own negative emotions (i.e., emotional eating) might be more likely to use instrumental feeding practices because they believe food will serve as positive reinforcement. Thus, fathers may use food to regulate their child's behavior since it is an easy and accessible way to solve short-term behavior difficulties (i.e., effective behavior management strategy). It is also possible that fathers use more instrumental feeding practices because they do not perceive their children to be able to successfully regulate their own behaviors. In support of this, previous studies have shown that fathers report lower self-regulation of eating scores for their children compared to mothers (Powell et al., 2017). There may also be child factors involved in the relation among paternal emotional eating, instrumental feeding, and child emotional eating. For example, researchers have suggested that children's own eating self-regulation abilities could explain the link between paternal, and maternal, use of instrumental feeding and child emotional eating (Powell et al., 2017). Since studies have documented significant conditional (Tan and Holub, 2015) and indirect effects (Powell et al., 2017) related to child self-regulation of eating in models of parent-child emotional eating and feeding, further investigations on father-child emotional eating and feeding practices should explore both how parent perceptions and child eating self-regulation abilities influence these processes.

The last significant indirect effect among fathers was for restrictive feeding practices. Similar to the results for mothers, fathers who reported higher levels of emotional eating were more likely to report higher levels of restrictive feeding and emotional eating of their child. However, fathers did report significantly greater use of restrictive feeding practices compared to mothers, and the effect sizes (i.e., standardized path coefficients) among fathers' emotional eating, restrictive feeding, and child emotional eating were higher than those for mothers. This is in line with previous research documenting that fathers are more likely than mothers to use restrictive feeding due to weight-related reasons (Musher-Eizenman et al., 2007). These results are among the first to document a significant indirect effect of restrictive feeding practices between paternal and child emotional eating. There is literature to suggest that paternal body dissatisfaction is related to greater control of children's food intake (Blissett et al., 2006). Thus, it is reasonable to assume that the association between paternal emotional eating and restrictive feeding could be explained by father's own sense of eating attitudes and body image beliefs. For example, fathers who engage in emotional eating and are dissatisfied with their appearance may want to restrict their child's food intake because they are trying to prevent their child from gaining weight and developing similar body dissatisfaction beliefs. This restrictive feeding can lead to increased consumption of high-calorie foods in children (Boots et al., 2015), which is another risk factor for emotional eating in children (Nguyen-Michel et al., 2007). Recent research has also shown that emotion dysregulation can moderate the relation between emotional eating and disordered eating symptoms (e.g., dietary restraint, concerns about eating, shape, or weight) in adults (Barnhart et al., 2021), suggesting that improving parents' emotion regulation skills may weaken the relation between their emotional eating and use of restrictive feeding practices, and subsequently reduce emotional eating in their children. Future studies should aim to identify additional mechanisms (e.g., paternal body image beliefs and emotion regulation, child caloric intake) that could explain the links between paternal emotional eating, restrictive feeding, and child emotional eating.

Overall, the conditional indirect effects for fathers suggest that the use of food to regulate child behavior (i.e., instrumental feeding) or emotions (i.e., emotion regulation feeding) may be more salient for fathers, compared to mothers, when it comes to their child's emotional eating. The present study advances the literature by documenting indirect effects of emotion regulation, instrumental, and restrictive feeding in the association between father's own and their child's emotional eating. Further research is needed to reproduce these findings and further examine the roles of different feeding practices between parent-child emotional eating, especially in fathers. Specifically, future studies in this area should focus on reproducing these exploratory results in balanced parent samples that include both mothers and fathers or samples of only fathers. Additional work could build upon the current results by investigating mechanisms that link paternal emotional eating to feeding practices (e.g., emotion regulation, body dissatisfaction) or those that account for the association between father's feeding practices and their child's emotional eating (e.g., child self-regulation, caloric intake, coping skills).

LIMITATIONS

There are several limitations of the current study that should be noted. First, this study was cross-sectional in nature and utilized all parent-report measures. Thus, it is not possible to determine directionality of any findings. Some researchers have found evidence that parental feeding practices predict later child emotional eating and not the other way around (Steinsbekk et al., 2016). Alternatively, others have argued that the relation between feeding and child emotional eating is bi-directional (Faith et al., 2004), particularly during middle childhood (i.e., children ages 6–10 years; Steinsbekk et al., 2018). Future work in this area should include longitudinal designs with multi-method assessments (e.g., collecting data from multiple informants, in different settings, with a variety of measures) to better understand the direct and indirect effects among parent emotional eating, feeding practices, and child emotional eating. Second, there were many more mothers included in this study compared to fathers. Unbalanced sample sizes can lead to underestimated moderation effects (Stone-Romero and Anderson, 1994). This is less of an issue for the current findings, since results still showed significant moderation effects; however, the exact parameter values could still be underestimated, especially for fathers' indirect effects since there were fewer fathers included in the sample compared to mothers. Third, although previous research has found differences in emotional eating and feeding based on child gender, the current study did not model differences by child gender or parent gender by child gender dynamics as this was not the focus of the study and would likely be underpowered to do so. Fourth, the parent stress measure included as a covariate in this study was only a single, subjective question of general stress rather than a specific parenting stress index as it was the only stress measure available. Future studies should include a more comprehensive assessment of parenting stress that may be more salient for parent emotional eating, feeding and child emotional eating, such as the Parenting Stress Index (Abidin, 1983) or Caregiver Strain Questionnaire (Brannan et al., 1997; see Holly et al., 2019 for more). One last limitation to note is that this was a convenience sample. As a result, the sample included mostly non-Hispanic White participants and no underrepresented gender identities, which limits the generalizability of the results and is not representative the diversity of genders, including 11% of the United States population that doesn't identify with the binary (Wilson and Meyer, 2021). Further, the measure of parent and child gender included in this study was also limited as it did not include the full continuum of gender identities which may have influenced participants to choose a binary option.

CONCLUSION

In sum, the current study contributes to the literature by highlighting putative mechanisms that could explain the relation between parent-child emotional eating behaviors and providing preliminary evidence that these mechanisms should be examined and interpreted differently for mothers and fathers. When considering both mothers and fathers simultaneously, restrictive feeding practices was the only feeding practice to partially account for the association between parent and child emotional eating. However, the current results suggest that patterns of parent emotional eating, feeding, and child emotional eating operate differently when considering the influence of maternal and paternal behaviors separately. Maternal use of restrictive feeding partially accounted for the relation between maternal and child emotional eating, but maternal emotional eating still was significantly associated with child emotional eating. In contrast, paternal use of emotion regulation, instrumental, and restrictive feeding practices fully accounted for the association between father-child emotional eating. Taken together, results suggest that restrictive feeding practices may be a key mechanism between parent and child emotional eating for mothers and fathers. These results also suggest that there is a strong direct effect between mother-child emotional eating, but an indirect effect of father's regulation skills (i.e., more use of food to regulate behavior and emotions of their child) between father-child emotional eating. The current study provides initial evidence that fathers' feeding practices may be more salient than mothers' when it comes to the intergenerational transmission of emotional eating. As such, research and intervention efforts aimed at reducing emotional eating in children may benefit from focusing on father's feeding practices (e.g., emotion regulation, instrumental, and restrictive feeding practices), and mother's own emotional eating behaviors, rather than parental feeding practices in general.

DATA AVAILABILITY STATEMENT

The dataset and analysis script generated for this study can be found in the Open Science Framework Repository for this study at the following link: https://osf.io/muzbj/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board of the University of Oregon. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NK, EB, and NG designed the study on which the present analyses were based. EB and NG collected the data. ST analyzed the data and wrote the manuscript. All authors edited drafts and approved the final version.

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Young Children's Eating in the Absence of Hunger: Links With Child Inhibitory Control, Child BMI, and Maternal Controlling Feeding Practices

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This study aimed to gain a better understanding of the associations between young children's eating in the absence of hunger (EAH), inhibitory control, body mass index (BMI) and several maternal controlling feeding practices (food as reward, restriction for health, restriction for weight control). In addition, to more properly assess the relationship between children's and maternal variables, the link between EAH and restriction was explored separately in two directionalities: "child to parent" or "parent to child." To do this, mothers of 621 children aged 2.00–6.97 years (51% boys, $M = 4.11$ years, $SD = 1.34$) filled in a questionnaire with items from validated questionnaires. Structural equation modeling (SEM) was used to analyze the data. The results showed, whatever the directionality considered, a positive association between children's eating in the absence of hunger and their BMI z-scores. Restriction for health and restriction for weight control were differently linked to EAH and to children's BMI z-scores. Namely, low child inhibitory control, food as reward and restriction for health were identified as risk factors for EAH. Restriction for weight control was not linked to EAH, but was predicted by child BMI z-scores. Interventions aiming to improve children's abilities to self-regulate food intake could consider training children's general self-regulation, their self-regulation of intake, and/or promoting adaptive parental feeding practices.

Keywords: parental feeding practices, preschoolers, self-regulation of food intake, executive functioning, restriction, food rewards, structural equation modeling

INTRODUCTION

The prevalence of overweight and obesity in children and adolescents has increased in a large number of countries since the 1980s (GBD 2015 Obesity Collaborators, 2017). World Health Organization (2018) reported that on average almost one in eight children aged seven to eight has obesity in Europe. This is a reason for concern given that childhood obesity has been associated with social, psychological, emotional and health effects both in the short and long terms (for reviews see Reilly et al., 2003; Pulgarón, 2013; Kelsey et al., 2014;

Rankin et al., 2016). Stimulating healthy eating habits from an early age could be an important way to prevent overweight and obesity in children, especially as it is known that eating habits established during childhood can persist into adolescence and adulthood (Nicklaus and Remy, 2013).

Young children are believed to have an innate capacity to self-regulate their food intake, by following their internal signals of hunger and fullness (e.g., Birch and Deysher, 1986). As they grow older, environmental factors, such as inappropriate portion sizes, the availability of energy-dense foods and parental controlling food practices could divert children from their internal signals and could cause them to overeat, resulting in an increased risk of weight gain (Birch et al., 2003; Fisher and Kral, 2008; Kral et al., 2012; Frankel et al., 2014; Monnery-Patris et al., 2019). Many studies have examined how the use of controlling feeding practices, in particular restriction and pressure to eat but also food as reward, influences child eating behaviors (e.g., Johnson and Birch, 1994; Fisher and Birch, 2002; Remy et al., 2015; Powell et al., 2017). Overall, the results of these studies indicated a counterproductive effect of these practices as they were linked to or resulted in less adaptive child eating behaviors.

Not only environmental factors, but also children's temperamental traits play a role in their ability to self-regulate food intake and their weight status. Inhibitory control is an executive functioning process that has been studied extensively in relation to eating behaviors. Inhibitory control refers to the ability to inhibit a dominant behavior or to engage in behavior required for an activity (Posner and Rothbart, 2000). A wide variety of methods exist to measure children's inhibitory control: both behavioral tasks (e.g., general or food-specific Go/No-Go task, Stroop test, Stop signal task, Peg tapping task) and scales such as the Children's Behavior Questionnaire (Rothbart et al., 2001) and its variants. In previous studies with children and adolescents, a lower inhibitory control has been linked with binge eating behaviors (Ames et al., 2014; Kittel et al., 2017), higher increases in food enjoyment and food responsiveness (Groppe and Elsner, 2015), lower abilities to self-regulate intake (Tan and Holub, 2011), and a higher body mass index (BMI) or more weight problems (e.g., Nederkoorn et al., 2006, 2012; Graziano et al., 2010; Houben et al., 2014).

An eating behavior reflecting self-regulation of intake that is of interest in relation to children's weight status is "eating in the absence of hunger" (EAH). EAH refers to children's susceptibility to eating when satiated if presented with palatable energy-dense foods (Cutting et al., 1999; Fisher and Birch, 2002), and has been associated with increased energy intake (Fisher and Birch, 1999; Birch and Fisher, 2000) and weight status (Fisher and Birch, 2002; Kral et al., 2012; Monnery-Patris et al., 2019). EAH has originally been measured in laboratory settings where children have *ad libitum* free access to foods after a meal and after having reported they were full. EAH referred to the energy intake (number of calories) consumed during the free-access session (Fisher and Birch, 1999). This paradigm is, however, costly and time-consuming, and the ecological validity of the paradigm has been questioned (Madowitz et al., 2014). As a response to these challenges, several questionnaires have been developed to measure EAH in a less costly and more efficient way, and to facilitate longitudinal studies. For example, the Eating in the Absence of Hunger Questionnaire for Children and Adolescence (EAH-C; Tanofsky-Kraff et al., 2008), a self-report for youth aged 6–19 years, and a parallel version for parents (EAH-P; Shomaker et al., 2013) have been proposed for English-speaking populations. A French questionnaire for parents has been developed to measure the degree of EAH in children aged 1–5 years (Monnery-Patris et al., 2019). Another concept that is of interest in relation to children's weight status is their appetite (Carnell and Wardle, 2008; Godefroy et al., 2016). Appetite is usually defined as a desire for food, and children with a low appetite usually have a lower weight than children with a high appetite (e.g., Lee and Song, 2007).

Some studies have already investigated possible links between EAH, and the previously mentioned environmental (parental controlling feeding practices) and temperamental factors (inhibitory control). For instance, Rollins et al. (2014) observed that the link between parental controlling feeding practices and EAH was moderated by girls' level of inhibitory control: more parental restriction for snacks was associated with higher increases in EAH from age 5 to 7 years, but only in girls with a lower inhibitory control. In a longitudinal study with assessments at age 5, 7, 9, 11, 13, and 15 years, Anzman and Birch (2009) identified parental restriction as a moderator between girls' inhibitory control and their BMI: here, a lower inhibitory control was associated with a higher BMI, and this relation was stronger in the presence of higher parental restriction. However, inconsistent results have been reported in the literature for the links between EAH, weight status and controlling feeding practices, and many questions remain. On the one hand, this might be due to the use of different measures for these constructs, as discussed above for EAH and inhibitory control. Different measures have also been used for studying parental controlling feeding practices. To illustrate, in the Child Feeding Questionnaire (Birch et al., 2001), the dimension "restriction" combines the constructs restriction and food as reward, while the Comprehensive Feeding Practices Questionnaire (Musher-Eizenman and Holub, 2007) contains separate dimensions to refer to food as reward and restriction, and even distinguishes between parental motivations/concerns behind the use of restrictive practices; resulting in the dimensions "food as reward," "restriction for health" and "restriction for weight control." On the other hand, inconsistent results might be found due to differences in authors' hypotheses and the associated statistical models and analyses. In fact, in some studies, parental controlling feeding practices were hypothesized to be the explaining variable, while in other studies they were the explained variable or a moderating variable. Small sample sizes in certain studies could also be problematic (Francis and Riggs, 2018).

Due to its assumed relation with children's weight status, it is crucial to gain a better understanding of factors that are linked to children's EAH. Therefore, this study aimed to assess the relationship between EAH and children's weight status, and to assess variables that could influence EAH in children (see **Figure 1**). More precisely, this study wanted to assess the influence of variables related to children's eating

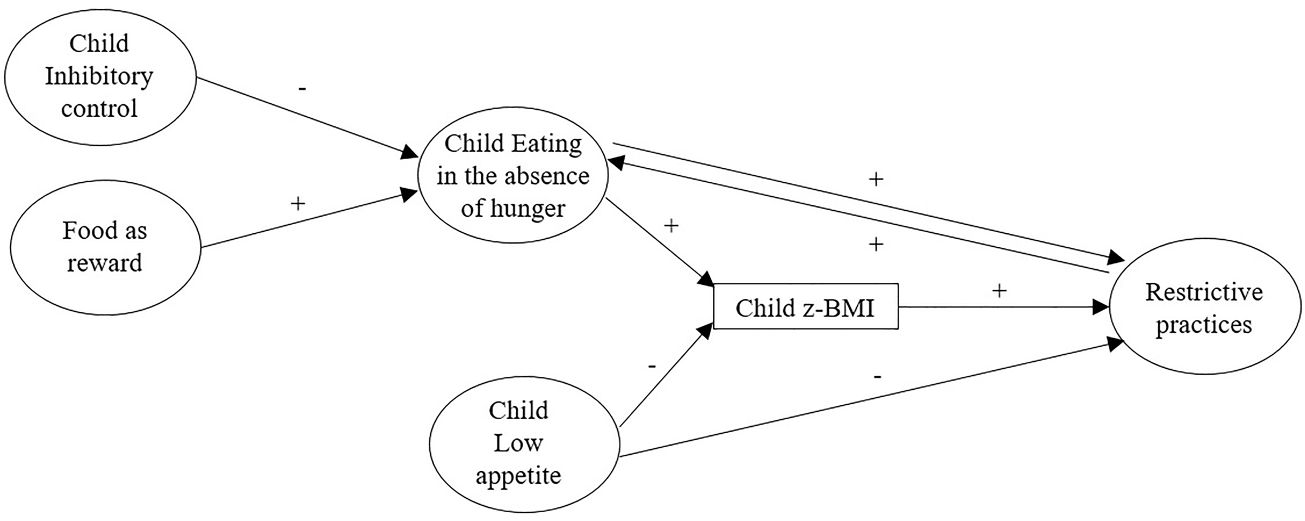

FIGURE 1 | Conceptual model of the study representing the hypotheses. A plus (+) indicates an expected positive relation between constructs, a minus (–) indicates an expected negative relation. The double arrow between eating in the absence of hunger (EAH) and restrictive practices represents two hypotheses that will be tested separately.

behavior, EAH and appetite, on children's BMI z-score, and the influence of child inhibitory control and maternal controlling feeding practices (food as reward, restriction for weight, and restriction for health) on EAH. In previous literature, maternal restriction has been considered as a cause (Birch et al., 2003) or a consequence (Tan and Holub, 2011) of children's EAH/self-regulation of eating. Therefore, to take into account these possibilities, both directionalities were considered in this study: an effect of "parent to child," or of "child to parent."

It was hypothesized, based on previous studies, that higher levels of EAH and appetite would be linked to higher BMI z-scores in children (e.g., Carnell and Wardle, 2008; Monnery-Patris et al., 2019), and that a lower inhibitory control in children (Nederkoorn et al., 2006, 2012), a higher use of food as reward (Remy et al., 2015), of restriction for health and of restriction for weight control in mothers (Birch et al., 2003; Tan and Holub, 2011) would be linked to higher levels of EAH in children.

MATERIALS AND METHODS

Participants' Recruitment and Procedure

The recruitment of participants took place as part of a project whose overall aim was to study parental feeding practices and their links with child eating behaviors in France, and which encompassed several research objectives (see, e.g., Philippe et al., 2021). Caregivers were recruited *via* daycare centers and preschools in France, with the use of social media (Facebook, Twitter) and through an internal database (ChemoSens Platform's PanelSens, CNIL no.1148039). They were invited to complete a hard copy version of the questionnaire or the online version, available on the platform SurveyMonkey. For the study presented in this article, all caregivers fulfilling a mother role for a child aged 2–6 years were eligible to participate. They were informed that their participation was voluntary and without compensation. An ethical approval (n°19–591) was granted for the large project by the Institutional Review Board (IRB00003888, IORG0003254, and FWA00005831) of the French Institute of Medical Research and Health, and a study registration was done by the data protection service involved (CNRS).

Measures

Questionnaires were used to collect data because of several reasons. First of all, they can be used easily in large-scale studies: to recruit a high number of people that are living in different areas. Moreover, a questionnaire may be more relevant than a laboratory setting, since it allows to take into account not only the eating behavior and adjustment of intake during one meal (i.e., short-term compensation), as in experimental settings, but also the pattern over a time period that is longer than just one meal. The same is true for children's temperament/behavior and parental feeding practices. For this study, questionnaires were selected that were already validated in French for parents of young children.

Child Eating Behaviors

Low Appetite

The child's low appetite was measured with three items of the Children's Eating Difficulties Questionnaire (CEDQ; Rigal et al., 2012). Mothers had to rate their agreement with each of the items [e.g., *My child eats small quantities (even if the food is liked)*] on a five-point Likert scale ranging from (1) "Strongly disagree" to (5) "Strongly agree." All items are presented in **Table 1**. A score was calculated for each child by averaging the scores on the three items; a higher score indicated a lower appetite.

TABLE 1 | Cronbach's alphas for dimensions and final item loadings in confirmatory factor analyses (CFA).

Items and related dimensions	Loading
Dimensions concerning the children	
Appetite[a] (Cronbach's alpha = 0.85)	
app1. My child eats small quantities (even if the food is liked).	0.77
app2. My child is a small eater (whatever is served, bad or good).	0.86
app3. My child has a big appetite. (Reversed item)	0.95
Eating in the absence of hunger[e] (Cronbach's alpha = 0.66)	
eah1. If my child is no longer hungry and I offer him something s/he particularly likes, s/he eats it.[b]	0.65
eah2. If my child is no longer hungry and I offer him something s/he particularly like, s/he takes them in order to have them later.[b] (Reversed item)	Removed
eah3. After s/he has finished his meal, if candies are available and I let him/her, s/he eats it.[b]	0.71
eah4. After s/he has finished his meal, if candies are available and I let him/her, s/he takes them in order to have them later.[b] (Reversed item)	Removed
eah5. If my child is no longer hungry and I offer him something s/he particularly likes… (*Tick your answer*)[c]	0.69
eah6. After s/he has finished his meal, if candies are available and I let him/her… (*Tick your answer*).[d]	0.73
Inhibitory control[f] (Cronbach's alpha = 0.66)	
ic1. My child can easily stop an activity when s/he is told "no."	0.64
ic2. My child can wait before entering into new activities if s/he is asked to.	0.82
ic3. My child has trouble sitting still when s/he is told to (at movies, etc.). (Reversed item)	0.42
ic4. My child is capable to follow instructions.	0.61
ic5. My child approaches places s/he has been told are dangerous slowly and cautiously.	0.49
Dimensions concerning the mothers	
Food as reward[b] (Cronbach's alpha = 0.76)	
fr1. I offer my child his/her favorite foods in exchange for good behavior.	0.84
fr2. I withhold sweets/dessert from my child in response to bad behavior.	0.72
fr3. I offer sweets (candy, ice cream, cake, pastries) to my child as a reward for good behavior.	0.85
Restriction for weight control[a] (Cronbach's alpha = 0.75)	
restr.w1. I encourage my child to eat less so he/she will not get fat.	0.76
restr.w2. I give my child small helpings at meals to control his/her weight.	0.85
restr.w3. If my child eats more than usual at one meal, I try to restrict his/her eating at the next meal.	0.71
restr.w4. I restrict the food my child eats that might make him/her fat.	Removed
restr.w5. I have to be sure that my child does not eat too many high-fat foods.	Removed
restr.w6. There are certain foods my child should not eat because they will make him/her fat.	0.72
restr.w7. I do not allow my child to eat between meals because I do not want him/her to get fat.	Removed
restr.w8. I often put my child on a diet to control his/her weight.	0.61
Restriction for health[a] (Cronbach's alpha = 0.71)	
restr.h1. I have to be sure that my child does not eat too many sweets (candy, ice cream, cake, or pastries).	Removed
restr.h2. If I did not guide or regulate my child's eating, s/he would eat too much of his/her favorite foods.	0.72
restr.h3. I have to be sure that my child does not eat too much of his/her favorite foods.	0.63
restr.h4. If I did not guide or regulate my child's eating, he/she would eat too many snacking foods type cookies, bars chips, sugary foods.	0.80

[a]*Answer modalities: five-point scale ranging from (1) "Strongly disagree" to (5) "Strongly agree."*
[b]*Answer modalities: five-point scale ranging from (1) "Never" to (5) "Always."*
[c]*Answer modalities: (1) S/he does not want it, (2) S/he eats a few bites, just to taste it, (3) S/he eats it. Scores have been recoded to (1), (3), (5) to match the scores of items eah1-eah4 (five-point scale).*
[d]*Answer modality: (1) S/he does not take any, (2) S/he takes one or two just to taste them, (3) S/he takes a lot. Scores have been recoded to (1), (3), (5) to match the scores of items eah1-eah4 (five-point scale).*
[e]*Some original items of this dimension and their answer modalities (Monnery-Patris et al., 2019) were modified for this study, aiming to enable more precise answers. The two original items were: eah1: "If my child is no longer hungry and I offer him something s/he particularly likes… (Tick your answer)" with the answer options (1) S/he does not want it, (2) S/he asks if s/he can have it later, (3) S/he eats a few bites, just to taste it, (4) S/he eats it up.; eah2: "After s/he has finished his meal, if candies are available and I let him/her… (Tick your answer)" with the answer options (1) S/he does not take any, (2) S/he takes them in order to have them later, (3) S/he takes one our two just to taste it, (4) S/he takes a lot.*
[f]*Answer modalities: seven-point scale ranging from (1) "Very untrue" to (5) "Very true."*

Eating in the Absence of Hunger

The child's eating in the absence of hunger (EAH) was measured with six items of a recent French questionnaire (Monnery-Patris et al., 2019). Some original items of this dimension and their answer modalities were slightly modified for this study, aiming to enable more precise answers (all items and additional information are presented in **Table 1**). For four items in this study, mothers had to rate their answer on a five-point scale ranging from (1) "Never" to (5) "Always" (e.g., *If my child is no longer hungry and I offer him something s/he particularly likes, s/he eats it*.). For the two other items, mothers had to identify one of the three answer options that best suited their child's behavior: e.g., for the item: "After s/he has finished his meal, if candies are available and I let him/her," they could choose between the options (1) "s/he does not take any," (2) "s/he takes one or two just to taste them," or (3) "s/he takes a lot." The answers to these two last items were recoded to (1), (3), (5) to match the answers of the other items (five-point scale). A score was calculated for each child by averaging the scores on all items; a higher score indicated a higher level of EAH and thus a poorer self-regulation.

Child Inhibitory Control

The child's inhibitory control was measured with five items of the Children's Behavior Questionnaire Short Form (CBQ; original English version: Putnam and Rothbart, 2006; French-Canadian version: Lemelin et al., 2020). Originally, this Short Form contains six items to measure inhibitory control (e.g., *My child can wait before entering into new activities if s/he is asked to.*). Based on feedback from parents who pretested the questionnaire used for the current study, it was decided to delete one item (i.e., *My child prepares for trips and outings by planning things s/he will need.*). Parents declared that this item was not fully adapted to age range of the children in the current study, as the CBQ was developed for children aged 3–8 years while we included children aged 2–6 years in the study. Mothers were asked to rate their agreement with each item on a seven-point scale ranging from (1) "Very untrue" to (7) "Very true," according to their child's behavior. All items are presented in **Table 1**. A score was calculated for each child by averaging the scores on all items; a higher score indicated a higher level of inhibitory control.

Maternal Controlling Feeding Practices

Maternal use of controlling feeding practices was measured with the Comprehensive Feeding Practices Questionnaire (Musher-Eizenman and Holub, 2007). For this study, the practices of interest were restriction for health (four items, e.g., *If I did not guide or regulate my child's eating, he/she would eat too many junk foods*), restriction for weight control (eight items, e.g., *I often put my child on a diet to control his/her weight*), and food as reward (three items, e.g., *I offer my child his/her favorite foods in exchange for good behavior*). All items are presented in **Table 1**. Mothers had to rate their agreement with each item on a five-point scale ranging from (1) "Strongly disagree" to (5) "Strongly agree," or from (1) "Never" to (5) "Always." The psychometric properties of this questionnaire have been demonstrated in French samples (Musher-Eizenman and Holub, 2007; Musher-Eizenman et al., 2009). A score was calculated for each parent for each of the three feeding practices by averaging the scores on the corresponding items; a higher score indicated a higher use of the corresponding controlling practice.

Anthropometric Data

Mothers were instructed to report the most recent measurements from the child's medical health book which were carried out by health professionals. If no recent measurements were available, or if the measurements of height and weight were not carried out within a short time span, mothers were instructed to measure and/or weigh the child in light clothes. Children's BMI (kg/m^2) was calculated and normed BMI z-scores were calculated using French growth standards for children (Rolland-Cachera et al., 1991, 2002). The child's birth date was used for a precise calculation of the child's age.

Statistical Analyses

R version 3.6.1 (R Core Team, 2019) was used to clean and analyze the data. The significance level was set at $p < 0.05$ for all analyses.

Data Cleaning and Preliminary Analyses

Questionnaires of mothers were excluded if the child was not aged 2–6.99 years, if the child was born premature (<37 weeks of gestation), if the child had an illness susceptible of affecting his/her eating behavior (e.g., swallowing problems, food allergies) or if information about one of these aspects was missing. Questionnaires were also excluded if the child's sex was not provided, if a mother already completed a questionnaire for a sibling, or if there was a high number of missing items. This resulted in the exclusion of 389 questionnaires. A total of 621 questionnaires were maintained for the analyses of the present study: 190 hard copies and 431 online copies.

Confirmatory factor analyses (CFA) with a structural equation modeling (SEM) approach (Bollen, 1989; Kaur et al., 2006) were performed to verify the internal consistency of the scales. First, before conducting the CFA's, imputation by predictive mean matching was used to account for missing data of the items of interest (the proportion of missing data was lower than 1% for each item). Then, different CFA measurement models were fitted: one for the child eating dimensions, one for child inhibitory control, and one for the maternal feeding practices. According to the fit indices and the estimated loadings, a few items had to be removed: two items for the dimension EAH, one item for restriction for health and two items for restriction for weight control. Finally, Cronbach's alphas were calculated with the retained items to report the internal consistency of the dimensions; they ranged between 0.66 (EAH; inhibitory control) and 0.85 (appetite). All Cronbach's alphas, final item loadings in the CFAs and removed items are presented in **Table 1**.

Main Analyses

Scores were calculated for child behaviors and for maternal feeding practices by averaging the scores on the corresponding items. Correlations were calculated to explore the links between the dimensions related to maternal feeding practices (food as reward, restriction for health, and restriction for weight control), child's inhibitory control, child's EAH, and child's BMI z-scores. Simple regressions were also performed to study possible effects of child age and sex on children's behaviors and maternal practices.

Thereafter, SEM analyses were conducted to assess the structure between these different dimensions, based on our hypotheses derived from past literature. SEM methodology was chosen because it enables to formulate several hypotheses in a global model and to test if the data are in line with the hypotheses. Following the idea that children's eating behavior influences their BMI z-scores, we hypothesized that EAH (the focus in this study) and appetite would be direct predictors of child BMI z-scores. Then, we assumed that maternal feeding practices (e.g., Birch et al., 2003) and child inhibitory control (Nederkoorn et al., 2006, 2012) could influence children's EAH, but not their appetite since this is considered as a fairly stable eating trait in children (Farrow and Blissett, 2012). In addition, previous studies have pointed out that children's EAH and (maternal perceptions of) their weight status and appetite could also predict maternal restrictive practices (Webber et al., 2010; Tan and Holub, 2011). We thus considered that restriction could be either a cause or a consequence of EAH. Finally, since we expected a stronger link with child BMI z-scores for restriction for weight control than for restriction for health, these two forms of restriction were considered in separated models.

Thus, we ran separate models for restriction for weight control and restriction for health, and two types of models were estimated to take into account the possible different directionalities between EAH and maternal restriction (effects of "child to parent" and of "parent to child"). This resulted in four separate models: (1A) "child to parent" with restriction for weight control, (1B) "parent to child" with restriction for weight control, (2A) "child to parent" with restriction for health, and (2B) "parent to child" with restriction for health.

All SEM analyses were conducted using the R package lavaan 0.6–7 (Rosseel, 2012). All items except child BMI z-score were declared as ordered. For all models, only data of participants without missing child BMI z-score were used. The root mean square error of approximation (RMSEA), the comparative fit index (CFI) and the Tucker–Lewis Index (TLI) were used to evaluate the fit of each model. A low RMSEA and high CFI and TLI indicate a good fit (cut-offs: acceptable fit: 0.08 for RMSEA, 0.95 for CFI and TLI; good fit: 0.05 for RMSEA, 0.97 for CFI and TLI; Schermelleh-Engel et al., 2003). As models 1B and 2B present cyclic structures (with a loop between EAH – z-BMI – restriction – EAH), the R package SEMID_0.3.2 was used to verify if these structures were identifiable. The codes used in R for the SEM analyses can be consulted on Zenodo,[1] together with the data set generated for this study, and the French items used. A metadata file provides information about the published data set and accompanying documents.

TABLE 2 | Mothers' characteristics.

Characteristics	Mothers ($N = 621$)	
	N	**%**
Hard copy/Online participation	190/431	31/69
Age, mean (SD)	35.26 (4.50)	
Weight status[a]:		
Underweight (BMI < 18.5 kg/m^2)	27	4
Normal weight (18.5 ≤ BMI < 25 kg/m^2)	368	61
Overweight (25 ≤ BMI < 30 kg/m^2)	132	22
Obesity (BMI ≥ 30 kg/m^2)	77	13
Level of education:		
No diploma	8	1
A level or a high-school diploma/degree	44	7
Diploma of higher education or 12th grade	77	13
Three-year university degree	122	20
Master's degree or Master 2	225	37
Higher than a Master 2 (PhD, medical studies)	135	22
Work status:		
Working (part-time or full-time)	477	78
Unemployed, job seeker	41	7
Student	9	1
Other (e.g., parental leave, parent at home)	50	14
Perception of financial situation:		
You cannot make ends meet without going into debt	6	1
You get by but only just	37	6
Should be careful	152	25
It's OK	276	46
At ease	135	22

[a]Mothers' height and weight, needed for BMI calculations (kg/m^2), were self-reported.

RESULTS

Participants' Characteristics

Mothers of 621 children aged 2.00–6.97 years (51% boys, mean age = 4.11 years, $SD = 1.34$) participated in this study. The characteristics of the mothers can be found in **Table 2**. According to maternal reports of child weight and height, 11% of children in our sample were underweight (z-BMI < −2), 71% had a normal weight (−2 ≤ z-BMI < 1), 10% were at risk for overweight (1 ≤ z-BMI < 2), 5% had overweight (2 ≤ z-BMI < 3), and 2% had obesity (z-BMI > 3; weight categories according to World Health Organization, 2006). Most children (87%) lived with both parents, 5% of children were in a co-parenting situation, and 8% of children lived with their mother only or with their mother and her partner.

Descriptive Statistics

Mean scores of the study variables, SDs, as well as Spearman correlation coefficients between each other are presented in **Table 3**. Significant positive correlations were observed between the three maternal controlling feeding practices (food as reward, restriction for health, restriction for weight control). EAH of the child was positively linked to food as reward, restriction for health, child BMI z-score, and negatively linked to child inhibitory control. No significant link was observed between EAH and restriction for weight control. Both types of restrictions and child low appetite were significantly linked to the child's BMI z-score.

In addition, the mean scores indicated that restriction for health is a commonly used feeding practice among French mothers of children aged 2–6 years. Food as reward and restriction for weight control are used to a lesser extent.

Furthermore, simple regression analyses indicated that child sex and child age were significant predictors for a number of child behaviors and maternal feeding practices. Girls showed higher levels of inhibitory control than boys ($\beta = +0.31$; $t = 3.86$; $p < 0.001$), and a lower appetite ($\beta = +0.34$; $t = 3.94$; $p < 0.001$). Children's inhibitory control increased significantly with age ($\beta = +0.10$; $t = 3.34$; $p < 0.001$), children showed a lower appetite with age ($\beta = +0.11$; $t = 3.32$; $p < 0.001$), and mothers reported using more food as reward ($\beta = +0.06$; $t = 2.77$; $p = 0.006$) and restriction for weight control ($\beta = +0.05$; $t = 2.39$; $p = 0.017$) with an increasing age of the child.

Structural Equation Models

Four different structural models were evaluated, of which two models included restriction for weight control (model 1A and

[1]https://zenodo.org/record/4436613#.X_8IeuhKi71

TABLE 3 | Spearman correlations, means, and SDs for study variables.

		Variables							Mean (SD)
		1	2	3	4	5	6	7	
Maternal feeding practices:									
Food as reward[a]	1	-							1.68 (0.75)
Restriction for health[a]	2	0.22***	-						3.08 (1.00)
Restriction for weight control[a]	3	0.18***	0.37***	-					1.66 (0.64)
Child behaviors and BMI:									
Low appetite[a]	4	0.05	0.02	−0.05	-				2.52 (1.08)
Eating in the absence of hunger[a]	5	0.18***	0.38***	0.04	−0.07	-			3.10 (0.86)
Child inhibitory control[b]	6	−0.09*	−0.16***	−0.07	0.04	−0.15***	-		5.06 (1.01)
Child BMI z-score	7	0.08	0.10*	0.17***	−0.19***	0.09*	−0.07	-	−0.22 (1.49)

[a]*Answer scale ranges from 1 to 5.*
[b]*Answer scale ranges from 1 to 7.*
**Significance level: $p < 0.05$; ***Significance level: $p < 0.001$.*

1B) and two models included restriction for health (model 2A and 2B). The A-models included the effect of "child (EAH) to parent (restriction)," while the B-models included the effect of "parent (restriction) to child (EAH)." For these models, the data of 541 participants were used (80 children had a missing BMI z-score).

Figures 2, 3 represent the structural part of the models, that is to say the links between the latent variables, respectively, with restriction for weight control and with restriction for health. The corresponding parameters (regressions and covariances) are presented in **Tables 4, 5** for models 1A and 1B, and in **Tables 6, 7** for models 2A and 2B. All models were identifiable and showed an acceptable fit (see footnote **Tables 4–7**), so neither of the two directionalities hypothesized could be rejected.

In all four models, a negative association was found between child inhibitory control and child EAH, meaning that higher levels of inhibitory control were linked to less EAH. Food as reward was also consistently positively associated with EAH. Furthermore, child low appetite was consistently negatively associated with child BMI z-score, and EAH was positively associated with child BMI z-score, except in model 2B (standardized estimate = 0.10; $p = 0.064$).

Figure 2 shows that restriction for weight control was only significantly associated with child BMI z-score: a higher BMI z-score was linked to more restriction for weight control. In contrast, **Figure 3** shows that restriction for health was unrelated to child BMI z-score. While a strong association was observed between restriction for health and child EAH in both the "child to parent" (2A) and the "parent to child" (2B) model (**Figure 3**), restriction for weight control was not significantly associated with EAH. Thus, for restriction for weight control, only an indirect link was observed with child EAH *via* child BMI z-score.

DISCUSSION

Using a large sample of French mothers, this study attempts to unravel the associations between preschoolers' EAH, inhibitory control, BMI z-score and different maternal controlling feeding practices. The SEM models aiming to estimate these associations were so constructed based on the idea that child weight is a result of children's eating behavior, and that children's eating behavior (EAH) is influenced by parental feeding practices and child temperament (Davison and Birch, 2001). In separate models, this study also wanted to take into account the possibility that parental feeding practices are influenced by child eating behavior (Birch et al., 2003; Jansen et al., 2018).

In line with previous studies (Fisher and Birch, 2002; Kral et al., 2012; Monnery-Patris et al., 2019), we observed a significant positive link between children's EAH and their BMI z-scores. This suggests that as early as the preschool period, poorer abilities to self-regulate food intake could be associated with overeating and could represent a risk of weight gain and for overweight or obesity in the longer run. We also observed that children's temperament can play a role in their vulnerability toward difficulties with self-regulation of eating. Previous studies have already linked the children's level of inhibitory control with their eating behavior and self-regulation of intake (e.g., Tan and Holub, 2011), even though the results have sometimes been inconsistent (Francis and Riggs, 2018). Our results seem to confirm that higher levels of inhibitory control could act as a protective factor in relation to eating in the absence of hunger, or vice versa that lower levels of inhibitory control could induce a vulnerability.

The results further indicated that environmental factors, specifically parental feeding practices, were linked to child EAH: both food as reward and restriction for health were significantly positively associated with EAH. One could argue that food as reward is mainly a parent-centered feeding practice; meaning that parents use food rewards in exchange for good behavior of the child, regardless of the child's eating behavior or eating temperament. For restriction for health, we explored the relation with EAH in two directions ("child to parent" or "parent to child"). In both models, and thus both directions, a significant association was observed. These results could suggest a bidirectional relationship, beyond the scope of the present paper, according to which poor self-regulation in the

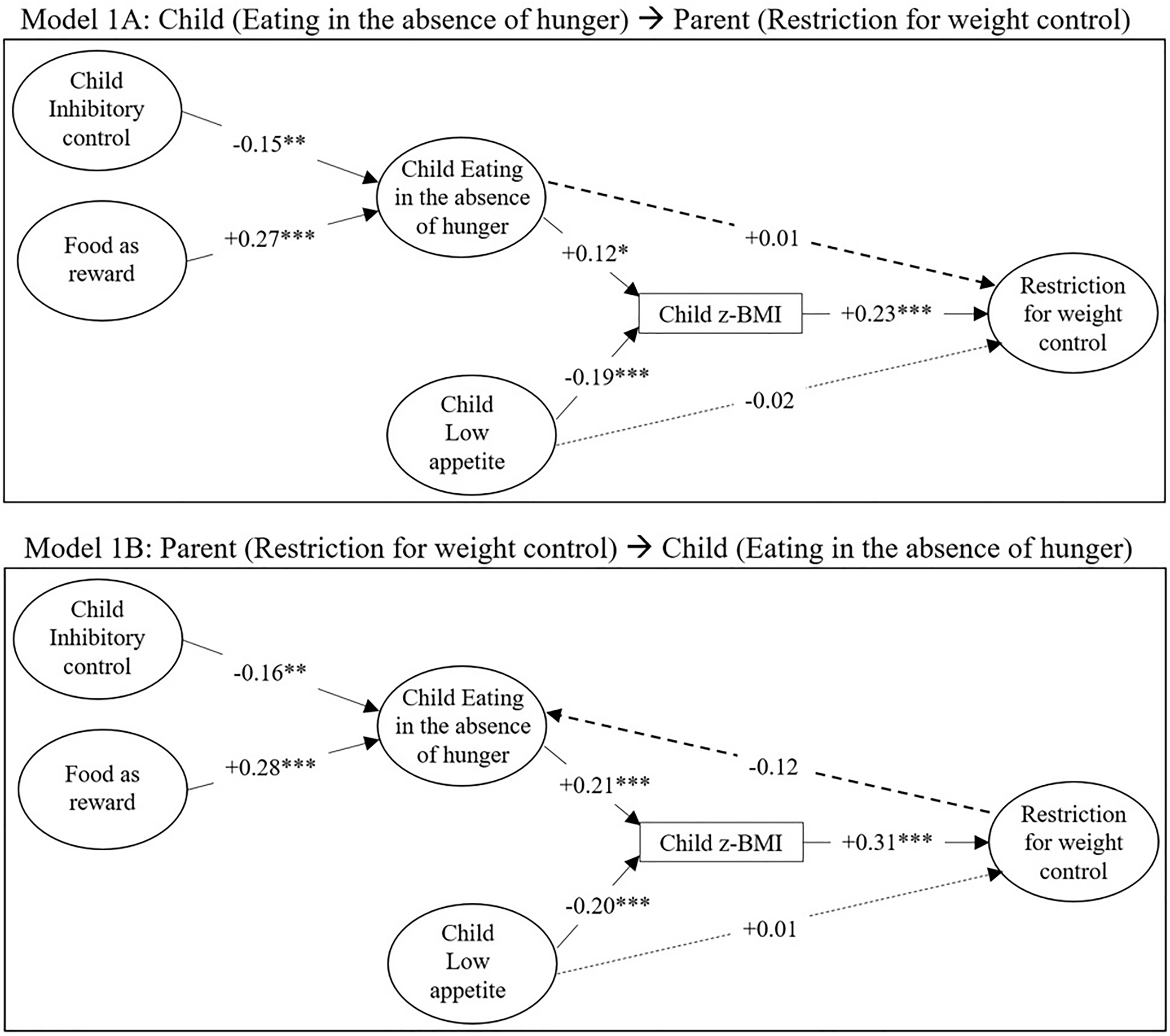

FIGURE 2 | Structural models for the associations between parental feeding practices (restriction for weight control, food as reward), child inhibitory control, child EAH, child low appetite and child body mass index (BMI) z-score. Numbers indicate standardized coefficients, solid lines indicate significant coefficients (* $p < 0.05$; ** $p < 0.01$; and *** $p < 0.001$), and dashed lines indicate non-significant coefficients. The correlations between the exogenous latent variables (food as reward, inhibitory control, low appetite) are not visualized here. Model 1A: model from child's EAH to mother's restriction for weight control. Model 1B: model from mother's restriction for weight control to child's EAH.

child might stimulate parents to impose restrictive measures, which in turn, could reinforce the child's poor self-regulation and divert them from their sensitivity to satiety cues. This bidirectional link was previously already suggested by Bergmeier et al. (2014). Longitudinal studies are, however, needed to further explore these possible bidirectional links between controlling feeding practices and children's self-regulation of eating. For restriction for weight control, no direct link with EAH was observed in this study, only an indirect link *via* child BMI z-scores. Based on this finding, we think that restriction for weight control could be mainly a child-centered practice: this practice could be dominantly implemented by parents based on the child's weight status and parental concerns related to this. Accordingly, Musher-Eizenman and Holub (2007) reported that restriction for weight control was significantly linked with parental concerns about the child being overweight (positive link) and concerns about the child being underweight (negative link). The absence of a link between restriction for weight control and EAH is in line with the results of Tan and Holub (2011), but not with those of Musher-Eizenman and Holub (2006), who found that maternal restriction for weight control significantly predicted preschoolers' EAH. These

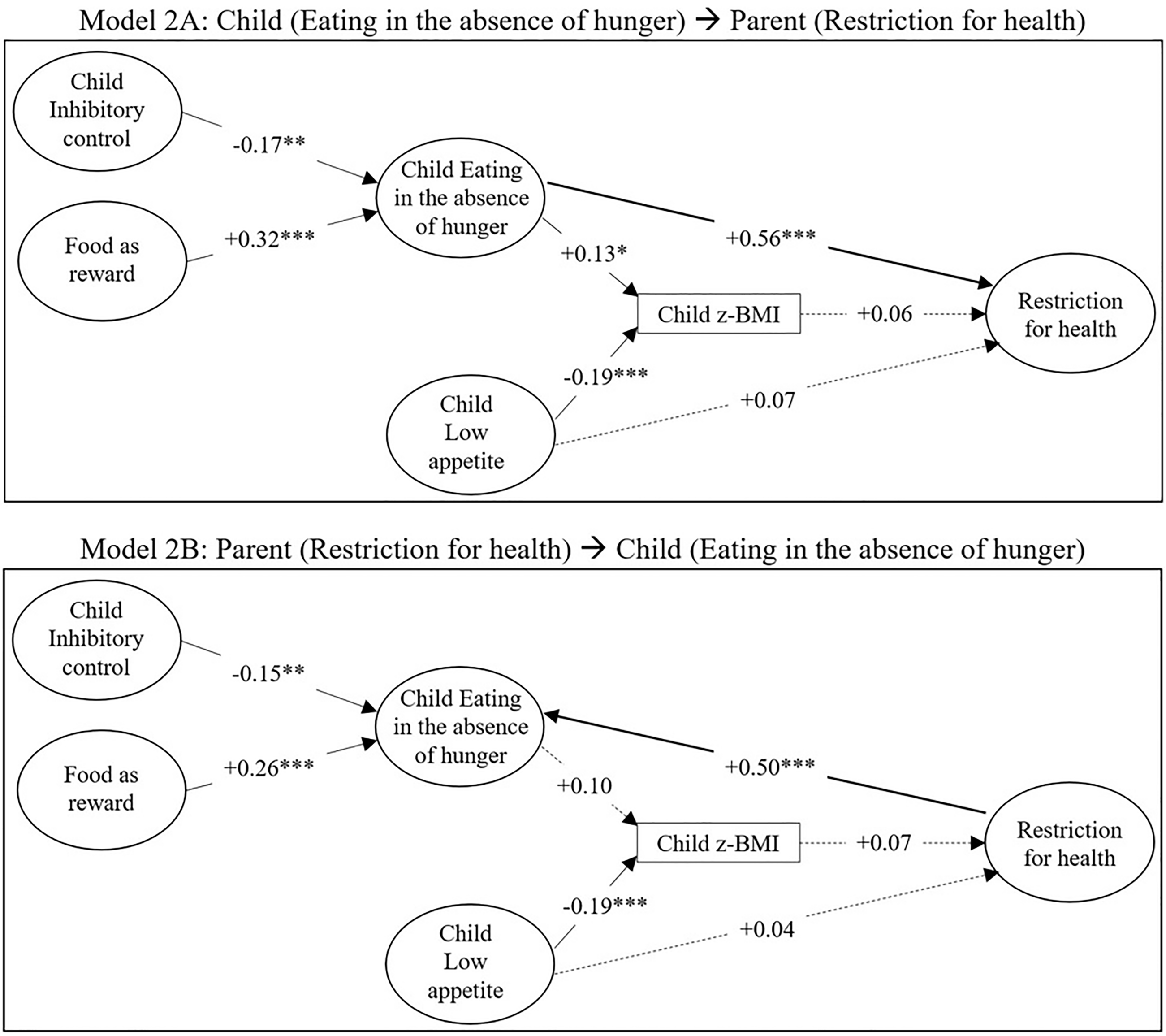

FIGURE 3 | Structural models for the associations between parental feeding practices (restriction for health, food as reward), child inhibitory control, child EAH, child low appetite and child BMI z-score. Numbers indicate standardized coefficients, solid lines indicate significant coefficients (*$p < 0.05$; **$p < 0.01$; and ***$p < 0.001$), and dashed lines indicate non-significant coefficients. The correlations between the exogenous latent variables (food as reward, inhibitory control, low appetite) are not visualized here. Model 2A: model from child's EAH to mother's restriction for health. Model 2B: model from mother's restriction for health to child's EAH.

mixed results could be due to sampling differences, but also due to the use of different measures for children's self-regulation of eating. For this study and the study of Tan and Holub (2011), parent-reported questionnaires were used, while Musher-Eizenman and Holub (2006) used a behavioral external eating task in a childcare center. This could indicate that both types of measures might tap into different aspects of children's self-regulation of eating (Tan and Holub, 2011). Moreover, we found that restriction for health was linked to EAH whereas restriction for weight control was not. Even if we cannot give a definite explanation, it is interesting to mention that the items representing restriction for health tap mainly into the types of foods that are restricted (i.e., unhealthy, well-liked foods), while the items representing restriction for weight control (after the removal of certain items based on the fit indices of the CFA's) tap mainly into the restriction of the amount of the foods (see **Table 1**). In our study, not only the motivations linked to restriction were thus different, but also the type of restriction. This could indicate that limiting the access to certain types of foods has a stronger link with self-regulation of eating than limiting merely the amount of intake of these foods. Accordingly, previous studies found that prohibiting the intake of certain types of foods leads to an increased desire for and consumption of these foods when granted access to Jansen et al. (2007, 2008).

TABLE 4 | SEM model 1A: parameter estimates, SE, *z*-values, value of *p*, and standardized estimates (i.e., completely standardized solutions) for regression parameters, and correlations between exogenous latent variables.

Structural regression coefficients	Estimate	SE	*z*-value	*p*	Std. estimate
Eating in the absence of hunger					
Child inhibitory control	−0.144	0.050	−2.857	0.004	−0.150
Food as reward	0.211	0.044	4.789	<0.001	0.274
Child z-BMI					
Eating in the absence of hunger	0.283	0.113	2.498	0.012	0.120
Low appetite	−0.344	0.079	−4.379	<0.001	−0.189
Restriction for weight control					
Child z-BMI	0.126	0.027	4.740	<0.001	0.234
Low appetite	−0.015	0.048	−0.321	0.748	−0.016
Eating in the absence of hunger	0.009	0.074	0.120	0.905	0.007
Correlations between exogenous latent variables					
	Food as reward	**Child inhibitory control**	**Low appetite**		
Food as reward	-				
Child inhibitory control	−0.113	-			
Low appetite	0.098	0.077	-		

Robust model fit indexes: RMSEA [90% CI]=0.050 [0.044; 0.056], CFI=0.957, TLI=0.950.

TABLE 5 | SEM model 1B: parameter estimates, SE, *z*-values, value of *p*, and standardized estimates (i.e., completely standardized solutions) for regression parameters, and correlations between exogenous latent variables.

Structural regression coefficients	Estimate	SE	*z*-value	*p*	Std. estimate
Eating in the absence of hunger					
Child inhibitory control	−0.149	0.051	−2.929	0.003	−0.155
Food as reward	0.216	0.044	4.892	<0.001	0.281
Restriction for weight control	−0.094	0.050	−1.871	0.061	−0.119
Child z-BMI					
Eating in the absence of hunger	0.475	0.131	3.636	<0.001	0.205
Low appetite	−0.354	0.079	−4.506	<0.001	−0.198
Restriction for weight control					
Child z-BMI	0.166	0.031	5.312	<0.001	0.305
Low appetite	0.013	0.049	0.275	0.783	0.014
Correlations between exogenous latent variables					
	Food as reward	**Child inhibitory control**	**Low appetite**		
Food as reward	-				
Child inhibitory control	−0.113	-			
Low appetite	0.101	0.076	-		

Robust model fit indexes: RMSEA [90% CI]=0.048 [0.042; 0.055], CFI=0.960, TLI=0.953.

Overall, our results seem to indicate that factors on both child and parent levels contribute to children's self-regulation of eating (EAH) and associated weight status, and this already at preschool age. They give rise to the idea that, for children, it could be important to guide them from a very young age in maintaining (or developing) adaptive self-regulation abilities for food intake and to avoid EAH. Parents and schools could play an important role in encouraging children to listen to their inner sensations of hunger and fullness for intake and in modeling these strategies. A limited number of intervention programs exist for children to promote a better self-regulation of eating. They include, for example, appetite awareness trainings, teach concepts of hunger and fullness (e.g., Johnson, 2000; Boutelle et al., 2011; Bloom et al., 2013), or they combine educational materials for parents with an interactive character-based technology platform for the child (Reigh et al., 2020). Some studies also suggest that children could benefit from interventions that train their inhibitory control (e.g., Jiang et al., 2016). However, studies with preschoolers are scarce (e.g., Graziano and Hart, 2016; Lumeng et al., 2017) and with varying results, especially in relation to the food domain (self-regulation of eating) and weight status. More research is needed in this domain. Furthermore, for parents, our results suggest that it is preferable to limit the use of controlling feeding practices, which is in accordance with conclusions in previous studies (Vaughn et al., 2016). In addition to discouraging the use of controlling practices in parents, it could be beneficial to stimulate the use of alternative feeding practices, such as structure-related practices (Rollins et al., 2016; Vaughn et al., 2016). These practices present a certain type of parental control, but in a non-coercive way: they encompass consistent rules and boundaries around eating (e.g., about what, when and where to eat), and are believed to facilitate children's competences and to promote the adoption of healthy eating behaviors (Jansen et al., 2014; Vaughn et al., 2016). They have also been found beneficial for children's self-regulation of eating (Frankel et al., 2018). A certain level of parental control in the form of limits, structure and routines could enable children to act autonomously within these predefined boundaries, which might stimulate them to maintain or adopt adaptive strategies to self-regulate their intake.

LIMITATIONS AND STRENGTHS

Several limitations should be noted for the current study. First, the cross-sectional design limits the results to mere associations. Longitudinal studies are necessary for studying the causality of the relationships. It is worthy to note, though, that this study did not aim to draw conclusions regarding causality between restriction and EAH, but merely wanted to take into account the possibility of a "child to parent" or a "parent to child" effect. Second, maternal controlling feeding practices were self-reported and might be subject to a social desirability bias. Third, child inhibitory control and EAH were not observed directly but were mother-reported, and might thus be influenced by parental beliefs and perceptions. In two studies, mothers were found to rate the self-regulation of eating of their child

TABLE 6 | SEM model 2A: parameter estimates, SE, *z*-values, value of *p*, and standardized estimates (i.e., completely standardized solutions) for regression parameters, and correlations between exogenous latent variables.

Structural regression coefficients	Estimate	SE	*z*-value	*p*	Std. estimate
Eating in the absence of hunger					
Child inhibitory control	−0.157	0.047	−3.306	0.001	−0.174
Food as reward	0.235	0.042	5.530	<0.001	0.323
Child z-BMI					
Eating in the absence of hunger	0.316	0.122	2.593	0.010	0.126
Low appetite	−0.345	0.078	−4.400	<0.001	−0.190
Restriction for health					
Child z-BMI	0.032	0.022	1.472	0.141	0.063
Low appetite	0.062	0.044	1.429	0.153	0.068
Eating in the absence of hunger	0.708	0.082	8.635	<0.001	0.555
Correlations between exogenous latent variables					
	Food as reward	**Child inhibitory control**	**Low appetite**		
Food as reward	-				
Child inhibitory control	−0.114	-			
Low appetite	0.108	0.073	-		

Robust model fit indexes: RMSEA [90% CI] = 0.044 [0.037; 0.051], CFI = 0.972, TLI = 0.966.

TABLE 7 | SEM model 2B: parameter estimates, SE, *z*-values, value of *p*, and standardized estimates (i.e., completely standardized solutions) for regression parameters, and correlations between exogenous latent variables.

Structural regression coefficients	Estimate	SE	*z*-value	*p*	Std. estimate
Eating in the absence of hunger					
Child inhibitory control	−0.137	0.048	−2.848	0.004	−0.149
Food as reward	0.191	0.042	4.549	<0.001	0.258
Restriction for health	0.391	0.049	8.016	<0.001	0.497
Child z-BMI					
Eating in the absence of hunger	0.253	0.137	1.855	0.064	0.103
Low appetite	−0.347	0.078	−4.438	<0.001	−0.191
Restriction for health					
Child z-BMI	0.038	0.028	1.372	0.170	0.074
Low appetite	0.039	0.049	0.797	0.425	0.041
Correlations between exogenous latent variables					
	Food as reward	**Child inhibitory control**	**Low appetite**		
Food as reward	-				
Child inhibitory control	−0.113	-			
Low appetite	0.113	0.072	-		

Robust model fit indexes: RMSEA [90% CI] = 0.059 [0.053; 0.066], CFI = 0.949, TLI = 0.939.

higher than fathers did, suggesting the vulnerability to subjectivity of parent-reports of self-regulation (Frankel et al., 2018; Frankel and Kuno, 2019). Parents might have difficulties to report on aspects of self-regulation of eating because these behaviors reflect children's inner sensations which could be difficult to read. Last, children's weight and height were mother-reported and the researchers did not know if the measurements were performed by health professionals or not. The quality of the measurements could therefore vary. Taken together, these limitations should be kept in mind when interpreting the results of this study. It would be interesting to conduct a study with data gathered at different time points to properly assess the directionality between the parent and child constructs. In addition, it would be preferable to combine observational and declarative measures to cross-validate the measures. It is also good to take into account the fact that a model is always a simplified representation of the relationships between different variables. For the aim of this study, a number of variables were selected in order to discuss how they relate to each other. Obviously, there are other variables (e.g., maternal weight status, sociodemographic variables) that could be of interest in relation to parental practices and child EAH and BMI. These associations could be explored in future studies.

This study also presents a number of strengths. A first and important strength of this study is its large sample size. Second, this study presents results of a French population which expands the results of studies mainly conducted in the United States. Third, distinct dimensions were used for different parental controlling practices (food as reward, restriction for health, and restriction for weight control) which, sometimes, have been used in combined, overarching dimensions in the past, resulting in mixed results. These distinctions enabled us to obtain a better understanding of the relations between these practices and child behaviors and BMI, and clearly showed that these restrictive practices should be studied as separate dimensions. Last, this study is original in its design by combining temperamental and environmental dimensions that could be linked to child self-regulation and BMI, and by exploring possible different directionalities in separate SEM models.

CONCLUSION

In sum, the results of the current study showed a link between young children's self-regulation of eating and their BMI, identifying EAH as a possible risk factor for the development of weight problems. Both temperamental traits (inhibitory control) and environmental factors (maternal controlling feeding practices) were associated with EAH, and restriction for health and restriction for weight control were linked differently to EAH and to children's BMI z-scores. Beyond the scope of this study, we think that interventions could focus on improving children's abilities to self-regulate intake, promoting inhibitory control or promoting adaptive parental feeding practices. It could also be of interest to take on a systemic approach in future interventions in which different actions are combined. These interventions could, for example, propose trainings for children to improve their general and food-related self-regulation.

In addition, trainings could guide caregivers in adopting responsive behaviors to their children's appetite and satiation cues, and in using structure-related parental feeding practices.

This study provided additional insight into the relationships between EAH, BMI, inhibitory control and different maternal feeding practices, but it is important to note that this study focused specifically on maternal feeding practices. Future studies with a large number of fathers are needed to replicate or refute the current results with mothers, as Frankel and Kuno (2019) showed that results regarding the relationship between restrictive feeding practices and children's self-regulation in eating from mother-only samples should not automatically be generalized to all parents.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are publicly available. This data can be found here: https://zenodo.org/record/4436613#.X_8IeuhKi71.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB00003888, IORG0003254, and FWA00005831) of the French Institute of Medical Research and Health. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KP, SI, SM-P, and CC conceptualized the study. KP and CC conducted all analyses. KP is first author, she drafted a first version of the manuscript, SI, SM-P, and CC thereafter contributed to editing the manuscript. All authors contributed to the article and approved the submitted version.

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