CONCEPTUALIZING AND MEASURING APPETITE SELF-REGULATION AND ITS DEVELOPMENT IN INFANCY AND CHILDHOOD

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CONCEPTUALIZING AND MEASURING APPETITE SELF-REGULATION AND ITS DEVELOPMENT IN INFANCY AND CHILDHOOD

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Editorial: Conceptualizing and measuring appetite self-regulation and its development in infancy and childhood

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Editorial on the Research Topic
Conceptualizing and measuring appetite self-regulation and its development in infancy and childhood

Effective self-regulation, including appetite self-regulation (ASR), is important for the healthy growth and development of children (1–3). One of the challenges facing researchers is identifying the theoretical basis for the measurement and conceptualization of ASR. To that end, parent report questionnaires and behavioral/observational measures have been developed and used to examine ASR and its development in childhood. These measures have typically been framed in terms of their relevance to outcomes such as weight gain and obesity rather than conceptually or theoretically.

Without a specific conceptual or theoretical foundation, a consequence is that the interpretation of results about ASR in childhood is often difficult. For example, while laboratory and questionnaire measures of eating in the absence of hunger (EAH) have been identified as predictive of weight in children, it is unclear whether children are more likely to eat in the absence of hunger due to increased attraction to food or to poor regulatory control. Similarly, while difficulty in food delay of gratification (DoG) tasks is linked to food intake and weight, it is uncertain whether this is due to the heightened attractiveness of the food or to poor regulatory control. Furthermore, without a clear theoretical foundation, construct definition, and measurement is more problematic.

The purpose of the Research Topic was therefore to contribute to advances in the conceptualization and measurement of ASR in infancy and childhood. One of the themes that emerged from the Research Topic collection centered around the bottom-up, top-down (dual process) theoretical model, where ASR is conceived in terms of bottom-up reactivity to food and hunger cues together with top-down regulatory control.

Although using different measures, several authors drew on this framework to conceptualize ASR and its measurement.

The model was applied by Harris et al. who measured food responsiveness (pertaining to bottom-up reactivity) and temperamental regulation (pertaining to top-down regulatory control). They found that mothers used more food to soothe at 6 months for infants lower in regulation and higher in food responsiveness, that is, infants who displayed characteristics already suggestive of ASR difficulties. Stein et al. also used the bottom-up, top-down theory and added a distinction between general self-regulation, appetite regulation, and appetite self-regulation. They used a novel food delay of gratification task (pre-feed and mid-feed delay) with infants at 2, 8, and 16 weeks, with measures of infant distress and subsequent milk consumption. Components of general self-regulation, appetite regulation, and appetite self-regulation (especially the bottom-up food approach) were drawn on in the interpretation of the results. A significant aspect of this research is that it considers elements of emergent eating behavior regulation.

Reigh et al. describe a protocol for a study that will examine the relationship between biological, cognitive, and psychological factors and children's (4.5–6 years of age) ASR. In particular, they will investigate the influence of food form on intake in short-term energy compensation, which they argue is a proxy indicator of energy intake self-regulation. Overall, the research is informed by a dual (bottom-up, top-down) process model of ASR developed by the authors. They postulate several bottom-up and top-down influences and measures, some of which will be included in the research. The model incorporates food DoG, EAH, and energy compensation as components of ASR.

EAH was the focus of Hohman et al. Preschoolers from three classrooms completed both classroom and individual EAH tasks. The results suggested that EAH performs similarly in classroom and individual settings, indicating that the classroom protocol could be a viable alternative approach. The authors provide a helpful conceptual analysis of EAH processes, including possible increased bottom-up sensitivity and reactivity to food cues, and/or reduced top-down regulatory capacities together with a poorer ability to recognize internal satiety cues.

A second theme of the Research Topic was about relationships between questionnaires and behavioral or observational measures. Papaioannou et al. reviewed the evidence on this question and found that studies comparing questionnaire measures of ASR with other questionnaire measures showed the most evidence of significant associations, whereas studies comparing questionnaire measures with observational tasks mostly showed weak significant associations or none at all. Questionnaire measures seemed to be more associated with BMIz than behavioral measures. The results of their review raise fundamental questions about definitions of ASR-related constructs, their measurement, and their relationships. For instance, the authors note that the questionnaire measures are described as "traits", whereas observational measures are more likely to be state-based or even as a measure of processes or skills (as the authors suggest could apply to the EAH protocol).

Consistent with the evidence from the Papaioannou et al. review, Hohman et al. found no relationships between EAH and parent-rated emotional overeating, enjoyment of food, and food responsiveness from the Children's Eating Behavior Questionnaire (CEBQ). They suggested that the CEBQ scales are about eating behaviors in general whereas the EAH measures behavior in a specific situation. Giuliani and Kelly also refer to the low convergence between survey and behavioral measures, in this case in relation to Executive Function (EF). These results in the Research Topic are similar to other findings about traits (questionnaire/self-report) vs. behavioral measures of self-control (4, 5). Papaiouannou et al. argue for more multi-method studies in recognition of the apparent multi-dimensional nature of ASR constructs in childhood.

Giuliani and Kelly contribute to questions about the conceptualization of DoG measures by investigating possible underlying processes in the food DoG task. They examined relationships between two food DoG tasks (snack delay and tongue task) and six cognitive measures that have been suggested to be implicated in top-down regulatory control (such as the Flanker task and Go/NoGo tasks). The cognitive measures were more consistently correlated with performance on the tongue task than the snack delay task. The authors raise the question of whether different DoG tasks could rely on separate underlying cognitive processes.

A third theme that emerged from the Research Topic was the contributions of variable-centered vs. person-centered approaches. As discussed by Russell et al., person-centered approaches can provide new insights and perspectives on ASR in childhood, especially in relation to fundamental processes and the components of ASR. This is achieved by identifying subgroups of children with different behavioral/psychological profiles on ASR and related measures, using latent class/latent profile analyses. For example, ASR difficulties in some children could arise from increased bottom-up reactivity to food cues, in other children from a limited top-down regulatory capacity, and in some children from a combination of bottom-up and top-down factors. Potential subgroups can be identified from cross-sectional data as well as from developmental trajectories. Person-centered approaches also facilitate analysis of the role of co-variates such as parent and family variables in ASR and its development. The importance of identifying subgroups in this way is founded partly on the evidence of very large individual differences in measures of ASR and trajectories of weight gain and obesity.

Russell et al. also applied a person-centered approach to describe appetitive trait trajectories across infancy and related those trajectories to infant and parent characteristics to understand emergent ASR. The authors used a group-based multi-trajectory analysis. Three multi-trajectory phenotype groups were identified. For example, the first group was described as food avoidant tending to a low food approach over time. The authors argued that the trajectories have their origins in both infant and parent characteristics as well as parent behavior and cognitions. They suggest that for some infants, difficulties in ASR emerge early in life.

Francis et al. also took a person-centered approach. They measured behavioral self-regulation (BSR) (e.g., teacher reports of inhibitory control and impulsivity) and ASR-related traits (parent reports of food approach and food avoidance traits). Latent profile analysis yielded four profiles, two described as discordant across BSR and ASR and two as concordant. For example, a concordant profile involved higher levels of BSR (e.g., higher inhibitory control and lower impulsivity) and ASR (e.g., higher food avoidance and lower food approach). Parents in the latter profile reported parenting practices with the highest levels of child control in feeding and the lowest levels of parental pressure to eat. These results show how a person-centered approach can yield insights into the processes and components of ASR in childhood as well as possible relationships with parenting practices (whether parent-to-child influence or child-to-parent influence).

Overall, the Research Topic supports a need for increased efforts to develop conceptual frameworks that will assist in constructing a definition and from there possibly even new approaches to measurement. The three main themes that emerged were around (i) the applicability of the top-down/bottom-up (dual process) model to understanding ASR, (ii) the limited convergence of questionnaire/self-report and behavioral/observational measures, and (iii) the value of both person-centered and variable-centered approaches to research. In proposing the original aims for the Research Topic, an area we noted was biological and neurological processes in ASR [e.g., (6–8)]. A limitation of the Research Topic is that, outside elements raised by Giuliani and Kelly, this aspect was not featured. This aside, insights gained into the conceptualization and measurement of ASR in childhood from the nine articles in this collection provide a basis for future scholarship on not only conceptualizing and measuring ASR but also the examination of influences on typical and atypical ASR development.

Author contributions

CR and AR contributed equally to conceptualization and writing of the editorial. CR and AR 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.

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Conceptualizing and Measuring Appetite Self-Regulation Phenotypes and Trajectories in Childhood: A Review of Person-Centered Strategies

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This review uses person-centered research and data analysis strategies to discuss the conceptualization and measurement of appetite self-regulation (ASR) phenotypes and trajectories in childhood (from infancy to about ages 6 or 7 years). Research that is person-centered provides strategies that increase the possibilities for investigating ASR phenotypes. We first examine the utility of examining underlying phenotypes using latent profile/class analysis drawing on cross-sectional data. The use of trajectory analysis to investigate developmental change is then discussed, with attention to phenotypes using trajectories of individual behaviors as well as phenotypes based on multi-trajectory modeling. Data analysis strategies and measurement approaches from recent examples of these person-centered approaches to the conceptualization and investigation of appetite self-regulation and its development in childhood are examined. Where relevant, examples from older children as well as developmental, clinical and educational psychology are drawn on to discuss when and how person-centered approaches can be used. We argue that there is scope to incorporate recent advances in biological and psychoneurological knowledge about appetite self-regulation as well as fundamental processes in the development of general self-regulation to enhance the examination of phenotypes and their trajectories across childhood (and beyond). The discussion and conclusion suggest directions for future research and highlight the potential of person-centered approaches to progress knowledge about the development of appetite self-regulation in childhood.

Keywords: phenotypes, appetite regulation, mixture models, developmental trajectories, latent class analysis, unobserved (or underlying) heterogeneity, eating behavior, child

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INTRODUCTION

In current food environments, where there is an abundance of palatable but unhealthy foods, it is important that children are able to self-regulate appetite. Appetite self-regulation (ASR) means that children are better able to resist tempting but unhealthy foods, better balance energy intakes with expenditure and select and consume healthier diets. The conceptualization and measurement of children's ASR is an emerging field and new approaches are needed. The recent application of person-centered approaches to research on children's eating and ASR provide new perspectives and insights and is the focus of the present review.

There has been some vagueness and uncertainty about definitions of ASR in childhood, including its components and fundamental processes. A number of theoretical models together with potentially relevant constructs are evident in the literature. There is a general acceptance that ASR has to do with responding to hunger cues as well as to cues of satiety and satiation (1, 2). Satiation and satiety have been conceived as separate but overlapping processes. Satiation leads to the termination of eating while satiety is a post-consumption process that leads to the inhibition of further eating and is an ingredient in the inter-meal interval (3–6). Beyond that, it has been variously treated as a multidimensional construct that includes traits (e.g., food responsiveness or satiety responsiveness), processes [e.g., as in the Satiety Cascade (4, 7)] and individual skills or strategies (e.g., delay of gratification) (8). Many of the traits have been associated with the subscales of the Children's Eating Behavior Questionnaire (CEBQ). This scale includes food approach behaviors such as food responsiveness (e.g., child is attracted to food and eating) and food avoidance behaviors such as satiety responsiveness (e.g., child gets full easily and leaves food on his/her plate) (9). The Satiety Cascade is a model that involves pre-consumption processes (such as hunger cues and food responsiveness), processes during consumptions such as satiety and habituation, and post-consumptions processes such as satiety cues.

The conceptualization of ASR has been assisted by the application of overall models such as the bottom-up, top-down model (10–12) or dual processing model (13) and the satiety cascade (4, 7). These models incorporate aspects of traits, processes, and skills. In the bottom-up, top-down model there is a recursive interplay between bottom-up reactive, often emotion driven and automatic, approach or avoidance behaviors (such as hedonic responses to hunger or food cues) and top-down regulatory control processes including inhibitory control. In the dual processing model, self-regulation is conceived as involving an interaction between regulatory processes such as inhibitory control (top-down) and approach-avoidance behaviors (bottom-up). Here, self-regulation is considered to involve an interplay between impulse generating and impulse controlling systems. It is possible to group many of the ASR-related constructs that have been described and investigated in the literature under the main headings of bottom-up (approach), such as food responsiveness, bottom-up (avoidance) such as food fussiness, and top down such as inhibitory control (12). The bottom-up, top-down model for conceptualizing ASR in childhood is helpful in the investigation of ASR phenotypes as it provides a framework for the interpretation of patterns of characteristics and behaviors.

Most of the existing research on the development of ASR has taken a variable-centered approach [c.f. the studies reviewed in (8)]. Similarly, the conceptualization of fundamental processes in ASR such as in the models described above has been substantially based on variable-centered research. To broaden knowledge about ASR in childhood, there is a need to give greater recognition to the nature and extent of individual differences in behaviors, processes, traits, skills and trajectories in the development of ASR. There is limited research and theory about ASR that focuses separately on traits, processes, and skills. Instead, consistent with the multidimensional treatment of ASR in infancy and childhood, research designs typically include measures of one or more of traits, processes, and skills although with a heavy emphasis on traits. In the present review, the focus is on possible advances in conceptualization that could be gained from a person-centered perspective to research and theory. We discuss ASR phenotypes, trajectories of individual ASR indicators, and trajectories of underlying ASR phenotypes. We argue that the exploration of ASR phenotypes and trajectories has implications for the conceptualization and measurement of ASR in childhood. If it can be assumed that scholarship is at a relatively early stage of developing an integrated model of ASR in childhood, person-centered strategies could provide insights into how traits, processes and skills might be organized and interrelated.

The initial scoping of the review was based on keyword and abstract literature searches in the main databases: PubMed, PsycINFO, SCOPUS, Web of Science, and Google Scholar. The searches covered theoretical articles (e.g., person-centered vs. variable centered), data analysis (e.g., latent class analysis, trajectory analysis), and research evidence (e.g., eating behavior phenotypes, latent class, and profile analyses of eating behaviors in childhood). We sourced articles under these headings from the literature on children's eating and ASR, as well as other areas of scholarship (such as clinical psychology, developmental psychology, and educational psychology). In contrast to the structured approach of a systematic review consistent with our purpose we chose articles for their illustrative significance in relation to the purpose of discussing the nature, role, and contribution of person-centered strategies in the investigation of ASR phenotypes and trajectories in childhood.

We begin with a discussion of person-centered vs. variable-centered strategies before considering the prospect for investigations of phenotypes to examine ASR components and processes in childhood. The main body of the review is then about the measurement of trajectories and the potential of this approach to contribute to knowledge about the development of ASR.

Person-Centered vs. Variable-Centered Approaches

Person-centered and variable-centered approaches answer different research questions, and can provide complementary

Abbreviations: FMM, Finite mixture modeling; LCA, Latent class analysis; LCGA, Latent class growth analysis; LPA, Latent profile analysis; LTA, Latent transition analysis; GBTM, Group-based trajectory modeling; GMM, Latent growth mixture modeling; LVMM, Latent variable mixture modeling; CEBQ, Children's Eating Behavior Questionnaire; BMI, Body Mass Index; EAH, Eating in the absence ofhunger; ASR, Appetite self-regulation.

information about a research field, including about child development (14–21). Variable-centered approaches (e.g., regression analysis, factor analysis, structural equation modeling) examine associations between variables in a population and are suited to questions about normative development and the effect of one variable on another, especially in terms of the contributions of predictor variables to outcome variables (16, 22–26). In this case, data are aggregated and individual differences are treated as "noise" or "errors" which provides more parsimony (19) but less specificity (16).

In contrast, individual differences, or an assumption that the sample is not uniform and that behavior and psychological processes are unique to the individual or differ from one group to another (15, 27), are the basis of person-centered approaches such as cluster analysis and finite mixture models (14, 15, 20, 27–31). In this case the emphasis is on individual and sub-group differences within the sample, including sub-group differences in development. Person-centered approaches are helpful for understanding possible developmental mechanisms (20) and allow investigation of inter-individual (between-person) differences in intraindividual (within-person) profiles of behavior or change (32, 33). Person-centered approaches categorize participants into subgroups, or phenotypes, based on a set of shared characteristics or attributes. The resulting phenotypes may be based on complex patterns of substantive variables to provide a more detailed and nuanced picture of development. For these reasons, person-centered approaches have the potential to advance knowledge about ASR and its development in childhood.

The Contribution of Phenotypes to the Conceptualization of ASR

Technically, a phenotype is a set of behaviors and characteristics arising from the interaction of the genotype with the environment (34). The phenotype concept is useful as a way of describing combinations of individual traits and behavior, especially as they apply to sub-groups of the population. The concept has been applied to children's eating behaviors as we discuss here, but also to parent feeding practices (35, 36), in developmental psychology (37–39), and in other areas of psychology such as educational psychology (40) and clinical psychology (41–43).

The examination of ASR phenotypes can contribute to the understanding of components and processes in ASR. The investigation of possible phenotypes enables ASR to be conceptualized in new ways by suggesting different combinations of measures of traits, processes, skills, behaviors and other ASR-related measures (e.g., neurobehavioral indicators) and how these combinations interact for separate sub-groups. For example, ASR difficulties could be associated with increased food approach tendencies in some groups of children, difficulties in responding to satiety and satiation cues in other groups, and increased impulsiveness and reduced inhibitory control in other children, or different combinations and patterns of change of these characteristics. The so-called patterns of change could vary from consistency across ages, to increases, decreases or other variations such as consistency followed by an increase or a decrease. Possible insights from the examination of phenotypes have been illustrated in an adult sample where four phenotypes of obesity-related behaviors and characteristics were derived from behavioral and questionnaire measures (44). One phenotype, labeled "hungry brain," was described as having abnormal satiation, and another phenotype, labeled "emotional eating," was high on hedonic eating. The other phenotypes were "hungry gut," involving abnormal satiety, and "slow burn" described as involving decreased metabolic rate. The authors assumed that the phenotypes revealed something about fundamental processes in weight gain and obesity and described them as "actionable" because they were helpful to target weight-loss treatments. The examination of phenotypes has been enhanced by the application of person-centered data analysis strategies. In the following section we describe the analytical strategies available for examining phenotypes and illustrate their use in ASR/eating behavior research. These include strategies for analyzing both cross-sectional and longitudinal data.

PERSON-CENTERED APPROACHES AND THEIR APPLICATION IN ASR PHENOTYPE RESEARCH

Earlier person-centered approaches for evaluating the underlying psychological attributes of weight gain in cross-sectional studies included cluster analyses using hierarchical (e.g., Ward's) or partitioning (e.g., k-means) methods (45, 46). However, finite mixture models (FMM), also known as model-based clustering or latent variable mixture models (LVMM), are newer techniques that have become a popular alternative for understanding population heterogeneity (47). Examples of such techniques include latent class analysis (LCA), latent transition analysis (LTA), and growth mixture models (GMM) (47). FMM draw on a structural equation modeling (SEM) approach and encompass a "collection of statistical approaches" for analyzing cross-sectional and longitudinal data [(41, 48), p. 175]. They take one or more observed input variables to model the probability of participants belonging to latent (i.e., unobserved or underlying) subgroups and classify participants to the subgroup with the highest probability of their belonging (41, 48). The resultant subgroups may be referred to as classes, profiles, typologies, or phenotypes, with the latter more commonly used in the field of psychology (32). Interested readers are referred to Berlin and colleagues (18, 48) for an introduction and non-technical account of cross-sectional and longitudinal FMM/LVMM approaches, covering assumptions and a "how to" description of their use.

Cross Sectional Studies: Latent Class and Latent Profile Analysis

LCA for categorical data and latent profile analysis (LPA) for continuous data are foundation person-centered strategies used in many fields including medical, biological, physical nutritional and social sciences (18, 31, 40, 48, 49). LCA and LPA are examples of FMM/LVMM used in cross-sectional studies (31) and identify latent subgroups based on specific combinations of observed variables (18, 48). The goal of the analysis is to determine the optimal number of latent subgroups that summarize the unique, and often complex, patterns of the observed variables within individuals (32).

In cross-sectional studies, distinct eating behavior subgroups, or phenotypes, have been identified in children using LCA or LPA. For example, Boutelle et al. (50) conducted LPA from multiple measures of eating behaviors in a sample of 8 to 12 year-old children with overweight or obesity. Three latent profiles were identified, labeled as (i) high satiety responsiveness, (ii) high food responsiveness and (iii) moderate satiety and food responsiveness. Although each phenotype was associated with overeating and overweight, the phenotypes involved combinations of different levels on the individual variables, such as eating in the absence of hunger (EAH), satiety responsiveness, food responsiveness, negative affect eating, loss of control eating and external eating.

In a sample of 4-year-old children, Tharner et al. (51) conducted LPA on Children's Eating Behavior Questionnaire (CEBQ) scores and identified six eating behavior profiles. Most children were in the "moderate eaters" (44.6%) or "avoidant eaters" (33.2%) profiles. The authors were mainly interested in the "fussy eater" profile (5.6%) which was characterized by high scores on the subscales of satiety responsiveness, food fussiness and slowness in eating combined with low scores on the enjoyment of eating subscale. This subscale was associated with dietary, weight and parental factors, demonstrating the utility of examining a number of eating behavior subscales as profiles rather than individual variables.

Longitudinal Studies of Subgroups: Latent Transition Analysis

LTA is a longitudinal extension of LCA and LPA that identifies unique latent subgroups based on combinations of observed variables, and an individual's transition, or movement, between these latent subgroups over time (40, 52–55). LTA has mostly been applied to two time points, but three may be used (16, 56, 57). In longitudinal research, LTA may be used to investigate different developmental paths or transitions from one phenotype to another over time (16, 47, 53). It also enables the examination of whether phenotypes might be age-specific or if they are established early and then are maintained across childhood. Further, it could assist in the examination of outcomes or changes associated with interventions (e.g., whether participants transition to a different phenotype following intervention).

Pitt et al. (58) illustrate the use of LTA to examine developmental change. The authors calculated phenotypes (using LCA) for dietary patterns at age 3 and 5 years and then used LTA to investigate changes in the subgroups over time. Similarly, development change was explored by Swanson et al. (59) who measured eating disorder symptoms in girls in five age groups from preadolescence, early adolescence, late adolescence and two young adulthood periods and calculated transition probabilities from the latent classes at age 9–12 to classes at age 19–22. Latent transition probabilities following LCA has also been used to investigate learning outcomes (55) in a way that could provide a parallel for the examination of eating-based intervention outcomes. These approaches examine transitions between groups, however changes over time are also usefully explored with modeling of trajectories.

Trajectories Modeling

Nagin (60) argued that charting and understanding trajectories in longitudinal research is fundamental to knowledge about development, including the possibility that sub-groups might follow distinct trajectories. Trajectory analyses in longitudinal research might inform the investigation of multifinality (a common starting point, but then divergence of trajectories), equifinality (different starting points, but convergence on a common end point, possibly via different routes or paths), and fanning (increasing interindividual differences in trajectories over time) (17, 61).

There are two kinds of analytical strategies for examining trajectories of ASR-related eating behaviors and the associated outcomes of weight gain, adiposity or BMI. The first involves the investigation of trajectories for individual variables. The second approach has been to examine trajectories that include multiple variables in the one analysis.

Longitudinal Studies of Trajectories of Single Variables: Latent Growth Mixture Modeling

GMM is a statistical approach for modeling the average rate of individual change, or trajectories, across three or more time points. Whilst LTA involves the identification of latent subgroups and then the calculation of transitions, GMM models include the trajectories when calculating the latent subgroups (16). GMM is an extension of the traditional latent growth curve model (62) and includes latent class growth analysis (LCGA), a simplified GMM, and group-based trajectory modeling (GBTM), a special case of LCGA that assumes error variances are the same for all latent subgroups (18, 21, 32, 33, 60, 63–68). Unlike conventional latent growth curve modeling which assumes the same pattern of growth corresponds to the whole population, GMM takes into account population heterogeneity and identifies latent subgroups of individual growth patterns, or developmental trajectories (62).

A number of authors compare the assumptions and use of the main approaches to GMM (18, 32, 43, 69). Nagin and Odgers (43) argue that while there are technical differences between these approaches (i.e., they make different assumptions about the distribution of trajectories in the population), they are all designed to assign individuals into trajectory groups. For example, LCGA is a restricted version of GMM that constrains the variations (i.e., variances and covariances) within each class to zero and as a consequence reduces the number of parameters and simplifies model selection (70). LCGA assumes that all individual growth trajectories within classes are homogeneous (71) and is often recommended as a first step in the exploration of possible latent classes. GMM relaxes the assumption that all individuals in a class are from a single homogenous population (67) and estimates all growth factors (e.g., means, variances and covariances). However, such increases in model complexity may lead to estimation difficulties, including non-convergence or non-optimal latent subgroup solutions; the model chosen should be one that best fits the data and leads to meaningful subgroup solutions based on substantive prior theory (62). Berlin et al. discuss when and how a researcher might use LCGA and GMM, including a step-by-step account of processes in the identification of latent trajectory subgroups (18, 48). After conducting Monte Carlo simulations of synthetic data, Den Teuling et al. (69) concluded that GMM provided the "best overall performance."

A common example of phenotypes defined in terms of trajectories of ASR-related constructs with a single variable is trajectories for weight gain or BMI. Norris et al. (72), for instance, examined weight trajectories from 0 to 60 months of age using GMM to identify five groups of individuals with different average trajectories. The subgroups included "average," "high-decreasing," and "stable-high" BMI trajectories. They then examined maternal (e.g., maternal BMI and education), family and birth characteristics of children associated with the different trajectories. Becnal and Williams (64) and Ventura et al. (73) followed a similar approach, using GMM to identify several weight trajectories. Risk factors were included as covariates and health outcomes associated with the trajectories were examined. In a birth cohort, van Rossem et al. (74) used LCGA to investigate trajectories for BMI until age 11 years. Trajectories of persistent overweight and overweight reduction were subsequently found to be related to early-life and parent factors including parent overweight.

Trajectories of individual ASR-related eating behaviors have also been explored. Derks et al. (75) used LCGA to examine trajectories for individual CEBQ scales assessed at ages 4 and 10 years. They found three patterns for emotional overeating and five patterns for food responsiveness, but no subgroups for enjoyment of food and satiety responsiveness. Follow-up regression analyses enabled them to explore early life predictors of each of the trajectories. Herle et al. (70) also used LCGA to investigate trajectories of child eating behaviors in the first 10 years of life from parent reports. They reported a number of trajectories for each of the single variables of overeating, undereating and fussy eating. The eating trajectories were associated with later zBMI in meaningful ways and were also found to be predictive of later eating disorder diagnosis.

These examples illustrate the potential contribution of person-centered trajectory analyses to the identification of developmental patterns for weight gain and ASR-related eating behaviors. They also show how predictors or risk factors can be related to trajectories as well as relationships between trajectories and outcomes.

Longitudinal Studies of Multiple Trajectories: Multi-Trajectory Modeling

Rather than using a single trajectory variable to assign individuals to a phenotype, multi-trajectory modeling, or multivariate GBTM, approach defines trajectory phenotypes using multiple and distinct trajectories variables (76). It is a variation of univariate GBTM. It defines a trajectory group in terms of trajectories for multiple indicators and takes account of the interrelationships among the indicators in a multivariate design. Nagin et al. (76) provide two illustrative examples and argue there is a need to sharpen guidelines for model selection and evaluation. Their first illustrative example was from male subjects in the Dunedin Multidisciplinary Health and Development Study with measures at different ages from 3 to 38 years. There were five trajectory groups, defined by the patterns of trajectories on three physiological outcome variables. The second illustrative example was from the Montreal-based longitudinal study of 1,037 males with measures from ages 6 to 17 years. The analysis yielded five trajectory groups based on the pattern of trajectories of four individual variables.

We illustrate this multivariate approach to the investigation of latent trajectory phenotypes for ASR-related eating behaviors with two studies. First, Epstein et al. (77) measured trajectories of food habituation to salty, sweet and savory foods in a sample of 8–12 year-old children. GBTM was used to identify individual trajectory phenotypes for the three foods and multivariate GBTM was used to determine trajectories for the combination of foods. The habituation phenotypes (such as "rapidly decelerating habituation" vs. "slower to initiate the decelerating rate of responding") were related to a measure of the reinforcing value of each of the foods. This approach is helpful in the examination of ASR, as it demonstrated that the children who habituated slower also found food more reinforcing than children with a rapid habituation phenotype, thereby providing new insights into possible processes in ASR in childhood.

Boutelle et al. (78) provide a second example of multi-trajectory modeling. They assessed four child (mean age 10.4 years) appetitive traits at 3, 6, 12, and 24 months after baseline. Multivariate GBTM yielded three "trait trajectories of appetitive subgroups." In a subgroup they labeled "high satiety responsiveness" there was an increasing pattern in satiety responsiveness, a decreasing pattern in food responsiveness and a low stable pattern in emotional eating and negative affect eating. The phenotypes, therefore, were characterized by a different pattern of trajectories for the four eating behaviors. Again, these phenotypes show the potential of multi-trajectory analyses for the investigation of ASR development because they show different combinations of eating behaviors in subgroups of children. The finding that only the high satiety responsiveness subgroup-maintained weight loss following a family-based treatment for children with overweight or obesity provides further support for separating appetite trajectory phenotype subgroups.

Some Strengths and Limitations of Using Person-Centered Approaches to Understand ASR

The literature includes extensive discussion of assumptions, processes and strategies in model selection, the inclusion of covariates and the limitations of these approaches to person-centered analyses (18, 32, 33, 42, 43, 48, 52, 79, 80). In all FMM, selecting the optimal number of latent subgroups requires the investigation of multiple model fit criteria (62). These may include information criteria statistics [e.g., Bayesian Information Criteria (BIC), Consistent Akaike's Information Criteria (CAIC), and Approximate Weight of Evidence Criterion (AWE)], entropy values, the log-likelihood sample size, and likelihood ratio tests comparing the k-class and k-1 subgroup model [e.g., Bootstrap Likelihood Ration Test (BLRT), Lo-Mendell-Rubin adjusted likelihood ratio test (LMR-LRT)]. Bray and Dziak (52) argue that sometimes the use of FMM/LVMM is something of an art as well as a science in model selection. This is particularly so when the sample size is small relative to the model complexity, or the quality of the measurement model is poor. They suggest that both statistical fit and theoretical interpretability should be considered and at times it is better to select a model with a few interpretable classes even if the statistical fit is not optimal. Herle et al. (32) also comment on "non-science" aspects of model selection. This includes taking account of the size and interpretability of classes (70). Lubke and Luningham (42) in a related way refer to the considerable uncertainty around model selection. Several practical guides to the selection and reporting of latent subgroups are available (81–83). Whilst there is currently there is no "rule-of-thumb" regarding a minimal sample size for FMMs, the impact of sample size on determining the optimal number of latent subgroups in FMM have been investigated in several Monte Carlo simulation studies (81, 84).

In relation to latent transition analysis, there is debate and guidance in the literature about procedures and decisions in the conduct of latent transition analyses including sample size and selection of classes [e.g., (52)]. There are challenges associated with causal analysis using these approaches, as well as the possibility for these analyses to compare different theoretical models and for linking latent classes to predictors and outcomes. Berlin et al. (18) alert researchers to issues in using FMM arising from sample size. They argue that insufficient sample sizes can lead to convergence problems, improper solutions and a limited ability to identify meaningful subgroups. They also point out difficulties in determining adequate sample size, such in relation to reliability and the distribution of variables.

A key advantage of all FMM is the ability to directly incorporate predictors or antecedents, covariates, including time-varying covariates, and outcomes in the model (27, 32, 43, 52, 85, 86). Many techniques have been suggested for the examination of covariates [e.g., (87)]. One possibility is based on a regression model where class membership is predicted by the covariates, or classes are used to predict outcome variables such as zBMI (70). Or, where the covariates are partitioned into the latent classes (32). Here, Herle et al. included a discussion of two approaches to the investigation of covariates and their use. Marsh et al. (88) provided a discussion of the inclusion of correlates: when, why and what it assumes. They argued that their inclusion should not qualitatively change the classes but should make them more accurate and that covariates should be antecedent not concurrent or outcome. The inclusion of covariates in models is complex but a useful discussion is provided by Lubke and Luningham (42) on the theoretical bases of FMM/LVMM and the inclusion of covariates.

Finally, scholarship associated with analytic approaches following a person-centered perspective is an active and expanding field. Authors have discussed additional analysis options or extensions of LCA, LPA, LTA (52), and GMM (60, 62). Bray and Dziak indicate that the FMM/LVMM framework is flexible and permits the specification of different types of mixture models that include path models, factor models, survival models, growth curve models, and that structural equation models can be specified for multiple subgroups.

In summary, and overall, research on ASR-related phenotypes, including trajectory phenotypes (whether using individual constructs or a multitrajectory approach) is contributing to an understanding ASR and its development in childhood. The extensive conceptual and technical literature on person-centered strategies in the investigation of subgroup differences also shows the potential of this approach to contribute to knowledge about ASR and its development in childhood. At the same time, researchers should be cognizant of the assumptions and limitations of this approach, as well as the art vs. science aspects of subgroup identification. An important consideration is also that the phenotypes identified are clearly a product of the number and type of individual variables that have been measured. Further, the inclusion of covariates and outcomes provided opportunities to better understand the predictors or possible origins of ASR, influences on its development and effects on important development outcomes such as BMI and weight gain. Below, we comment further on the importance of phenotype research for advancing knowledge about ASR and its development. We argue for the need to expand measures into new domains of ASR-related constructs.

DISCUSSION

Knowledge and understanding of ASR can be advanced in many ways: through conceptual and theoretical developments, improvements in research design and methods (especially measurement) and progress in approaches to data analysis and statistics. In this review we have taken a slice through some of these matters via the distinction between person-centered and variable-centered approaches to research, and then a focus on person-centered strategies.

In the discussion we first explore insights from extant person-centered approaches for the conceptualization and measurement of ASR in childhood together with suggestions for future research. Second, we discuss possibilities for combining person-centered and variable-centered approaches in scholarship about ASR and children's eating behaviors in childhood. Third, we argue that person-centered approaches could assist in the design of intervention strategies and in the measurement of intervention outcomes.

Insights From a Person-Centered Approach for Conceptualizing and Measuring ASR

Research on phenotypes from cross-sectional and longitudinal data has the potential to examine underlying processes and dimensions of ASR in childhood. This is apparent from the labels applied to the latent subgroups [e.g., "high satiety responsiveness" (78), "rapidly decelerating habituation" (77)] and the particular measures used to characterize them in the research reviewed here. This research can also contribute to knowledge about (a) antecedents, precursors, or correlates of ASR-related phenotypes, and (b) associations between phenotypes and outcomes (either developmental outcomes or outcomes from interventions).

Latent class/profile and trajectory analyses have been described as data driven and exploratory [e.g., (43, 89)].

Consistent with this description, findings from person-centered analyses should not be used to infer causality, but rather to generate hypotheses for future testing. Also in line with this description, Bergman and Trost (20) emphasize the vagueness of guiding theories in the case of person-centered approaches, especially about how the studied system operates, for example, about how different measures might interact and coordinate to form distinct phenotypes or how and why there could be different trajectories of ASR and its components. For example, in the Derks et al. (75) study although many patterns were found for each of the measured appetitive traits and these were linked to early life predictors, due to the absence of a clear theoretical foundation for the development of appetitive traits, it is unclear why, for instance, three patterns of emotional eating and 5 patterns for food responsiveness may arise. While recognizing the potential of person-centered approaches for advancing knowledge about ASR and its development, it is important to keep in mind that it needs to be built on sound theory as well as efforts to integrate it with variable-centered approaches. As we mention below, recent data analysis strategies that enable a more confirmatory approach and assessment of predictions are also helpful.

Because person-centered strategies in relation to ASR have been mainly exploratory, an important role of these strategies could be in the development and clarification of conceptualization and measurement. Central to a person-centered approach is the assumption that the individual is an integrated totality over time, with behaviors interwoven and interacting (20). This approach is suited to the exploration of possible developmental mechanisms and to inductive theory building (16). A complexity here is that while ASR could be changing over time, other developmental processes and changes are also occurring. This means that person-centered strategies to investigate the development of ASR will need to take account of wider developmental changes and processes.

Morin et al. (27) suggest that some areas of research might not be sufficiently advanced in theory and with a substantial enough body of results to generate clear hypotheses about the expected nature of profiles. They argue that when this is the case, construct validation is important, through showing that the profiles have heuristic and theoretical values and are meaningfully related to key correlates or outcomes. In this case, confirmatory approaches may be applied. Schmiege et al. (89) discuss approaches to confirmatory latent class analysis, including a dual sample approach and confirmatory testing of a latent class structure. As person-centered evidence on ASR expands, it is possible that these more stringent theoretical tests will become more important.

Fundamentally, phenotypes are suggestive of central components and processes in ASR. But the latent subgroups are limited and constrained by, and entirely reflect, the individual measures used. Person-centered strategies with a focus on ASR-related phenotypes will be better placed to contribute to conceptualization and measurement with the continued addition of individual measures of behaviors, characteristics, traits or processes based on emerging evidence about processes and individual differences in ASR. This includes evidence from biologically based research such as genetic susceptibility, psychoneurological measures, as well as measures about general self-regulation from psychology, neuroscience and from areas such as the effects of highly processed food and the rewarding value of food. When covariates and outcomes are included in the research design, person-centered strategies could progress knowledge about the possible origins of ASR, influences on the development of ASR, and developmental outcome associated with ASR.

Indeed research on ASR-related behaviors, characteristics, traits and processes has expanded considerably in recent years and there is now a growing set of possibilities for inclusion in research about ASR phenotypes in childhood including: temperament (such as impulsivity and effortful control) (90), Executive function (such as inhibitory control), genetic susceptibility, reward sensitivity, hedonic responses to food, cognitive function (91), cognitive control and negative affect (92), state and/or trait food cue reactivity (93), brain reward sensitivity to food cues (94), dietary measures, such as dietary fat or carbohydrates (95, 96), fructose consumption (97), intake of processed food (98), sensory sensitivity (99), neuroimaging functional connectivity (100), metabolomics and analysis of the gut microbiome (101, 102), measures of the social facilitation of eating (103), susceptibility to modeling (104), effects of portion size cues (105) and attachment security (106), behavioral and neural measures of appetitive traits such as through neuroimaging measures (107, 108). A helpful broadening of work on ASR phenotypes is also suggested by attention to endophenotypes where genetic predisposition and neural substrates as well as behavioral measures are included (107, 109–112).

However, the inclusion of many behaviors, characteristics, and traits to determine ASR phenotypes may be too computationally burdensome for the model-based person-centered approaches discussed in the present review. Future ASR research may need to employ machine learning, or data mining, methods to determine phenotypes from large and complex datasets (113–115).

Combining Person-Centered and Variable-Centered Strategies

Comparisons of person-centered and variable-centered approaches to research have highlighted their differences in assumptions, purpose, sampling, research questions, analytic approach and strengths (16). The two approaches can also be complementary (16, 20, 116). Derks et al. (75) for example, demonstrated how combining the two approaches can provide information about children's ASR. They identified different trajectory patterns of children's eating behaviors using LCGA (person centered) and then investigated the early life or other predictors of those patterns (variable centered). Predictors could include child and family characteristics (51) and BMI-z (50) or socio-demographic and clinical characteristics (117). Another option to combine the two approaches is to first identify latent profiles of ASR and use these as predictors of subsequent outcomes such as BMI or diet [e.g., (118)]. Much of the research on risk factors for obesity or weight gain has examined individual predictor variables. This type of research could be helpfully expanded to include relationships between ASR phenotypes and subsequent measures of weight, thereby gaining greater specificity about potential risks as well as possible processes associated with weight gain and obesity.

Phenotype and other person-centered analyses also enable reflections on theoretical models such as a biopsychosocial approach (119) that incorporate variable and person-centered elements. For instance, these analyses could enable the examination of how biological, psychological and social measures combine in the formation of phenotypes, how they differ from one phenotype to another, and then how the phenotypes relate to model outcomes such as weight gain and adiposity. It would also be possible to incorporate parent and child measures from cross-lagged designs to examine transactional processes via phenotypes and co-variate analyses. Other designs could also provide important insights, such as parallel process latent growth modeling which could investigate ASR trajectories alongside other developmental trajectories, such as BMI or emotion regulation.

In the present review we highlighted the potential of person-centered strategies for the conceptualization and measurement of ASR in childhood and infancy. In contrast to a systematic review, the emphasis of the present review was not on an assessment of the evidence or findings from person-centered strategies. Aligned to the purpose of the review, the literature chosen was supportive rather than critical of these strategies and does not cover nor assess the suitability or quality of all research on person centered approaches to advancing the conceptualization of ASR. We briefly discussed the roles and contributions of person-centered vs. variable centered approaches. There is value in further appraisal of these two approaches to the conceptualization and measurement of ASR in infancy and childhood. Further, as evidence accumulates, there is a need for systematic reviews to appraise and synthesize evidence from the two approaches.

Person-Centered Strategies in Intervention Design and Measurement of Outcomes

There is scope for person-centered approaches to contribute to the design of intervention strategies and in the measurement of outcomes. Person-centered analyses could better inform intervention strategies by a greater focus on the specificity arising from the identification of phenotype subgroups that could be tied to personalized intervention strategies (44, 78, 117). Phenotype and trajectory analyses could be used to examine intervention outcomes such as through changes in phenotypes following an intervention, and transitions from one phenotype to another, such as has been described in the literature on teaching and learning (40, 120). Finally, in contributing to intervention design and the measurement of outcomes, person-centered approaches could contribute to knowledge about possible developmental processes and assist theory development.

CONCLUSION

Person-centered strategies can make an important contribution to advances in the conceptualization and measurement of ASR in children, including to an understanding of developmental paths and processes. This appears to be especially so for person-centered strategies that explore phenotypes, whether based on cross-sectional data or trajectories. The potential contribution seems to be enhanced when combined with variable centered approaches that include predictors or co-variates and that examine outcomes. Possible gains from person-centered approaches should be strengthened by further evidence about individual skills, traits and behaviors that comprise ASR, as well as increased evidence about ASR processes and developmental change/trajectories. There is also a need for overall theory development, more confirmatory research and a greater integration with variable-centered approaches. Finally, evidence about children's appetitive phenotypes and trajectories could assist in the design and measurement of intervention outcomes.

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Infant Appetitive Phenotypes: A Group-Based Multi-Trajectory Analysis

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Background: Examining appetitive traits with person-centered analytical approaches can advance the understanding of appetitive phenotype trajectories across infancy, their origins, and influences upon them. The objective of the present study was to empirically describe appetitive phenotype trajectories in infancy and examine the associations with infant and parent factors.

Materials and Methods: In this longitudinal cohort study of Australian infants, parents completed three online surveys ~3 months apart, beginning when the infant was <6 months. Appetitive traits were assessed with the Baby Eating Behavior Questionnaire (BEBQ) and parent feeding practices with the Feeding Practices and Structure Questionnaire (FPSQ) infant and toddler version. Parent demographics and cognitions were also collected. Infant weight and length were transcribed from health records and converted to a BMI *z*-score. Group-based trajectory modeling identified appetitive phenotype trajectories using the BEBQ. Multilevel modeling examined change in feeding practices and child BMI *z*-score over time by appetitive phenotype trajectories.

Results: At time 1, 380 participants completed the survey (mean infant age 98 days), 178 at time 2 (mean infant age 198 days), and 154 at time 3 (mean infant age 303 days). Three multi-trajectory appetitive phenotype groups were identified and labeled as (Phenotype 1) food avoidant trending toward low food approach (21.32% of infants), (Phenotype 2) persistently balanced (50.53% of infants), and (Phenotype 3) high and continuing food approach (28.16% of infants). Formula feeding was more common in Phenotype 1 ($p = 0.016$). Parents of infants in Phenotype 1 were more likely to rate them as being more difficult than average, compared to infants with phenotypes 2 or 3. Phenotype 2 had the greatest increase in persuasive feeding over time [0.30; 95% CI (0.12, −0.47)].

Conclusions: Distinct multi-trajectory appetitive phenotype groups emerge early in infancy. These trajectories appear to have origins in both infant and parent characteristics as well as parent behaviors and cognitions. The infant multi-trajectory appetitive phenotype groups suggest that for some infants, difficulties in self-regulating appetite

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emerge early in life. Investigation of infant multi-trajectory appetitive phenotype groups that utilize a range of measures, examine relationships to key covariates and outcomes, and extend from infancy into childhood are needed.

Keywords: appetitive traits, appetitive phenotype, trajectories, infant, parent feeding, weight, appetite self-regulation, multi-trajectory analysis

INTRODUCTION

Children differ greatly in what and how they eat (1), with evidence that these differences emerge or are present in infancy (2, 3). These differences in children's early eating behaviors and attitudes have, in turn, been shown to contribute to later overweight and obesity in childhood (4). Appetitive traits are quantifiable individual differences in patterns of behaviors and attitudes related to food and eating (5, 6), typically measured with the parent-reported Baby Eating Behavior Questionnaire (BEBQ) for infants. Appetitive traits have been broadly classified into "food approach" (more avid appetite, greater interest in or desire to eat food) and "food avoidance" (lower appetite, lower interest in and desire to eat food) tendencies. Avid appetitive traits appear to make some individuals more susceptible to the effects of the obesogenic environment (e.g., the presence of food cues) and therefore greater weight gain (4, 7). Appetitive traits are highly heterogeneous, even in infancy (1–3) and while they are constitutionally based to varying degrees (3, 8), they are influenced over time by experiences (e.g., parent feeding practices) and development (9, 10).

The predominance of evidence about children's appetitive traits has focused on individual traits (such as fussiness or food responsiveness), with an analytic approach that is variable centered (4). Variable-centered approaches look at relationships between variables (e.g., satiety responsiveness and weight) to identify key variables and look at their prevalence and relationships to other variables in different groups (11). This approach is useful for answering research questions about the relative contributions of such variables to outcomes like weight gain. However, variable-centered approaches tend to use average scores on eating behavior variables and therefore do not examine individual differences or the presence of subgroups (12). A person-centered approach, in contrast, can answer research questions about individual and subgroup differences and looks for underlying latent variables that distinctively characterize different groups of children through underlying latent constructs. Latent profile or latent class analysis can be used with cross-sectional studies to assign individuals to a "profile" or "typology" based on patterns of relationships among particular variables of interest. This can lead to the identification of behavioral phenotypes or subgroups of children based on profiles of eating, that is, distinct patterns of behavior that arise due to a combination of genetic and environmental effects that impact health outcomes (5). Applying person-centered analytical approaches over time can lead to the identification of subgroups of individuals based on their different trajectories of, for instance, eating behaviors or weight (13). These approaches can examine trajectories of a single variable, or can consider trajectories based on multiple trajectory variables (14). For example, group-based trajectory modeling allows for analyses of trajectories of change across multiple variables to be considered when grouping participants (14, 15). This exploratory approach is primarily interested in understanding differences between individuals or subgroups in their eating behaviors and how they change over time. It can be useful for answering questions about group differences in the development of eating behaviors over infancy/childhood and can provide insights into the possible underlying mechanisms that can be tested in follow-up research.

A small number of studies from the United Kingdom and the United States have used person-centered approaches to identify appetitive phenotypes in childhood (1, 16–19), with some (1, 13, 18, 20, 21) examining appetitive phenotype trajectories or changes over time. In cross-sectional research, Boutelle et al. (13) identified three phenotypes from a combination of behavioral and self-report measures on a sample of 8- to 12-year-old North American children who were seeking treatment for overweight or obesity. Clairman et al. (22) also reported on three distinct phenotype groups in using multiple measures of appetite in overweight children/adolescents in Canada. Galloway et al. (20) reported three profiles of fussy eating based on scores from five subscales from the Children's Eating Behaviour Questionnaire (CEBQ). These studies have demonstrated how person-centered analyses of cross-sectional data can use multiple measures of appetitive behavior to create phenotypes, with these phenotypes highlighting individual subgroup differences in possible mechanisms in appetite self-regulation.

Further insights into appetite self-regulation and its development can be gained when data are longitudinal, and attention is directed to trajectories. Several studies have reported trajectories for individual appetitive traits: Fernandez et al. (21) identified three fussy eating phenotype trajectories in children from 4 to 9 years of age from low-income families in the United States. Also in the United States, Boutelle et al. (13) measured multiple appetitive traits at four time points in children (mean age 10 years) with overweight and obesity, and calculated trajectories for each of the traits. In the only published longitudinal study of appetite phenotypes beginning in infancy that we were aware of, Herle et al. (1) used latent class growth analysis to identify latent classes of trajectories of children's eating behaviors based on parents' reports of their concerns about their child's eating at six time points from age 15 months to 9 years. This study, using data collected in the Avon Longitudinal Study of Parents and Children (UK), found four classes of children for overeating and six each for undereating and fussy eating. In addition to the identification of latent classes, these studies also frequently investigated covariates or predictors and associations between the latent classes and outcome variables such as the BMI.

These studies have demonstrated that person-centered analyses of children's appetitive behaviors can provide additional insights into the development of children's eating behaviors beyond those identified with variable-centered approaches. Notably, person-centered approaches to the investigation of children's eating have the potential to contribute insights into individual differences, including individual differences in development. In the present research, we extend this approach in three ways: (1) the research is longitudinal rather than cross-sectional, thereby enabling the investigation of trajectories, (2) the analysis uses a multi-trajectory approach rather than an investigation of changes in individual variables, and (3) it focuses on infancy. This approach can provide insights into typologies of children's eating and appetite, including insights into the possible mechanisms.

The multi-trajectory approach used in the present study has been outlined by Nagin et al. (14). In this approach, the phenotypes are calculated from the trajectories of multiple variables. It conceptualizes phenotypes in terms of patterns of developmental pathways rather than patterns of measures taken cross-sectionally. However, although it is recognized that children's eating behaviors emerge early in life, to our knowledge, there are no studies describing appetitive phenotype trajectories using multiple indicators of appetite or eating in infants. Identifying appetitive phenotype trajectories using multiple, distinct trajectory variables in infancy contributes to knowledge on the origins of, and influences on, appetite self-regulation. That is, through understanding the features of the unique subgroups of eating, how they change in infancy and associate with covariates and outcomes, we are better able to understand the mechanisms and processes influencing the development of appetite self-regulation. It also helps to identify children on pathways likely to put them at greater risk of overweight or poor diet quality.

To better understand such trajectories and influences upon them, a biopsychosocial approach (23), which emphasizes understanding the development from birth or infancy as well as describing the processes and mechanisms that shape diet and weight over time, beginning with the biological characteristics of children can be useful. According to this model, through bidirectional and transactional processes, the impact of any emergent appetitive traits in infancy can be additive over time. In this way, it can help to explain developmental trajectories and identify opportunities for influencing such trajectories should they be considered problematic. This model informs the design and analysis of the current analysis where it is used to inform the examination of appetitive phenotype trajectories in infancy, the characteristics of infants (e.g., biological gender, birth weight) that are associated with different infant appetitive phenotype trajectories, and the environmental factors that influence those trajectories (23).

Considering the role of the environmental influences outlined in the biopsychosocial model, parent feeding practices have been identified as an important environmental factor related to children's appetitive traits (9, 24–26). Parent feeding practices and infant/child appetitive traits influence each other in contemporaneous, bidirectional, and transactional ways (27). Parent feeding practices are also influenced by parent cognitions such as attributions for the infant's behavior, perceptions of child/infant's weight as being too high or too low, or their own dieting and weight control cognitions (28, 29). Galloway et al. (20) linked parent feeding practices with child appetite phenotypes to show that parental pressure to eat was greater for children with a "picky eater" phenotype and lower for children with a "joyful" eating phenotype. Similarly, Fernandez et al. (21) observed differences in parent feeding between their groups of fussy eating phenotype trajectories. However, presently, the prevailing approach has been to associate such factors with individual appetitive traits rather than with infant appetitive phenotypes or phenotype trajectories. The role of parent feeding practices in appetitive phenotype trajectories of infants is therefore unclear and requires further exploration.

The present research, therefore, seeks to understand the early emergence of appetitive trait phenotypes in infants in the first year of life. The main aims were to (1) identify possible infant appetite phenotype trajectories, (2) examine relationships between infant appetite phenotype trajectories and infant/parent factors including infant weight and parent feeding practices.

MATERIALS AND METHODS

This was a longitudinal cohort study of infants and their parents recruited through an early parenting support service in Australia. Participants were asked to complete three surveys (time 1, time 2, and time 3), ∼3 months apart, beginning when their infant was aged <6 months.

Recruitment

Parents were recruited *via* Tresillian Family Care Centers, an early parenting support service (https://www.tresillian.org.au/) in New South Wales, Australia. At the Tresillian centers, flyers and posters were displayed around the buildings and nurses handed them to parents. Interested parents were then provided a Plain Language Statement and were given a hard copy of the questionnaire if they chose to participate. Parents returned the completed questionnaire to a sealed box at their Tresillian Center, which was subsequently collected by research staff. Parents were also recruited *via* advertisements on the Tresillian Facebook group. With this method, if parents responded to the advertisement they were linked to an electronic version of the Plain Language Statement and survey (which was hosted on SurveyGizmo). All participants who indicated a willingness at baseline to be contacted for follow-up and provided their email address were emailed an invitation to complete the subsequent survey 3 months after each survey completion, with reminders sent 1 week after the initial invitation. Surveys were hosted on SurveyGizmo. Eligibility criteria were: parent of an infant <6 months of age, parent aged 18 years, and able to read and write in English. Participants were excluded from analysis if their infant was >6 months of age at baseline, born at <35 weeks gestation, <2,500 g birthweight, living outside Australia, or had a health condition that affected feeding. Participants were offered the opportunity to enter into a draw to win one of two iPads. The University of Technology Sydney Human Research Ethics Committee (REF NO. 2015000528) and the Sydney Local Health District Human Research Ethics Committee (Protocol No X15-0233) granted ethical approval for the study.

Questionnaire

Socio-Demographic Characteristics and Potential Confounders

The self-reported questionnaire included demographic variables: infant age and gender, parity, parent age and gender, parent relationship with child, parent level of feeding responsibility, infant feeding mode (breastfed, formula-fed, mixed-fed), and parent education level and country of birth. Potential confounders were infant feeding mode and several demographic characteristics: parent's age, parent's country of birth (Australia/other), parent's education (university/no university; categories collapsed from no formal qualification, finished year 12, post-school certificate, and university degree to ensure enough participants in each category), infant's gender (male/female), infant's age at baseline, and if ever formula-fed (yes/no).

Infant Appetitive Traits

Appetitive traits were measured with the BEBQ (2). The BEBQ consists of 18 items across four subscales (food responsiveness, enjoyment of food, slowness in eating, satiety responsiveness) and one single-item subscale (general appetite). The responses were recorded on Likert scales, ranging from 1 to 5 (never to always). After reversal of appropriate items, the item scores of each subscale were averaged to obtain a continuous score for each eating behavior. The BEBQ was originally designed to be a retrospective measure. However, in the present study, parents were asked about their infant's current behaviors. As such, wording of BEBQ items was changed to present tense (e.g., "my baby loved milk" was changed to "my baby loves milk"). The tool has shown good internal reliability (Cronbach's alpha coefficient of 0.62–0.77 at T1, 0.57–0.73 at T2, and 0.63–0.74).

Infant's Weight and Length

In each survey, parents reported their infant's most recent weight, length, and date of measurement from the infant's health record. Infant weight and length measurements recorded in the health record are taken at regular health check-ups with a health professional (e.g., nurses, general practitioners) using appropriate equipment. At the baseline survey, parents also reported their infant's birth weight and length recorded in their infant's health record (plus any measurements taken at a Tresillian center) and the date at which they were taken. To calculate the BMI z-scores, the World Health Organization's age- and gender-specific growth charts were used (30). BMI z-scores were used as a continuous variable.

Parent Cognitions and Characteristics

Parent perceptions of their infant's weight (underweight, about right, overweight), perception of their baby as being easier or more difficult than others, and parent self-reported height and weight (BMI) were considered as parent cognitions and characteristics.

Parent Feeding Practices

Parent feeding practices were measured with the Feeding Practices and Structure Questionnaire (FPSQ) for infants and toddlers (31). The FPSQ is theoretically grounded in the concept of authoritative feeding measuring both a parent's responsiveness to their child and provision of structure around mealtimes. The FPSQ infant and toddler version can either be used with parents who currently milk-feed their child (18 items) or solid-feed their child (21 items). At times 1 and 2 the milk feeding version was administered and at time 3 the solid feeding version was offered to parents who were predominantly solid-feeding (3+ meals or snacks per day) and the milk version to parents who were feeding solid foods <3 times per day. Four subscales of feeding practices were assessed: feeding on demand *vs*. feeding routine (e.g., "I let my baby decide when she/he would like to have a feed," higher scores indicated more feeding on demand), using food to calm (e.g., "I feed my baby to make sure that she/he does not get unsettled or cry"), persuasive feeding (e.g., "If my baby indicates she/he is not hungry, I try to get him to feed anyway"), and parent-led feeding (e.g., "I feed my baby for a set time"). Responses were recorded on Likert scales, ranging from 1 to 5 (never to always). After reversal of appropriate items, the item scores of each subscale were averaged to obtain a continuous score for each feeding practice. This measurement tool was developed and validated in the current sample with good psychometric indicators, it showed good internal reliability with all Cronbach's alphas being above 0.7 (31).

Statistical Analysis

The statistical analyses were conducted using Stata 16 (Stata Corp., College Station, TX, United States). Group-based trajectory modeling was utilized to identify the appetitive phenotype trajectories using continuous scores of the five scales from the BEBQ (satiety responsiveness, slowness in eating, food responsiveness, general appetite, and enjoyment of food) across the three times. The best-fitting model was determined based on the statistical model fit criteria, the class size, and the interpretation of the classes. The statistical criteria examined were the Bayesian Information Criteria (BIC), Consistent Akaike's Information Criteria (CAIC), Approximate Weight of Evidence Criterion (AWE), and the log-likelihood (32). The model that minimized the value of the BIC, CAIC, AWE, and the log-likelihood was determined to be the best fit statistically (32). The optimal number of classes was identified by analyzing 1-class through to 4-class models, with several polynomial types (linear, quadratic, and cubic) (32). The class sizes should be of sufficient size to examine the differences between the trajectory groups while class interpretation was based on looking at the average characteristics for the different variables included in the classes. Missing values were assumed to be missing completely at random, which was confirmed by checking each variable with the complete case.

Next, the mean and standard deviation or number and percentage of infant and parent characteristics, parent feeding practice, and cognitions were calculated for all participants, as well as for each appetitive phenotype. Chi-square, Fisher's exact test, and linear regression were used to test for associations between characteristics of infants and parents, parent feeding practice, and cognitions and Phenotypes.

Multilevel modeling was used to examine change in parent feeding practices and child BMI *z*-score over time by Phenotype. Participants had to have child BMI *z*-scores or parent feeding practices measured at least two of the times to be included in the analysis since multilevel modeling permits subjects with missing outcome data at some of the time points (33). Model 1 included outcome measures (i.e., child BMI *z*-score and parent feeding practices) by time. Model 2 included outcomes measures by time, appetitive phenotype trajectory groups, and time * appetitive phenotype trajectory groups. While Model 3 included Model 2 plus potential confounders (parent's age, parent's country of birth, parent's education, child's gender, child's age, and BMI *z*-score at birth).

A multilevel linear regression model was used to model the outcome measures (child BMI *z*-score and parent feeding practices) by time (model 1) to determine if child BMI *z*-score and parent feeding practices changed over time for all participants. For child BMI *z*-score, this examination was from birth to time 3, for parent feeding practices this examination was from time 1 to time 3. Likelihood ratio tests were used to determine if the model fit improved by including a random slope in addition to a random intercept. It was determined that the inclusion of a random slope was better for assessing the change in BMI *z*-score over time. However, including a random intercept only was better for assessing the change in parent feeding practices over time. To assess whether change in child BMI *z*-score and parent feeding practices over time differed depending on the Phenotype, an interaction between Phenotype and time was included in the model, in addition to the main effect of time and Phenotype (model 2). Potential confounding variables were included next (model 3). Phenotype 1 was considered as the reference category in models 2 and 3.

To interpret the interaction effects, a *post-hoc* analysis was conducted (predictive margins test) (34) to estimate the change in child BMI *z*-score and parent feeding practices over time for each of the three multi-trajectory appetitive phenotype groups.

RESULTS

Sample Characteristics

Table 1 shows the characteristics at time 1 of the total sample and for each appetitive phenotype trajectory group. In total, 445 provided some data; 65 participants were excluded, leaving 380 participants at baseline, 178 at time 2, and 154 at time 3 (**Table 1**). At time 1, just over half of the participating infants were men (54.8%) and all but one (father) was the infant's mother. The mean age of the children at time 1 was 98 (range: 5–183) days, at time 2 it was 198 (98–294), and at time 3 it was 303 (193–401) days. The mean BMI *z*-score for all children at birth was −0.08 (SD = 1.17), at time 1 it was −0.28 (SD = 1.31), at time 2 it was 0.27 (SD=1.35), and the mean BMI *z*-score at time 3 was 0.49 (SD = 1.37). Of the 380 children who participated at baseline, 335 (88%) had BMI *z*-score reported at least twice, while 182 (48%) had parent feeding practices reported at least twice, to enable inclusion in the longitudinal analysis. Other reasons for exclusion were birthweight < 2,500 g, living outside of Australia, gestation <35 weeks, if the infant was older than 6 months at baseline, or had a health condition affecting feeding.

Appetitive Phenotype Trajectories

The three-group solution of multi-trajectory appetitive phenotype groups, herein called "Phenotypes," was chosen based on class size, interpretation, and statistical model fit (lowest values for LL). **Figure 1** shows the mean for each appetitive trait trajectory within each phenotype at each time point. The majority ($n = 192$; 51%) of infants were in Phenotype 2 (see description below), with Phenotype 3 representing 28% ($n = 107$) of the sample, and the remaining 21% ($n = 81$) of infants in Phenotype 1.

The appetitive traits at each time point for each appetitive phenotype trajectory group are shown in **Table 2**. At baseline, Phenotype 1 had the lowest mean score over time for enjoyment of food, food responsiveness, and general appetite while having the highest score for satiety responsiveness and slowness in eating, suggesting a more "food avoidant" phenotype. In contrast, Phenotype 3 and Phenotype 2 both had high scores for the enjoyment of food. General appetite was particularly high in Phenotype 3, coupled with the highest scores for food responsiveness and lowest scores for satiety responsiveness. Phenotype 2 represented a relatively balanced phenotype at baseline, scoring relatively high on "food approach" appetitive traits (particularly enjoyment of food), but somewhere in between the two other phenotypes. In terms of changes over time, mean score differences in the appetitive traits scores across the three multi-trajectory phenotype groups were similar at time 2 and time 3, yet there were differences in the trajectories of the BEBQ subscales: Phenotype 1 showed increasing enjoyment of food and general appetite, along with decreasing slowness in eating, food responsiveness, and satiety responsiveness. Phenotype 2 showed stable enjoyment of food, increasing general appetite, and decreasing slowness in eating, satiety responsiveness, and food responsiveness. Phenotype 3 also showed decreasing slowness in eating and food responsiveness, along with increasing general appetite, while enjoyment of food remained relatively stable at high levels and satiety responsiveness relatively stable at low levels.

Characteristics of Infants and Parents According to Phenotypes

As shown in **Table 1**, compared to infants in Phenotypes 2 or 3, infants in Phenotype 1 were more likely to be formula fed ($p = 0.016$). There was no evidence of differences in the other measured infant or parent characteristics according to the multi-trajectory appetitive phenotype group.

Associations Between Parent Feeding Practices and Phenotypes

Model 1 showed that "feeding on demand" [0.69, 95% CI (0.62, 0.77)], "persuasive feeding" [0.22, 95% CI (0.16, 0.29)], and

TABLE 1 | Characteristics of the participants at time 1 and by Phenotype ($n = 380$).

Variable	All participants	Phenotype 1 (n = 81, 21.32%)	Phenotype 2 (n = 192, 50.53%)	Phenotype 3 (n = 107, 28.16%)	P-value
***n* (%) or mean (SD)**					
Infant characteristics					
BMI *z*-score at birth	−0.08 (1.17)	−0.13 (1.03)	−0.17 (1.27)	0.11 (1.07)	0.128
Child age (days)	98.09 (47.39)	101.96 (43.63)	98.86 (49.00)	93.78 (47.27)	0.192
Child gender					0.139
Male	206 (54.79)	36 (45.00)	108 (57.14)	62 (57.94)	
Female	170 (45.21)	44 (55.00)	81 (42.63)	45 (42.45)	
Ever formula fed					**0.016***
Yes	138 (36.32)	40 (49.38)	66 (34.55)	32 (29.63)	
No	242 (63.68)	41 (50.62)	125 (65.45)	76 (70.37)	
Parent characteristics					
Parent education					0.713
University	219 (59.67)	49 (63.64)	111 (59.04)	59 (58.42)	
No university	148 (40.33)	28 (36.36)	77 (40.96)	43 (42.16)	
Parent age (years)					0.689
29 and under	149 (39.95)	27 (33.75)	77 (40.96)	45 (42.86)	
30–34	146 (39.14)	36 (45.00)	73 (38.83)	37 (35.24)	
35 and over	78 (20.91)	17 (21.25)	38 (20.21)	23 (21.90)	
Country of birth					0.148
Australia	318 (85.71)	73 (92.41)	157 (83.96)	88 (83.81)	
Other	53 (14.29)	6 (7.59)	30 (16.04)	17 (16.19)	
Parent BMI	27.75 (6.09)	27.63 (6.39)	27.93 (6.01)	27.52 (6.04)	0.901

**p* < 0.05. *Bold values indicate statistical significance.*

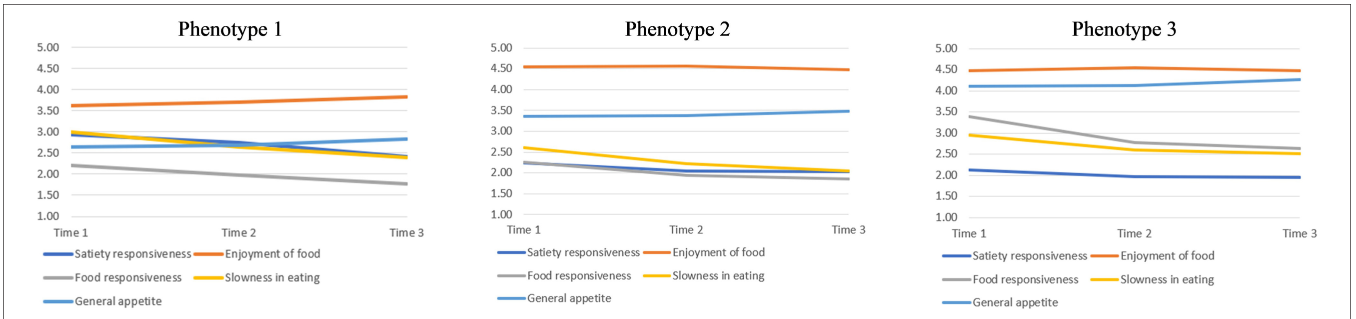

FIGURE 1 | The multi-trajectory appetitive phenotype groups (Phenotype 1, Phenotype 2, and Phenotype 3, respectively) and their Baby Eating Behavior Questionnaire (BEBQ) subscale trajectories.

"parent-led feeding" [0.19, 95% CI (0.13, 0.24)] increased on average between time 1 and time 3 for all phenotypes, while "using food to calm" [−0.31, 95% CI (−0.37,−0.25)] decreased between time 1 and time 3 for all phenotypes (**Tables 3–6**). The estimates of subsequent models (2 and 3) from the multilevel models are also presented in **Tables 3–6**. There was evidence that change in "persuasive feeding" differed according to infant phenotypes (**Figure 2**). Findings from the *post-hoc* analysis showed that Phenotype 2 had the greatest increase in "persuasive feeding" over time [0.30; 95% CI (0.12, −0.47)], while Phenotype 3 [0.21; 95% CI (0.01, −0.39)] and Phenotype 1 [0.02; 95% CI (−0.13, 0.17)] showed less increase over time. There was no evidence that the change in "feeding on demand," "parent-led feeding," or "using food to calm" over time differed according to the phenotypes (**Figures 3–5**).

Associations Between Parent Cognitions and Infant Phenotypes

Parents reported that compared to the other appetitive phenotypes, at time 1 infants in Phenotype 1 were more likely ($p = 0.001$) to be seen as "more difficult than average," with a similar finding at time 2 ($p = 0.018$) and 3 ($p = 0.017$) (**Table 7**). The majority of parents indicated that their infant's weight was "about right" at each time, with statistical significance noted between the phenotypes at time 1 ($p = 0.012$), but not at time 2 and time 3.

TABLE 2 | Appetitive traits (Baby Eating Behavior Questionnaire) and feeding practices scores for each time point according to Phenotypes.

Variable (BEBQ subscales)	All participants (n = 380)	Phenotype 1 (n = 81, 21.32%)	Phenotype 2 (n = 192, 50.53%)	Phenotype 3 (n = 107, 28.16%)
Mean (SD)				
Time 1 (mean age in days = 80)				
Satiety responsiveness	2.35 (0.79)	2.94 (0.93)	2.23 (0.66)	2.12 (0.66)
Slowness in eating	2.78 (0.84)	3.00 (0.90)	2.61 (0.77)	2.95 (0.83)
Food responsiveness	2.57 (0.74)	2.20 (0.60)	2.26 (0.49)	3.38 (0.58)
General appetite	3.42 (0.93)	2.63 (0.80)	3.36 (0.73)	4.12 (0.81)
Enjoyment of food	4.33 (0.58)	3.62 (0.56)	4.55 (0.43)	4.47 (0.39)
Feeding on demand	2.02 (0.84)	2.34 (0.09)	2.01 (0.07)	1.81 (0.07)
Food to calm	2.54 (0.83)	2.49 (0.08)	2.38 (0.06)	2.84 (0.08)
Parent-led feeding	1.62 (0.69)	1.83 (0.07)	1.58 (0.05)	1.55 (0.07)
Persuasive feeding	1.94 (0.75)	2.22 (0.09)	1.75 (0.05)	2.08 (0.08)
Time 2 (mean age in days = 171)				
Satiety responsiveness	2.17 (0.74)	2.75 (0.80)	2.04 (0.68)	1.96 (0.58)
Slowness in eating	2.42 (0.73)	2.65 (0.78)	2.22 (0.65)	2.60 (0.74)
Food responsiveness	2.18 (0.68)	1.97 (0.49)	1.94 (0.61)	2.77 (0.57)
General appetite	3.45 (0.86)	2.69 (0.75)	3.37 (0.71)	4.12 (0.63)
Enjoyment of food	4.37 (0.59)	3.70 (0.48)	4.56 (0.43)	4.55 (0.53)
Feeding on demand	2.22 (0.83)	2.47 (0.13)	2.80 (0.09)	1.92 (0.10)
Food to calm	2.41 (0.85)	2.38 (0.13)	2.22 (0.08)	2.76 (0.12)
Parent-led feeding	1.78 (0.67)	1.97 (0.11)	1.78 (0.08)	1.62 (0.08)
Persuasive feeding	1.84 (0.64)	2.10 (0.12)	1.66 (0.06)	1.94 (0.09)
Time 3 (mean age in days = 271)				
Satiety responsiveness	2.06 (0.76)	2.41 (1.06)	2.03 (0.70)	1.93 (0.60)
Slowness in eating	2.25 (0.73)	2.40 (0.70)	2.04 (0.64)	2.52 (0.78)
Food responsiveness	2.08 (0.68)	1.76 (0.55)	1.85 (0.55)	2.63 (0.62)
General appetite	3.62 (0.99)	2.84 (0.85)	3.48 (0.88)	4.26 (0.85)
Enjoyment of food	4.37 (0.50)	3.83 (0.56)	4.48 (0.39)	4.49 (0.45)
Feeding on demand	3.49 (0.70)	3.58 (0.15)	3.57 (0.09)	2.34 (0.10)
Food to calm	1.83 (0.54)	1.81 (0.13)	1.83 (0.07)	1.86 (0.08)
Parent-led feeding	1.94 (0.68)	1.99 (0.12)	1.96 (0.07)	1.89 (0.10)
Persuasive feeding	2.44 (0.65)	2.55 (0.13)	2.40 (0.08)	2.44 (0.10)

Subscales of the Baby Eating Behavior Questionnaire (BEBQ) (2) and Feeding Practices and Structure Questionnaire (FPSQ) for infants and toddlers, both with a possible range from 1 to 5 (31).

TABLE 3 | Multilevel models of associations between Phenotypes and "parent-led feeding" over three times (n = 182).

Fixed effects	Model 1			Model 2			Model 3[a]		
	Coefficient	95% CI	*P*-value	Coefficient	95% CI	*P*-value	Coefficient	95% CI	*P*-value
Time	0.19	0.13, 0.24	**<0.001*** **	0.10	−0.02, 0.23	0.112	0.10	−0.03, 0.23	0.133
Appetitive phenotype									
Phenoty pe 1				–	–	–	–	–	–
Phenotype 2				−0.30	−0.54, −0.07	**0.011***	−0.34	−0.58, −0.10	**0.005****
Phenotype 3				−0.33	−0.59, −0.08	**0.010***	−0.31	−0.57, −0.05	**0.018***
Appetitive phenotype × time									
Phenotype 1 × time				–	–	–	–	–	–
Phenotype 2 × time				0.13	−0.02, 0.28	0.096	0.14	−0.02, 0.29	0.081
Phenotype 3 × time				0.07	−0.09, 0.23	0.398	0.07	−0.09, 0.23	0.386

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. Bold values indicate statistical significance.
[a]Model 3 adjusted for parent's age, parent's country of birth, parent's education, child's gender, child's age, and BMI z-score at birth.

TABLE 4 | Multilevel models of associations between Phenotypes and "persuasive feeding" over three times ($n = 182$).

Fixed effects	Model 1			Model 2			Model 3[a]		
	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value
Time	0.22	0.16, 0.29	**<0.001*** **	0.03	−0.12, 0.18	0.677	0.02	−0.13, 0.17	0.789
Appetitive phenotype									
Phenotype 1				–	–	–	–	–	–
Phenotype 2				−0.64	−0.88, −0.41	**<0.001*** **	−0.67	−0.92, −0.42	**<0.001*** **
Phenotype 3				−0.31	−0.57, −0.05	**0.019***	−0.34	−0.61, 0.06	**0.015***
Appetitive phenotype × time									
Phenotype 1 × time				–	–	–	–	–	–
Phenotype 2 × time				0.29	0.12, 0.46	**0.001****	0.30	0.12, 0.47	**0.001****
Phenotype 3 × time				0.17	−0.01, 0.35	0.071	0.21	0.01, 0.39	**0.030***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Bold values indicate statistical significance.
[a] Model 3 adjusted for parent's age, parent's country of birth, parent's education, child's gender, child's age, and BMI z-score at birth.

TABLE 5 | Multilevel models of associations between Phenotypes and "feeding on demand" over three times ($n = 182$).

Fixed effects	Model 1			Model 2			Model 3[a]		
	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value
Time	0.69	0.62, 0.77	**<0.001*** **	0.55	0.38, 0.72	**0.001****	0.56	0.38, 0.73	**<0.001*** **
Appetitive phenotype									
Phenotype 1				–	–	–	–	–	–
Phenotype 2				−0.37	−0.66, −0.08	**0.011***	−0.32	−0.60, −0.03	**0.032***
Phenotype 3				−0.53	−0.84, −0.22	**0.001***	−0.44	−0.75, −0.12	**0.007****
Appetitive phenotype × time									
Phenotype 1 × time				–	–	–	–	–	–
Phenotype 2 × time				0.20	−0.00, 0.40	0.050	0.19	−0.01, 0.40	0.065
Phenotype 3 × time				0.15	−0.06, 0.36	0.158	0.14	−0.08, 0.36	0.200

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Bold values indicate statistical significance.
[a] Model 3 adjusted for parent's age, parent's country of birth, parent's education, child's gender, child's age, and BMI z-score at birth.

TABLE 6 | Multilevel models of associations between Phenotypes and "using food to calm" over three times ($n = 182$).

Fixed effects	Model 1			Model 2			Model 3[a]		
	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value	Coefficient	95% CI	P-value
Time	−0.31	−0.37, −0.25	**<0.001*** **	−0.36	−0.51, −0.21	**<0.001*** **	−0.37	−0.52, −0.22	**<0.001*** **
Appetitive phenotype									
Phenotype 1				–	–	–	–	–	–
Phenotype 2				−0.16	−0.42, 0.11	0.249	−0.20	−0.47, 0.07	0.153
Phenotype 3				0.28	−0.02, 0.56	0.064	0.21	−0.09, 0.51	0.172
Appetitive phenotype × time									
Phenotype 1 × time				–	–	–	–	–	–
Phenotype 2 × time				0.12	−0.06, 0.29	0.194	0.11	−0.07, 0.29	0.212
Phenotype 3 × time				−0.02	−0.21, 0.16	0.806	−0.00	−0.19, 0.19	0.974

***$p < 0.001$. Bold values indicate statistical significance.
[a] Model 3 adjusted for parent's age, parent's country of birth, parent's education, child's gender, child's age, and BMI z-score at birth.

Associations Between Infant BMI *z*-Score and Infant Phenotypes

Model 1 showed that BMI *z*-scores increased on average between birth and time 3 [0.21, 95% CI (0.12, 0.29)]. The estimates of subsequent models (2 and 3) from the multilevel models are presented in **Table 8**. There was no evidence that BMI *z*-score change over time differed depending on the phenotype. However, an inspection of trends showed that children in Phenotype 3

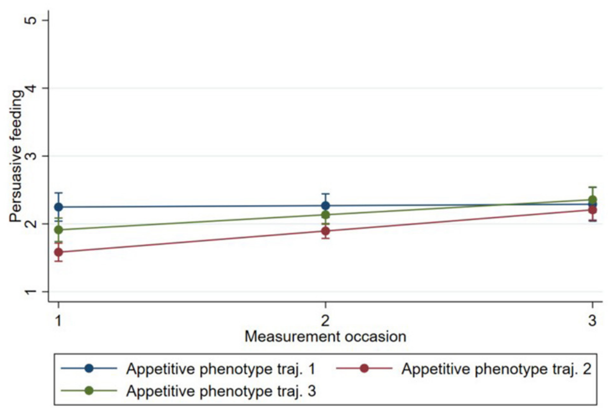

FIGURE 2 | Change in "persuasive feeding" over time by Phenotype based on estimates from fully adjusted multilevel model of the association between Phenotype and persuasive feeding.

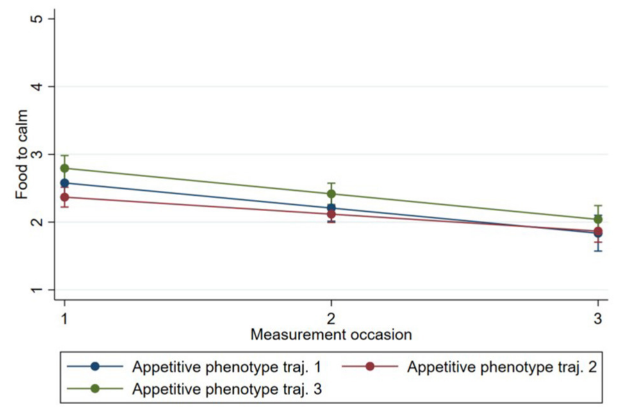

FIGURE 4 | Change in "using food to calm" over time by Phenotype based on estimates from fully adjusted multilevel model of the association between Phenotype and "using food to calm".

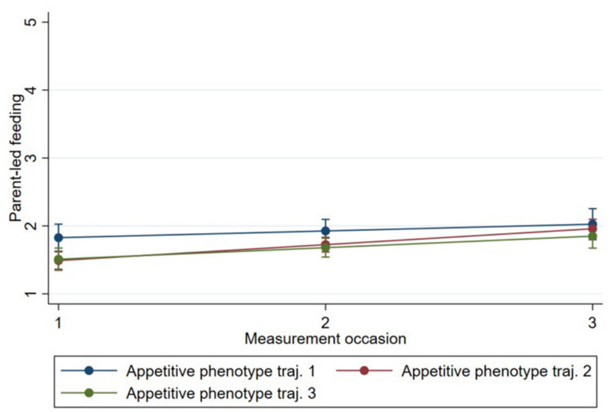

FIGURE 3 | Change in "parent-led feeding" over time by Phenotype based on estimates from fully adjusted multilevel model of the association between Phenotype and "parent-led feeding".

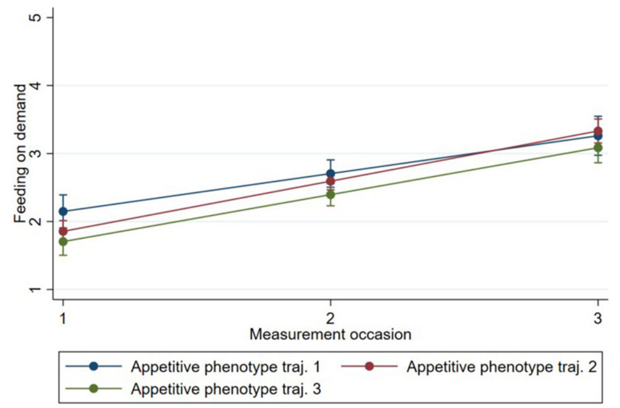

FIGURE 5 | Change in "feeding on demand" over time by Phenotype based on estimates from fully adjusted multilevel model of the association between Phenotype and "feeding on demand".

had the highest BMI *z*-score at birth, yet findings from the *post-hoc* analysis showed that children in Phenotype 3 had the smallest incline of BMI *z*-score over time [−0.07; 95% CI (−0.31, 0.17)]. Phenotypes 1 and 2 had lower BMI *z*-score at birth, while Phenotype 2 had the highest BMI *z*-score at time 3. These findings are illustrated in **Figure 6**.

DISCUSSION

This study described three empirically distinct appetitive phenotype trajectory groups among a group of Australian infants labeled as (Phenotype 1) food avoidant trending toward low food approach (Phenotype 2), balanced, and (Phenotype 3) high and continuing food approach. There was no evidence to support infant or parent demographic characteristics, nor infant BMI *z*-score differing according to the phenotypes. However, for the measured parent feeding practices, persuasive feeding changed over time according to phenotypes while for parent cognitions, perceptions of the infant's weight and how difficult or easy they were differed according to the phenotypes. The findings provide novel evidence suggesting that distinct infant appetite phenotype trajectories emerge early in life, and may partly have their origins in both infant characteristics and eating experiences, as well as being related to parent feeding practices and cognitions. The findings aid our understanding of when and how appetite self-regulation develops and highlights the need for a greater focus on person-centered approaches to understanding appetite self-regulation in infancy.

Previous research has shown that differences in approaches to eating (appetitive traits) emerge early in life (1–3, 35). However, this body of work has primarily examined mean scores across individual appetitive traits, and not examined profiles of infants based on appetitive traits, as an appetitive phenotype, nor examined appetite phenotype trajectories either with single or

TABLE 7 | Parent cognitions according to Phenotypes.

	All participants (n = 380)	Phenotype 1 (n = 81, 21.32%)	Phenotype 2 (n = 192, 50.53%)	Phenotype 3 (n = 107, 28.16%)	*P*-value
***n* (%) or mean (SD)**					
Parent cognitions					
Perception of baby compared to others at time 1					**0.001****
Easier than average	162 (43.67)	23 (29.87)	93 (49.47)	46 (43.40)	
Average	139 (37.47)	28 (36.36)	72 (38.30)	39 (36.79)	
More difficult than average	70 (18.87)	26 (33.77)	23 (12.23)	21 (19.81)	
Perception of baby compared to others at time 2					**0.018***
Easier than average	89 (52.05)	13 (35.14)	55 (63.95)	21 (43.75)	
Average	65 (38.01)	18 (48.65)	24 (27.91)	23 (47.92)	
More difficult than average	17 (9.94)	6 (16.22)	7 (8.14)	4 (8.33)	
Perception of baby compared to others at time 3					**0.017***
Easier than average	80 (54.42)	7 (28)	45 (60.81)	28 (58.33)	
Average	45 (30.61)	9 (36)	21 (28.38)	15 (31.25)	
More difficult than average	22 (14.97)	9 (36)	8 (10.81)	5 (10.42)	
Perception of baby's weight at time 1					**0.012***
Underweight	19 (5.12)	10 (12.99)	4 (2.13)	5 (4.72)	
About right	336 (90.57)	65 (84.42)	176 (93.62)	95 (89.62)	
Overweight	16 (4.31)	2 (2.6)	8 (4.26)	6 (5.66)	
Perception of baby's weight at time 2					0.649
Underweight	6 (3.51)	2 (5.41)	4 (4.65)	0 (0.00)	
About right	155 (90.64)	33(89.19)	77 (89.53)	45 (93.75)	
Overweight	10 (5.85)	2 (5.41)	5 (5.81)	3 (6.25)	
Perception of baby's weight at time 3					0.278
Underweight	8 (5.44)	3 (12)	4 (5.41)	1 (2.08)	
About right	130 (88.44)	21 (84)	67 (90.54)	42 (87.50)	
Overweight	9 (6.12)	1 (4)	3 (4.05)	5 (10.42)	

$^{*}p < 0.05$, $^{**}p < 0.01$. Bold values indicate statistical significance.

TABLE 8 | Multilevel models of associations between Phenotypes and BMI z-score over four times (n = 335).

Fixed effects	Model 1			Model 2			Model 3[a]		
	Coefficient	95% CI	*P*-value	Coefficient	95% CI	*P*-value	Coefficient	95% CI	*P*-value
Time	0.21	0.12, 0.29	**<0.001*****	0.19	0.01, 0.37	**0.041***	0.19	0.00, 0.37	**0.046***
Appetitive phenotype									
Phenotype 1				–	–	–	–	–	–
Phenotype 2				−0.11	−0.41, 0.18	0.453	−0.06	−0.36, 0.24	0.687
Phenotype 3				0.05	−0.28, 0.38	0.771	0.09	−0.24, 0.43	0.589
Appetitive phenotype × time									
Phenotype 1 × time				–	–	–	–	–	–
Phenotype 2 × time				0.07	−0.15, 0.29	0.545	0.07	−0.15, 0.29	0.529
Phenotype 3 × time				−0.06	−0.29, 0.18	0.635	−0.07	−0.31, 0.17	0.560

$^{*}p < 0.05$, $^{***}p < 0.001$. Bold values indicate statistical significance.
[a]Model 3 adjusted for parent's age, parent's country of birth, parent's education, child's gender, child's age, and formula feeding.

multiple indicators of appetite. Consequently, the heterogeneity in infant appetite profiles across the course of infancy has often been overlooked, and therefore our understanding of the developmental course of appetite self-regulation is hindered. Our findings provide new evidence that distinct phenotypes of appetitive trait trajectories emerge early in infancy. In the present study, Phenotype 2 (50.53% of infants) was considered "balanced" (normal), showing a relatively high general enjoyment of food and appetite with decreasing satiety responsiveness and food responsiveness over time, starting from a moderate level.

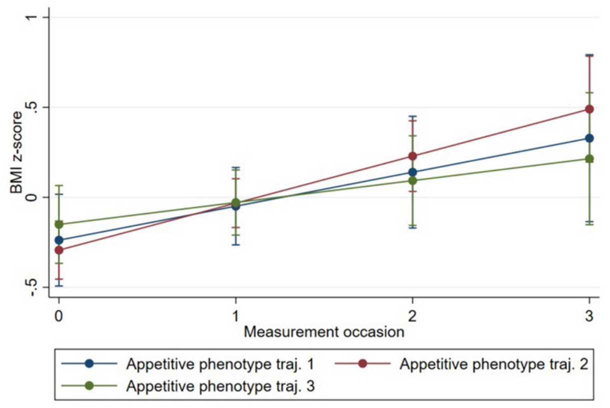

FIGURE 6 | Change in infant BMI *z*-score over time by Phenotype based on estimates from fully adjusted multilevel model of the association between Phenotype and infant BMI *z*-score.

Phenotype 1 (21.32% of infants) was relatively low in food enjoyment and appetite while being relatively higher in satiety responsiveness and slowness in eating, with food responsiveness decreasing over time, suggesting that these children have a food avoidance phenotype initially. However, trajectories of the BEBQ subscales in Phenotype 1 are suggestive of a shift toward greater (but still relatively low) food approach tendencies over time with general appetite, enjoyment of food increasing at the same time as slowness in eating and satiety responsiveness are decreasing. Phenotype 3 (28.16% of infants), in contrast, was relatively higher in the enjoyment of food and appetite initially, while being low in satiety responsiveness. This phenotype showed increasing levels of general appetite in combination with reduced levels of slowness in eating while maintaining high levels of enjoyment of food and low levels of satiety responsiveness. These early signs suggest that this appetitive phenotype trajectory group is likely to promote excess weight gain if the trajectories were to continue along the same path. It is also worth noting that this phenotype did not differ from the others in terms of parent demographics (e.g., education level, country of birth), nor child's biological gender highlighting the need to tailor personalized obesity prevention approaches to their unique appetitive trait profile and influences upon it, rather than demographic characteristics (23). Infancy (36) toddlerhood, and the preschool years are developmental periods when children rapidly learn about food and eating (37), and it would be valuable to explore whether these trends continue across later periods of development.

Phenotype 1, which appeared to have a food avoidant profile at baseline, could also be considered in obesity prevention efforts. The trajectories observed within this phenotype included increasing enjoyment of food and general appetite along with decreasing slowness in eating, emulating the trends seen in Phenotype 3 despite different mean levels. Although there are relatively fewer studies with infants than there are with children, a systematic analysis of the BEBQ identified prospective associations between variables measuring food responsiveness, enjoyment of food, general appetite, and higher adiposity; while satiety responsiveness and slowness in eating were prospectively associated with lower adiposity (4). It could therefore be expected that in the present study, Phenotype 1 would be associated with a lower BMI *z*-score, and Phenotype 3 with a higher BMI *z*-score. While there was no evidence that BMI *z*-scores differed dependent on phenotype over time in the present study, it is likely that any effects of the appetitive phenotypes on BMI would only be observed over longer timeframes due to the cumulative direct and indirect effects of the appetitive phenotype profiles on food intakes (27). It is also worth noting that infants in Phenotype 1 differed from the other phenotypes in other characteristics: parents perceived them as "more difficult than average" at both time 1 and time 2, more infants were perceived as being underweight at time 1, and they were more likely to have been formula-fed. It is possible that, broadly, these infants inherently have low interest in food and smaller appetites, along with being seen by their parents as having more difficult temperaments and being underweight early on. This broadly supports the ideas outlined in biopsychosocial models of children's eating and weight, whereby combinations of infant characteristics, parent perceptions, and parent feeding practices, like those observed here, can help explain trends in the development of children's appetitive traits, and over greater time periods where additive effects may be evident, may also influence weight (27).

The examination of feeding practices revealed that "feeding on demand," "persuasive feeding," and "parent-led feeding" increased over time, while "using food to calm" decreased over time for all three appetitive phenotype trajectory groups. However, of the four measured feeding practices, only the change in persuasive feeding was related to phenotype: Phenotype 2 had the greatest increase in persuasive feeding over time, while phenotypes 3, and 1 showed less increase over time. The "persuasive feeding" subscale represents non-responsive feeding practices that are likely to negatively impact the development of aspects of appetite self-regulation (31). Although it is speculative due to the short-term nature of the study, the upward trend in the BMI *z*-score observed in this group (**Figure 6**) may be at least partly attributed to the greater use of non-responsive parent feeding practices in this group. So, the findings suggest that while, in general, parent feeding practices change with children's development in many common ways, some differences can already be observed in the use of particular parent feeding practices according to infants' appetite phenotypes. This concurs somewhat with previous research showing that parental feeding practices are associated with appetitive phenotypes in children (20) and that parent feeding practices are both reactive to, and influence infant/child eating and weight (9, 10, 38). These findings highlight the need for future research over longer periods with age-appropriate repeated measurement of key constructs to identify how and why early parent feeding practices affect and are affected by infant appetitive phenotypes and can affect appetite infant self-regulation.

Strengths and Weaknesses

Strengths include a sample that involved a balanced proportion of male and female infants, and the use of an age- and feeding-mode appropriate measure of parent feeding practices. However, the present study was limited in its reliance upon a single informant, and is therefore subject to common method bias (e.g., potentially inflating correlations between parent perceptions of how easy/difficult the infant is and their appetitive traits) (39–41). It was also reliant upon the parent-reported BEBQ, which is subject to several biases and limitations including limited data on validity, and parent recall and social desirability bias, and poor factorial validity (35) and it was originally developed for use retrospectively with younger, exclusively milk-fed infants (2). The reliance upon parent-reported infant height and weight is also a limitation, although the use of the infant health record for weight and length measurements as well as using concurrent (rather than retrospective) measures of the BEBQ would have tempered some of these limitations. In addition, there are probably interrelations between variables such as between parent perceptions and infant appetitive traits, and these could not be teased out with the current study. There was also a lag between the date of weight/length measurements and the date at which parents completed the survey at each time point (a mean of 18 days at T1, 24 days at T2, and 34 days at T3), which reduces the precision of that variable. A combination of behavioral and parent-reported parent measures of infant appetitive characteristics as well as utilizing data from multiple informants (e.g., from more than one caregiver) would have strengthened the present research.

The present study examined infants over ∼6 months with parents enrolling in the study when their infants were aged <6 months of age. This meant that at each time point the age range of infants was wide, and this may have influenced the appearance of appetitive traits over time. It could be useful in future studies to limit each time point to a narrower age band. The present study was also relatively short in duration, while traversing the transition from milk to solid foods, which is a period of change and adjustment in parent feeding and infant eating. Feeding interactions change quickly with infants, and therefore we have captured a snapshot moment that might not be reflective of longer-term trends in infant eating and parent feeding interactions. To address this, studies of longer duration are needed to understand the different trajectories, how infants and parents within each of these trajectories change over time, and how they relate to a range of dietary and weight outcomes. The person-centered, group-based trajectory modeling approach allowed for distinct trajectories of infant eating behaviors to be examined. However, this approach is subject to limitations that affect the interpretability of findings. In particular, larger or different samples may result in different subgroups being identified, and so reproducibility of the current findings should be tested in other, larger samples. It should also be noted that missing data due to dropout was high. Multilevel models permit subjects with missing outcome data at some of the time points, so this helped reduce the risk of bias for the BMI z-score outcome. However, as we only had three time points for the feeding practices, the outcome risk of bias due to dropout may still be high. We also performed additional analyses to see if there was retention bias, with only parental education level being of concern: slightly more university-educated parents did not drop out of the survey (60% of the sample at T1 were university-educated while at T3 this was 70%), a common issue found in longitudinal studies relying on parents of young children. Future studies with larger sample sizes and lower dropout rates would be beneficial.

Future Directions

Looking forward, identifying and understanding early predispositions toward overeating, food avoidance, or healthy eating as well as the factors that explain their development is important for understanding how and why appetite self-regulation develops. In general, children's appetite self-regulation declines from infancy across childhood, although large individual differences are evident (42). Prior research on eating phenotypes has mostly examined older children and has utilized variable-centered approaches, and so the early origins of appetitive phenotypes are largely unknown. In studying the emergence of appetitive phenotypes and their changes in infancy, new insights are gained when examining individual differences in appetite self-regulation and its possible early origins. This information is needed to advance the theory and conceptualization of appetite self-regulation and to inform early intervention to address such traits before the development of overweight (43). The present research has provided new evidence that early in infancy there are signs that infants already have particular typologies of eating, and that these may set in train patterns of eating and possibly later weight outcomes. The present study also identified that these appetitive phenotypes appear to have their origins in both infant (e.g., birth weight) and parent characteristics and behaviors (e.g., perception of the infant, feeding practices). To better explain the processes underlying the development of infant appetitive phenotypes, studies informed by biopsychosocial models of eating and weight are needed. The biological origins of children's appetite and temperament are important components of developmental pathways, along with the psychological and social contexts that interact with these biological characteristics. Future studies that are able to elucidate the complex changes in both infant appetitive characteristics along with the factors that influence their development are needed (44). Looking beyond cross-sectional differences in children's phenotypes at baseline to understand developmental patterns of change and the processes explaining these changes will provide greater insights into the origins of, and influences on eating behaviors. These approaches will also help improve the utility of interventions aiming to improve children's diets and prevent excess weight gain by allowing for better matching of intervention features with infants' or family's needs (5, 13). In addition, appetitive phenotypes will be composed of several factors affecting eating and appetite and so will be a function of the selected measures. Further work to identify the relevant components of appetitive phenotypes, including their interactions and synergistic effects, across biological, behavioral and psychological factors of eating and appetite, with attendant appropriate measurement, is important for understanding trajectories of eating and appetite (5, 43). To that end, the study of appetitive traits in infants would be advanced by the development of additional age-appropriate tools and measurements beyond that of the BEBQ, that are suitable for different samples and contexts.

CONCLUSIONS

The present study identified three appetitive phenotype trajectory groups in infants. The majority of infants showed a persistent balanced profile, more than a quarter of infants had a profile that may indicate greater obesity risk, and around a fifth a profile that at baseline was largely food avoidant but showed trends of increasing food approach tendencies. Phenotype trajectory groups were related to infant formula feeding, and parent persuasive feeding practices and cognitions, but not to the trajectory of BMI *z*-score, nor parent or infant demographics. The findings provide preliminary evidence about the nature and origins of infant appetitive phenotypes and their trajectories, and therefore the possible origins of subgroup differences in appetite self-regulation in infants. Mechanistic and longer studies with sophisticated measurement of infant appetite and parent feeding are needed to further understand appetitive phenotype trajectories, their determinants, and links to dietary, health, and weight outcomes in later childhood.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, upon reasonable request. Please note that access to the data is subject to approval by an Ethics Committee.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Technology Sydney Human Research Ethics Committee (Ref No. 2015000528) and the Sydney Local Health District Human Research Ethics Committee (Protocol No. X15-0233) granted ethical approval for the study. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CGR, JA, CF, EJ, CR, and ED-W designed the study. CGR, JA, CF, CR, and ED-W collected the data. AB analyzed the data with input from CGR, JA, and EJ. CGR led the writing of the article. All authors reviewed, critiqued, and approved the manuscript.

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Validation of a Classroom Version of the Eating in the Absence of Hunger Paradigm in Preschoolers

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Eating in the absence of hunger (EAH), a measure of children's propensity to eat beyond satiety in the presence of highly palatable food, has been associated with childhood obesity and later binge eating behavior. The EAH task is typically conducted in a research laboratory setting, which is resource intensive and lacks ecological validity. Assessing EAH in a group classroom setting is feasible and may be a more efficient alternative, but the validity of the classroom assessment against the traditional individually-administered paradigm has not been tested. The objective of this study was to compare EAH measured in a classroom setting to the one-on-one version of the paradigm in a sample of Head Start preschoolers. Children ($n = 35$) from three classrooms completed both classroom and individual EAH tasks in a random, counterbalanced order. In the group condition, children sat with peers at their classroom lunch tables; in the individual condition, children met individually with a researcher in a separate area near their classroom. In both conditions, following a meal, children were provided free access to generous portions of six snack foods (∼750 kcal) and a selection of toys for 7 min. Snacks were pre- and post-weighed to calculate intake. Parents completed a survey of their child's eating behaviors, and child height and weight were measured. Paired *t*-tests and intraclass correlation coefficients were used to compare energy intake between conditions, and correlations between EAH intake and child BMI, eating behaviors, and parent feeding practices were examined to evaluate concurrent validity. Average intake was 63.0 ± 50.4 kcal in the classroom setting and 53.7 ± 44.6 in the individual setting, with no significant difference between settings. The intraclass correlation coefficient was 0.57, indicating moderate agreement between conditions. Overall, the EAH protocol appears to perform similarly in classroom and individual settings, suggesting the classroom protocol is a valid alternative. Future studies should further examine the role of age, sex, and weight status on eating behavior measurement paradigms.

Keywords: eating in the absence of hunger, disinhibited eating, children, measure, eating behavior

INTRODUCTION

Eating in the absence of hunger (EAH) measures the propensity to eat beyond satiety in response to the presence of highly palatable foods (1). EAH intake is a measure of hedonic eating (eating for pleasure, as opposed to homeostatic eating or in response to energy needs) (2) and is assumed to be an individual characteristic reflecting poorer appetite self-regulation. The underlying mechanisms that determine a child's tendency to engage in EAH are not well established, but may involve increased sensitivity and reactivity to food cues (i.e., "bottom-up" approach responses), and/or reduced capacity to self-regulate and inhibit such responses (i.e., "top-down" regulatory strategies) (3). Children with poorer ability to recognize internal satiety cues may also be at increased risk for EAH. EAH is associated with child overweight cross-sectionally (4–8) and has been shown to predict later adiposity (9, 10) and binge eating (11). Children who exhibit high EAH are particularly susceptible to excess energy intake in the current environment in which highly palatable foods are readily available. Exposure to food cues increases as children get older and spend more time in a variety of eating contexts. Thus, preventing increases in EAH early in life, especially among susceptible children, is an important target for obesity prevention.

The EAH task is traditionally conducted one-on-one in a controlled laboratory setting. Children consume a standardized meal to satiation followed by an *ad libitum* snack period in which they are provided with a variety of typically energy-dense, nutrient-poor foods, as well as alternative activities (e.g., toys, coloring supplies). EAH is operationalized as the number of calories consumed during the free-access period. Allowing for a high level of control and internal validity, EAH measured individually, in a laboratory or controlled environment, is considered the gold standard. Yet, assessing individual children in the laboratory is resource intensive. Not only are laboratory-based designs costly for the researcher, but requiring families to come to laboratory visits can limit the representativeness of a study sample, thus threatening external validity. Given that 61% of 3–5-year-olds in the US are enrolled in center-based childcare (12) and enrolled children eat up to 75% of their daily meals and snacks there (13), collecting EAH data in the classroom will allow researchers to access larger and more diverse samples of children in a cost-effective manner.

Although the feasibility of conducting EAH in a group classroom setting has been shown in previous studies (8, 14, 15), classroom assessment paradigms have not been validated against the traditional EAH task. Peer-influence in a group setting has the potential to change EAH kcal intake for some children. For example, data indicate children eat more snacks in the presence of friends vs. parents (16) and in larger vs. smaller groups (17). Therefore, it is critical to understand whether a classroom EAH protocol captures the same eating behavior construct as the laboratory task that was used in the majority of foundational literature on children's EAH behavior and its link with longer-term health outcomes. The purpose of this study is to compare a modified EAH protocol that can be conducted with a group of children in a classroom setting to the more traditional one-on-one version of the task in the same children. Furthermore, a limitation of earlier feasibility studies of EAH in a group setting is that known correlates of EAH and factors that have been shown to moderate the association between EAH and adiposity (i.e., child sex) were either not examined (15), or revealed mixed findings (8, 14). Therefore, this study also aims to determine concurrent and external validity by examining whether EAH is associated with child body mass index *z*-scores (BMIZ), and parent-reported child eating behaviors and whether observed associations hold across settings and among subgroups of children (e.g., age, sex, weight status).

MATERIALS AND METHODS

Participants

Participants were child-caregiver dyads recruited from three Head Start classrooms in Central Pennsylvania in fall 2019. A study information packet, including consent forms and a caregiver survey, was sent home with all children. An opt-out process was used for children's participation; parents who did not wish their child to participate in data collection completed an opt-out form and returned the form to their child's classroom. Children with allergies to the study foods were not eligible to participate. Caregivers were also invited to complete a survey packet, which included an implied consent form stating that caregivers could consent to their own participation by completing and returning the survey to their child's classroom or by mail through a prepaid envelope. Caregivers received a $20 gift card as compensation for completing the survey. Caregiver participation in the survey was not a requirement for child participation. Of 52 packets distributed, 3 parents elected to opt their child out of the study. Of 49 enrolled children, 35 completed both the classroom and individual EAH sessions. Reasons for incomplete data include child absence on the day of the classroom EAH ($n = 5$) or child refusal of the individual EAH session ($n = 9$; no children refused participation in the classroom session). Of these 35, 33 had completed caregiver questionnaires and 30 had BMI measurements.

Procedure

Participating children completed the EAH task in the preschool setting on two separate days under two conditions: (1) individually with a research assistant in a private space near the child's classroom (e.g., nearby office or conference room), and (2) with their classmates in a group session. Order of the two tasks was randomly assigned and counterbalanced, such that half of the children in each classroom completed the individual condition before the classroom condition, and half completed the individual condition after the classroom condition. In one classroom, 4 children who were absent on the day of the classroom EAH task completed the task together in the classroom on a separate make-up day. All procedures were approved by the Penn State University Institutional Review Board.

EAH Tasks

The EAH task was conducted after a Head Start-provided lunch in 2 classrooms and after breakfast in the third. For both the

TABLE 1 | Participant characteristics for $n = 35$ children included in analysis.

Variable	Mean (SD) or *n* (%)
Child characteristics	
Age, years	4.1 (0.6)
Sex, % female	16 (45.7%)
Race-ethnicity, %	
Non-Hispanic white	23 (79.3%)
Hispanic or Latino	6 (20.7%)
Overweight (BMI ≥ 85th percentile), %	14 (46.7%)
Parent characteristics	
Age, years	30.7 (5.9)
Sex, % female	30 (90.9%)
Race-ethnicity, %	
Non-Hispanic white	23 (79.3%)
Hispanic or Latino	6 (20.7%)
Relationship to child, %	
Parent	31 (93.9%)
Grandparent	2 (6.1%)
Highest educational level completed, %	
Less than high school	5 (15.2%)
High school graduate	22 (66.7%)
College graduate	6 (18.2%)
Relationship status, %	
Married	11 (33.3%)
Not married but living with partner	9 (27.3%)
Single	9 (27.3%)
Divorced/separated	4 (12.1%)
Income, %	
<$20,000	7 (21.2%)
$20,000–49,999	12 (36.4%)
≥$50,000	7 (21.2%)
Do not know	11 (33.3%)
Employment, %	
Employed full time	13 (39.4%)
Employed part-time	10 (30.3%)
Student	1 (3.0%)
Unemployed	7 (21.2%)
Other	2 (6.1%)
Overweight/obesity, %	21 (72.4%)
Supplemental Nutrition Assistance Program (SNAP) participant, %	21 (63.6%)
Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participant, %	20 (62.5%)
Household food insecurity, %	8 (24.2%)

Sample size varies for each variable due to missing data.

individual and classroom conditions, research staff recorded an estimate of children's intake at the lunch or breakfast meal (i.e., ate none, less than half, more than half, or all of food initially served). Both EAH tasks occurred within 20 min of completing the meal. For the individual condition, children were invited after a meal to join a research assistant in a separate area to complete the task. Children were seated at a desk or table with the research assistant next to them. The researcher then read children a brief story to orient them to a hunger/fullness scale consisting of drawings of a child with empty, half-full, and full stomachs. Children's comprehension of the scale was assessed, and they were asked to use the scale to rate their own current feeling of hunger/fullness. Because of limitations around rescheduling the classroom condition, we did not exclude or reschedule children who reported they were hungry, but instead used hunger rating to identify a subset of children for sensitivity analysis. Children were then asked to taste and rate small pieces of 6 snack items as "Yummy", "Just OK", or "Yucky" using a three point, smiley face scale. Once the taste ratings were completed, children were presented with a selection of small toys and generous portions of 6 snack foods (total available kcal=758): cheese crackers (22 g), corn chips (20 g), cheese puffs (18 g), mini chocolate sandwich cookies (28 g), fruit snacks (46 g), and mini shortbread fudge cookies (28 g) (**Supplemental Table 1**). Researchers told the children they were to sit quietly while they did some work elsewhere in the room, and that they could eat any of the snacks and play with any of the toys while they waited for the researcher to return. Children were given 7 min of free access to the snacks and toys; researchers stood away from children but within eyeshot during the free access period, and verbally checked on the child halfway through the 7 min period ("Is everything ok? I just have a little bit more work to do—I'll come back in a few more minutes and get the foods and toys"). At the end of 7 min, the snacks and toys were removed and children returned to their classroom.

In the classroom condition, after breakfast or lunch was completed, children moved to their classroom's circle time area where one research assistant read the story explaining the hunger/fullness rating scale to the class, while other research assistants set up for the EAH task at the classroom's lunch tables. Cardboard dividers were used to designate an individual section of the table for each child. Children were dismissed from the circle-time area back to the table, where researchers asked each child to rate their current level of hunger using the picture scale. Plates with sampling portions were distributed and children were told to refrain from touching or eating the samples until instructed to do so. One research assistant led the classroom in tasting each of the six samples together, instructing children to indicate their rating of each food by holding up a picture of the corresponding "yummy," "just ok," and "yucky" faces. Other research assistants (1 per 3–4 children) recorded each child's responses. Once the taste test was completed, the snacks and toys (identical to those used in the individual condition) were distributed to each child. Children were instructed that they had 7 min of 'activity time' where they could eat any of the snacks and play with any of the toys, but that they must stay in their seat, play quietly, and not take any snacks or toys from other children at the table. Research assistants monitored the children, reminded them of the rules as needed, and collected any dropped food for later weighing. For both conditions, snacks were pre- and post-weighed to determine consumption. Energy intake in kcals was determined using manufacturers' information.

Anthropometrics

Children's height and weight were measured by trained research staff using a portable stadiometer (Model 217; Seca Corporation) and digital scale (Model 876; Seca Corporation) on a separate day. Weight was measured in duplicate to the nearest 0.1 kg, with a third measure taken if the first two differed. Height was measured in duplicate to the nearest 0.1 cm, with a third measure taken if the first two differed by more than 1 cm. Height and weight were used to calculate age- and sex-specific BMI z-scores and percentiles using the 2000 CDC Growth Charts (18). Overweight was defined as a BMI ≥85th percentile.

Caregiver Questionnaire

Caregivers completed a survey packet that included demographic questions and measures of food security, feeding practices, and child eating behaviors. Food security was assessed using the 18-item USDA Household Food Security Module (19). Participant households were classified as food insecure if their score was 3 or greater. Children's appetitive traits were assessed using the Child Eating Behavior Questionnaire (20). We examined three subscales that were theoretically relevant to EAH—food responsiveness ($\alpha = 0.82$), enjoyment of food ($\alpha = 0.89$), and emotional overeating ($\alpha = 0.89$). Though the satiety responsiveness scale was also potentially relevant, it had poor reliability in this sample ($\alpha = 0.40$), so we did not analyze it further. Parents also completed the Eating in the Absence of Hunger Questionnaire (EAH-Q) for their child (21). The EAH-Q consists of three subscales—EAH in response to External Eating cues ($\alpha = 0.73$), in response to Negative Affect ($\alpha = 0.93$), and in response to Fatigue/Boredom ($\alpha = 0.89$)—as well as a total score ($\alpha = 0.89$).

Statistical Analysis

Data were analyzed using SAS 9.4 (SAS Institute, Cary, NC). Associations among meal intake and hunger ratings were assessed using Spearman correlations. Differences in kcal intake between the two conditions were assessed using a paired *t*-test. Intraclass correlation coefficients were calculated using a freely available SAS macro (22), and a Bland-Altman plot was generated to examine agreement between the two protocols. We also repeated these analyses after excluding children who did not eat any of the meal served ($n = 4$) or did not indicate they were half-full or all the way full ($n = 10$) at one or both meals. To assess validity, Pearson correlations between EAH kcal in both conditions and theoretically related constructs derived from literature were examined. Theoretical correlates included child BMI *z*-score, age, total and subscale scores from the EAH-Q, and child appetitive traits from the CEBQ (23). To further explore the validity of the classroom EAH protocol, all analyses were performed in subgroups of participants divided by age, sex, and weight status. The study had a power of 0.90 to detect a 35-kcal difference in EAH kcal intake between settings, and for this primary analysis, statistical significance was considered as $p < 0.05$. The study was not powered for subgroup analyses or validity correlations with parent-reported measures, so these analyses are reported with a focus on effect sizes rather than statistical significance, and should be considered exploratory.

RESULTS

Participants

Child and caregiver demographic characteristics are listed in **Table 1**. Children were on average 4.1 years old, non-Hispanic white (79.3%) or Hispanic/Latino (20.7%), and nearly half had BMI percentiles in the overweight or obese range. Caregivers were predominantly female parents. Consistent with Head Start eligibility, families were lower income, with approximately two-thirds participating in the Supplemental Nutrition Assistance Program (SNAP), and a quarter of households were classified as food insecure.

Meal Intake and Hunger Rating

Prior to the classroom EAH session, 6% of children consumed all of what they were initially served at their Head Start-provided meal, 60% consumed more than half, 26% consumed less than half, 6% consumed nothing, and 1 child (3%) had missing data due to observer error. In the hunger assessment, 57% selected the "full" stomach image, 20% selected "half-full," 17% selected "empty," and 6% did not select an answer. Prior to the individual EAH session, 20% consumed all of their meal, 49% consumed more than half, 29% consumed less than half, and 3% ate nothing. In the hunger assessment, 63% selected the "full" stomach, 14% selected "half-full," 9% selected "empty," and 14% did not provide an answer. There were no significant associations between amount consumed at the meal and hunger rating, nor any associations between these variables and amount consumed in the EAH task in either setting. Hunger ratings in the individual and classroom settings were significantly correlated ($\rho = 0.53$, $p = 0.003$).

Liking of Test Foods

All six foods provided were generally liked by the children and ratings were similar between the two conditions. During the classroom condition, 73–80% of children rated each food as "yummy" with 2–11% rating them as "just ok"; in the individual condition 69–81% rated the foods as "yummy" and 6–16% rating them as "just ok". Liking did not significantly predict intake.

Classroom vs. Individual EAH

Total intake, sweet and salty subcategories, and individual foods, are listed in **Table 2**. Children consumed an average of 63.0 ± 50.4 kcal in the classroom condition and 53.7 ± 44.6 kcal in the individual condition. The mean difference between settings was 9.2 ± 43.4 kcal; this difference was not statistically significant in a paired *t*-test ($p = 0.22$). The intraclass correlation coefficient for kcal intake was 0.57 (95% confidence interval: 0.35–0.77), indicating moderate agreement. Examination of a Bland-Altman plot (**Figure 1**) did not indicate systematic differences in agreement by magnitude of EAH. A sensitivity analysis restricting the sample to children who ate something at the breakfast/lunch meal and indicated they were half full or completely full prior to both EAH sessions ($n = 21$) produced similar results. The mean difference in the

TABLE 2 | Kcal intake in classroom vs. individual eating in the absence of hunger (EAH) tasks ($n = 35$ children).

Item	Kcal served	Classroom setting, kcal consumed		Individual setting, kcal consumed		Paired *t*-test	Intraclass correlation (ICC)	
		Mean (SD)	Range	Mean (SD)	Range	*P*-value	ICC	95% CI
Cheese cracker	111	3.3 (5.7)	0–18.5	4.0 (5.1)	0–18.0	0.49	0.43	0.20–0.70
Corn chip	114	4.6 (6.1)	0–28.6	2.4 (2.8)	0–10.3	0.04	0.18	0.02–0.66
Cheese puff	103	5.7 (11.8)	0–52.5	4.3 (6.2)	0–20.0	0.46	0.31	0.10–0.65
Chocolate sandwich cookie	130	13.7 (22.5)	0–76.8	9.2 (22.0)	0–84.5	0.22	0.51	0.28–0.74
Fruit snacks	160	21.2 (30.9)	0–134.3	23.9 (31.1)	0–94.7	0.50	0.71	0.53–0.85
Shortbread fudge cookie	140	14.4 (21.4)	0–87.0	9.9 (15.0)	0–56.5	0.13	0.54	0.31–0.75
Total salty	328	13.6 (17.3)	0–63.8	10.7 (10.0)	0–34.6	0.32	0.28	0.08–0.64
Total sweet	430	49.4 (47.0)	0–143.1	43.0 (42.9)	0–142.0	0.32	0.65	0.44–0.81
Total	758	63.0 (50.4)	0.5–156.0	53.7 (44.6)	0–159.2	0.22	0.57	0.35–0.77

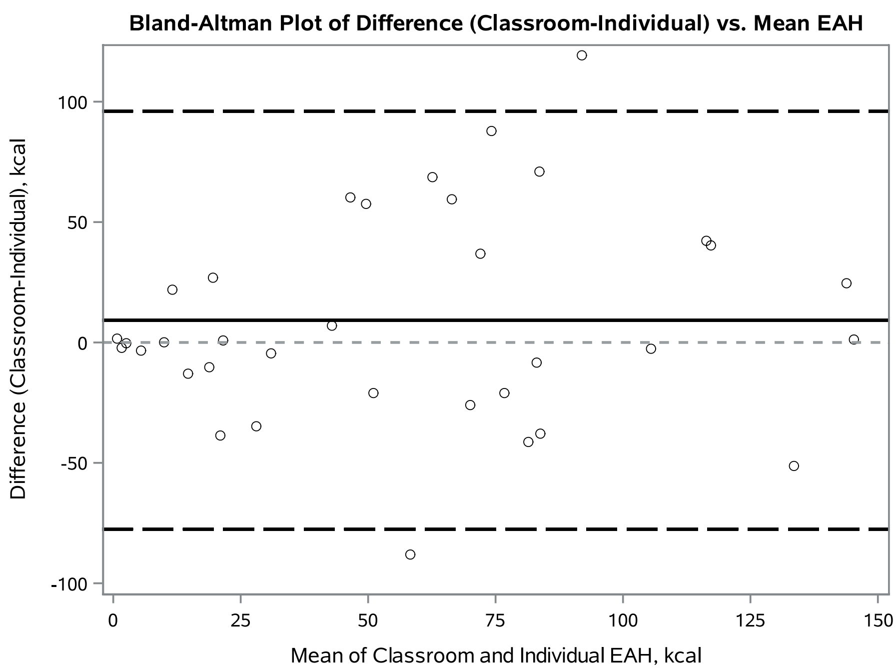

FIGURE 1 | Bland-Altman Plot for total kcal intake in classroom and individual Eating in the Absence of Hunger paradigms in preschoolers. The solid line represents the mean difference of classroom minus individual kcal intake. The dark dashed lines represent 2 standard deviations from the mean.

paired t-test was 14.2 ± 47.3 kcal ($p = 0.18$) and the intraclass correlation coefficient was 0.55 (95% confidence interval: 0.26–0.80).

For sweet and salty subcategories as well as individual foods, there were no differences in intake between the two conditions, except for corn chips; more corn chips were consumed in the classroom than in the individual condition (4.6 ± 6.1 vs. 2.4 ± 2.8 kcal, $p = 0.04$). Intake of, and agreement between settings, was generally higher among sweet foods than salty items. T-tests and ICCs for sweet and salty subcategories and individual foods in the sample restricted by meal intake/fullness rating were similar to those in the full sample.

Validity Analysis

Correlations between EAH kcal in both conditions and theoretically related constructs are provided in **Table 3**. There were no statistically significant correlations between EAH in either condition with child BMI z-score or parent report of child appetitive traits from the CEBQ. There were marginally statistically significant correlations between parent-reported EAH (total and negative affect and external eating subscales) and individual EAH kcal intake (**Table 3**), but not with classroom EAH kcal. BMI-z and parent reports of child eating behavior were not correlated with difference in kcal intake between the two conditions. In the subset restricted by meal intake/fullness rating, stronger correlations between parent-reported variables

TABLE 3 | Correlations between eating in the absence of hunger (EAH) kcal in the classroom and individual settings, and theoretically related constructs.

		Correlations					
		Classroom EAH kcal		Individual EAH kcal		Difference (Classroom-individual)	
Variable	**Mean (SD)**	***r***	***p***	***r***	***p***	***r***	***p***
BMI *z*-score ($n = 30$)	1.08 (1.03)	−0.11	0.57	−0.004	0.98	−0.11	0.56
Parent report of child appetitive traits (child eating behavior questionnaire) ($n = 33$)							
Food responsiveness	2.1 (0.7)	0.05	0.79	−0.09	0.62	0.14	0.42
Enjoyment of food	3.4 (0.7)	−0.11	0.54	−0.10	0.59	−0.03	0.88
Emotional overeating	1.4 (0.6)	0.19	0.28	0.10	0.56	0.11	0.55
Parent report of child eating in the absence of hunger (EAH-Q) (n = 33)							
Total score	1.8 (0.6)	0.19	0.28	0.33	0.06	−0.12	0.52
Negative affect	1.2 (0.5)	0.18	0.33	0.31	0.08	−0.12	0.51
External eating	2.9 (0.8)	0.13	0.45	0.33	0.06	−0.18	0.31
Boredom	1.5 (0.8)	0.19	0.29	0.20	0.27	0.01	0.95

Both questionnaires have answers ranging from 1 (never) to 5 (always).

and EAH intake were observed, particularly for the classroom condition (**Supplemental Table 2**).

Subgroup Analyses

Age

Age subgroups included 3 year-olds ($n = 13$) and 4–5 year-olds ($n = 19$). Among 3 year-olds, there was no difference in kcal intake between the classroom and individual conditions (56.3 ± 40.2 vs. 58.5 ± 48.5, $p = 0.79$). The ICC for 3 year-olds was 0.81 (95% CI: 0.49–0.95), indicating good agreement. In contrast, 4–5 year olds tended to consume more calories in the classroom setting than the individual setting (69.5 ± 54.6 vs. 50.6 ± 44.9, $p = 0.12$). The ICC for 4–5 year olds was comparatively poorer than 3 year-olds at 0.45 (95% CI: 0.17–0.76). There was no significant difference by child age group in kcal consumed for either condition.

Sex

Girls ($n = 16$) tended to consume more calories in the classroom relative to the individual setting (62.2 ± 43.7 vs. 44.8 ± 36.8, $p = 0.051$). In contrast, boys ($n = 19$) consumed similar amounts in both settings (63.6 ± 56.6 vs. 61.3 ± 50.1, $p = 0.84$). The ICCs for girls (0.59, 95% CI: 0.28–0.84) and boys (0.55, 95% CI: 0.26–0.81) were similar to each other and to the sample overall. There was no significant difference by child sex in kcal consumed for either condition.

BMI

Children with overweight ($n = 14$) consumed similar amounts in both the classroom and individual conditions (54.0 ± 39.1 vs. 49.7 ± 44.9, $p = 0.84$), and had an ICC of 0.60 (95% CI: 0.27–0.86), indicating moderate agreement between conditions. Children with normal weight ($n = 16$) tended to consume more in the classroom than in the individual session (71.7 ± 54.2 vs. 55.2 ± 49.4, $p = 0.21$) and had a lower ICC at 0.49 (95% CI: 0.18–0.81). There was no significant difference by weight status in kcal consumed for either condition.

DISCUSSION

This study examined the validity of the EAH paradigm in a classroom (i.e., group) setting compared to the classic individual setting and found no significant difference between classroom and individual EAH total kcal intake in preschoolers aged 3–5 years. When examined by age, sex, and weight status, the two protocols performed most similarly for younger children, boys, and children with overweight, while older preschoolers, girls, and normal weight children tended to consume more calories in the classroom compared to the individual condition. However, the mean differences between conditions in these groups were small (<20 kcal) and do not suggest reduced validity of the paradigm in these subgroups. This is the first study to test the validity of a preschool classroom-based EAH protocol in comparison with a more traditional, one-on-one version of the paradigm.

In this within-subjects design, total kcal intake did not differ significantly between the two conditions, and examination of the Bland-Altman plot did not reveal any systematic differences by average kcal intake between classroom and individual EAH. This suggests that the EAH classroom protocol is a valid alternative to the well-established individual paradigm. Results were similar after excluding children who did not eat at the meal prior to EAH or did not report feeling at least half full in one or both conditions. Average total EAH kcal intake in this study was 53.7 kcal and 63.0 kcal (7–8% of offered kcal) in the individual and classroom settings, respectively. This is similar to other reports in preschool aged children, where average intake ranged from 55 to 90 kcal in classroom-based protocols (14, 15) and 36–216 kcal in laboratory studies (1, 9, 24).

Though we used cardboard dividers to provide some separation and instructed children not to talk to their classmates, with frequent reminders during the task, these protocols were not entirely effective at preventing children from interacting with or looking at their peers during the task. Potential effects of this social setting were seen in older children, who consumed more kcals in the classroom setting than in the individual setting. This is consistent with previous literature showing that preschoolers ate more of a snack when seated in larger vs. smaller groups (17). Additionally, it has been shown that children aged 5–7 years consumed more unhealthy snacks in the presence of friends than in the presence of their mother, but healthy snack consumption did not differ (16, 25), while children 5–11 years ate more cookies with their sibling than with an unfamiliar peer or when alone (26). These data suggest that, even with dividers to block children's view of each other, classroom EAH kcal intake may be subject to peer influence, especially among older children. However, this may in fact increase ecological validity of the EAH task as overeating commonly occurs in social settings. Conducting the EAH task in the classroom group setting may also tap aspects of general self-regulation in addition to appetite self-regulation. In the classroom protocol, children were required to wait for others to be served before eating the snack foods and to refrain from interacting with their peers. In the one-on-one condition, research assistants were able to exert more direct control over the protocol. Future studies using the classroom protocol should consider including a measure of general self-regulation to use as a covariate.

In contrast to previous findings, our data show that girls and children with normal weight consumed more kcals in the classroom setting than in the individual setting, though most of this previous work was with older children. Salvy and colleagues reported that adolescent girls (but not boys) and children with overweight (but not normal weight) ate more healthy and fewer unhealthy snacks in the presence of friends than in the presence of their mother (16, 25). Among 7–9 year olds completing EAH in a classroom setting, there was a linear association between weight status and EAH for boys, but a quadratic relationship in girls, such that girls with overweight and obesity had slightly lower EAH than girls with BMIs between 50 and 85th percentile. The authors suggested that this may reflect overweight girls responding to the task in a way they consider to be socially desirable, such as limiting intake (8). In primary school children, the effect of peers' eating on participant snack intake differed by participant weight status. Children with overweight ate more when a peer ate a large portion of the snack, while children with normal weight ate less when the peer did not eat the snack (27). Taken together, these findings suggest that girls and children with overweight are more likely to limit their intake in a group setting based on social norms. However, in our preschool age sample, girls and children with normal weight, but not overweight, consumed more in the classroom vs. individual setting. Further work is needed to clarify how the role of peer influence on eating evolves through development, particularly for girls and children with overweight.

Contrary to our expectations, we did not find significant associations between EAH in either setting and theoretically-related parent-reported appetitive behaviors from the CEBQ. It is likely that our small sample size increased the risk for type II error. Additionally, appetitive traits and EAH were measured in different settings (at home as reported by parents and observed in preschool, respectively), so it is possible that the correlations would be stronger if a teacher reported child appetitive traits. The CEBQ also asks questions about eating behaviors in general, while the EAH tasks taps behavior in a very specific situation, i.e., free access to palatable snacks following a meal. However, other studies examining the relationship between EAH kcal and such variables in this age group have also had mixed findings. For example, food responsiveness was not significantly correlated with EAH in our sample. Other groups have found a small positive ($r = 0.19$) (28) or no correlation (29–32) between food responsiveness and EAH. Enjoyment of food was not correlated with EAH, which is consistent with other studies (28, 30). For emotional overeating, we observed a positive but not statistically significant association with EAH kcal in both settings; similar findings have been previously reported ($r = 0.13$–0.15) (28, 29). We did observe correlations around $r = 0.3$ between parent-reported child EAH and EAH kcal in the individual condition, which approached statistical significance, but smaller correlations with EAH kcal in the classroom condition. In the restricted subsample of children who ate at the meal and reported fullness before both EAH conditions, correlations with the EAH-Q were higher and more similar between the two conditions. The EAH-Q has been primarily used in older children (21, 33, 34), but our results suggest that this questionnaire is predictive of observed EAH behavior in preschoolers, particularly if the observations are made truly "in the absence of hunger"; however, confirmation in larger samples is required.

We found no significant association between BMI-z and total EAH kcal in either setting. While a systematic review found that EAH was positively associated in both cross-sectional and longitudinal studies with child weight status among children 12 years of age or younger (23), the evidence for this relationship specifically in preschool age children is somewhat more mixed. In Fisher and Birch's original study of 3–5 year olds, weight-for-height was positively associated with child kcal intake for girls ($r = 0.38$) but not boys ($r = -0.08$) (1). Kcal consumed in an EAH session was positively associated with BMI-z in French preschoolers ($r = 0.14$) (14) and U.S. Hispanic children in Head Start ($r = 0.20$) (31), while other studies have found no association between EAH and BMI or weight status in young children (30, 32, 35, 36). Our ability to detect an association between BMI an EAH may have been limited due to the small sample size and relatively high average BMI among this sample; nearly half of children had a BMI exceeding the 85th percentile. Variation in EAH protocols (e.g., standardization of meal, length of delay between meal and free access, foods offered, length of free access period) also makes comparisons between studies challenging. Future research should determine optimal configurations of the EAH task to best detect a phenotype that is associated with adverse health outcomes.

Most EAH kcal intake in this study came from sweet foods. Additionally, we found that intake of certain salty foods differed between classroom and individual EAH (i.e., children ate significantly more corn chips in the classroom). Overall intake of sweet foods was more similar between the two settings than salty foods. Revisions to salty snack offerings (e.g., substituting another sweet for one of the salty snacks) could be considered in future studies as it may improve agreement. Anecdotal feedback from our research team suggested that some of the toys that were included in our protocol (i.e., magnetic building pieces) were particularly novel and exciting for the children and may have been more rewarding than the foods offered. Including toys that provide an alternative activity to eating, but that are not overly interesting may improve the concurrent validity (e.g., EAH association with BMI-z) in future research.

Findings from this study should be interpreted in consideration of the study's strengths and limitations. Strengths include a randomized, counter-balanced crossover design and using objective measures of height and weight to calculate BMI. We also made improvements to our protocols [e.g., use of individual (rather than shared toys) for each child and teaching children about the concept of hunger prior to the EAH task (with a story book)], based on recommendations from a prior study that examined feasibility of classroom EAH (15). This study also had limitations. We used school-provided meals, which, while cost saving, gave us little control over what was offered. We conducted the individual EAH sessions in areas outside the classroom but still within Head Start facilities; while this protocol replicates the one-on-one nature of the classic laboratory EAH paradigm, it may still be a more familiar environment to children than a research laboratory. Additionally, while sufficiently powered to detect a meaningful difference in calorie intake between the two conditions, the sample size was relatively small, which may preclude our ability to detect associations between EAH and other measures.

In conclusion, findings from this study provide preliminary support for the validity of a group-based EAH protocol in preschool classrooms compared to the classic individual task. Standardization of the meal and other measures to ensure children are not hungry prior to the free access period may help to improve validity. Further testing in larger samples may help to confirm validity of the EAH classroom task and allow for better exploration of the differences in appetite self-regulation across age, sex, and weight status in eating behavior studies. In conclusion, a classroom-based EAH task will allow for broader application of assessing EAH in studies with young 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 Pennsylvania State University Institutional Review Board. Written informed consent for participation was not provided by the participants' legal guardians/next of kin because: Parents provided informed consent but written documentation requirement was waived by the Institutional Review Board. Parents were provided with study information and completed a form if they wished to opt their child out of participation of the study being conducted in their classroom.

AUTHOR CONTRIBUTIONS

EH, KM, SE, and JS designed and executed the study. EH analyzed the data. EH, KM, and SE drafted the initial manuscript. EH, KM, SE, LF, KK, and JS interpreted the data and critically revised the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2021.787461/full#supplementary-material

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Infant Food Responsiveness in the Context of Temperament and Mothers' Use of Food to Soothe

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Parents' use of food to soothe an infants' non-hunger related distress may impair an infants' development of appetite self-regulation. Parents tend to use food to soothe if their infant has more 'difficult' temperamental tendencies. However, the role of infant appetite in this association is unclear. This study investigates the moderating effect of infant food responsiveness on cross-sectional and prospective associations between infant temperament and mothers' use of food to soothe. Mothers ($n = 200$) from low-income households reported their infants' temperament (i.e., surgency, negative affect and regulation) and food responsiveness at age 4 months, and their use of food to soothe at age 4 and 6 months. Temperament × food responsiveness interactions on mothers' use of food to soothe were examined using general linear models, adjusting for covariates. Cross-sectional associations showed that mothers used more food to soothe at 4 months for infants who were lower in negative affect and higher in food responsiveness (negative affect × food responsiveness interaction: $p = 0.03$). Prospective associations showed that mothers used more food to soothe at 6 months for infants who were lower in regulation and higher in food responsiveness (infant regulation × food responsiveness interaction: $p = 0.009$). Other interactions were not significant. Infant food responsiveness was consistently associated with mothers' use of food to soothe, independent of some temperamental dimensions. The findings highlight the salience of infant food responsiveness, both independent of and in association with temperament, on mothers' use of food to soothe.

Keywords: appetite, emotional feeding, food to soothe, food responsiveness, infant feeding, low income, self-regulation, temperament

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INTRODUCTION

Individual differences in appetite self-regulation (ASR) emerge through a complex interplay of biological predispositions, the psychosocial environment, and wider sociocultural factors (1). ASR broadly describes feedback mechanisms that 'cue' individuals to eat to meet their nutritional and energy needs (2). One mechanism includes internal signaling hunger and fullness cues to encourage individuals to start and stop eating, respectively. An individual's phenotypic appetitive tendencies, or 'appetitive traits', are intrinsically linked to ASR (3). One such trait is 'food responsiveness', which in developmental terms may represent a bottom-up, approach-related response to food and food cues (3). Food responsiveness describes an individuals' affinity to food and eating, responsiveness to external food cues, such as the sight, smell and taste of palatable foods (4). Individual differences in food responsiveness are apparent from infancy, and increased food responsiveness has been associated with rapid weight gain and overweight (5–7). While appetitive traits are genetically influenced, psychosocial environmental factors, such as parenting and the child-parent relationship, also interact with the expression of these phenotypes (8). Moreover, epidemiological evidence suggests that socioeconomic disadvantage predicts increased expression of food responsiveness from toddlerhood to the preschool period (9). While the origins of ASR remains unclear, research rarely considers the *context* in which it is expressed and evolves. Contextual understanding of the origins of ASR requires a thorough understanding of individuals' predispositions, and how this interacts with their immediate environment, beginning in infancy (10).

Young infants rely on their caregivers (most often their parents) to regulate their physical and emotional needs. This includes responding to their infants' hunger and fullness cues and providing opportunities for them to practice and develop self-regulatory skills. Just like the dynamic infant-parent interactions that contribute to an infants' social and emotional development (11), so too are feeding interactions likely to impact an infants' ASR development. Black and Aboud (12) suggest that parents' responsive feeding practices align with infant hunger and fullness cues to support infant development of eating autonomy. Conversely, controlling feeding practices may (unintentionally) override a child's ability to start and stop eating in response to internal signals of hunger and fullness, and thus disrupt ASR (12). An example of a controlling feeding practice – and the focus of this current study – is parents' use of food to soothe a non-hungry but distressed infant. While effective in the short-term, parents' use of food to soothe may have unintended consequences on the development of ASR. For example, infants may learn that negative emotions are attenuated with the pleasurable effects of feeding, while parents may learn that feeding has a potent, calming effect on an infants' emotional state (13). This may minimize an infant's opportunities to build self-soothing skills (14) which is component of general self-regulation. Furthermore, parents' use of food to soothe has been associated with children's emotional overeating (15) and weight gain (16, 17), which may indicate a disruption of ASR. Use of food to soothe is observed more frequently in mothers from low-income households or with lower levels of education (18, 19). Therefore, examining this feeding interaction in populations where use is intensified may illuminate processes involved in ASR development.

Feeding interactions involve complex and bidirectional transactional processes between infant and parent (20). In other words, parent feeding practices influence infants' eating or behaviors, and so too do infant characteristics influence parent feeding practices. Infant temperament, for example, may play a role in evoking parents' use of food to soothe (21, 22). Temperament refers to individual differences in behavior that are biologically based or inborn, and is characterized by an infants' reactivity and self-regulation (23). Broad dimensions of temperament include surgency (high activity and approach to novelty/reward), negative affect (fussiness/ crying) and orienting/ regulation (effortful control, ability to self-regulate emotions or focus attention) (24). These temperamental traits in infancy may be precursors to 'top-down' regulatory processes involved in general self-regulation, and possibly, ASR (3). Cross-sectional studies demonstrate that infants or children who tend to express more 'difficult' temperamental tendencies have parents who use feeding as a soothing mechanism (21, 22). Despite the established associations between temperament and parents' use of food to soothe, the role of appetite in this association remains unclear. Similarly to food responsiveness, aspects of child temperament have also been identified as a risk factor for weight gain and obesity (8).

Although temperament and appetitive traits are two distinct constructs (23), appetitive traits are hypothesized to manifest through temperament. This has been prospectively demonstrated from early to middle childhood (25). Scant evidence shows that mothers of infants higher in food responsiveness are more likely to report using food to soothe (26). This suggests that parents may learn that feeding is an effective soothing tool for infants who respond favorably to food. It is therefore conceivable that the association between difficult infant temperament and parents' use of food to soothe may be exacerbated for infants higher in food responsiveness. In other words, infant temperament and food responsiveness may interact in a 'top down, bottom up' model which may contribute to parents' use of food to soothe and bidirectionally influence ASR.

The current study examines how infant characteristics (i.e., temperament and food responsiveness) are associated with mothers' use of food to soothe. We examine these associations in a sample of mother-infant dyads from low-income households. As early infancy marks a period of rapid development and dietary transitions, we examined the associations of infant temperament and food responsiveness at 4 months on mothers' (i) concurrent use of food to soothe at infant age 4 months, and (ii) prospective use of food to soothe at infant age 6 months, to examine how these effects may manifest over this period. The relationship between temperaments that are perceived to be more 'difficult' (greater surgency and negative affect, lower orienting/regulation) and mothers' use of food to soothe was hypothesized to be stronger for infants with greater food responsiveness, both cross-sectionally and prospectively.

METHODS

Study Design and Population

The current study is a secondary analysis of mother-infant dyads from the WEE Baby Care study, a pragmatic randomized clinical trial (RCT) designed to promote responsive parenting and to prevent rapid infant weight gain (27). Detailed information regarding the study design has been published (27). Briefly, mothers and their newborn infants were recruited from July 2016 to May 2018 in northeastern Pennsylvania, an area geographically characterized as Medically Underserved by the Health Services and Resources Administration (28). Mother-infant dyads were recruited if they attended Special Supplemental Nutrition Program for Women, Infants and Children (WIC) clinics and well-child visits (WCVs) at pediatric Primary Care Providers (PCPs) that participated in the study. Mother-infant dyads were excluded if: there were plans for the newborn to be adopted, the newborn's birth weight was <2500 g, the mother anticipated switching to a non-participating provider within 6–9 months, they did not live in the service area of the participating WIC clinics, or either mother or infant had significant health issues that would affect study participation or feeding and/or growth. Enrolled dyads were randomized into a 6-month responsive parenting intervention group ($n = 131$) or a standard care control group ($n = 157$). In addition, care for mother-infant dyads assigned to the responsive parenting intervention group was coordinated and integrated across pediatric PCPs and WIC settings using advanced Health Information Technology strategies (29). This study was approved by the Institutional Review Boards of The Pennsylvania State University and Geisinger. All participants provided written informed consent.

Mothers completed surveys at three time points when infants were approximately aged 2, 4 and 6months. The current study examines dyads with data on infant temperament and food responsiveness at infant age 4 months, and mothers' use of food to soothe at infant age 4 ($n = 199$) and 6 months ($n = 200$; one participant had missing data on food to soothe at 4 months). Mothers who were excluded due to missing data on the variables of interest ($n = 88$) were younger and came from lower income households compared to the analytic sample ($n = 200$). Infant birth date and date of assessment completion were used to calculate infant age in months at each time point.

Measures

Sociodemographic Characteristics

Participants completed surveys online through the REDCap electronic survey system (30) or paper questionnaires. Demographic variables were collected from mothers at enrollment, including age, marital status, highest level of education attained, employment status, household income and number of people living in the household. Infant sex, gestational age and birth weight were obtained from patient electronic health records (EHR). Infant anthropometric data was assessed by trained staff in pediatric PCP clinics at infant age 6 months. Mothers reported their infant's race and ethnicity. At infant age 4 and 6 months, mothers reported whether they were exclusively breast feeding and whether they had introduced solid foods (i.e., complementary feeding).

Infant Temperament

At infant age 4 months, mothers reported on their infant's temperament using the Infant Behavior Questionnaire (IBQ - Revised) – Very Short Form (31). The current study examines three broad temperament dimensions on the IBQ: positive affectivity/surgency (herein referred to as 'surgency'), 'negative affect' and 'orienting/ regulation' (herein referred to as 'regulation'). Surgency relates to an infant's approach to novelty, activity level, vocal reactivity, high intensity pleasure, smiling/ laughter and perceptual sensitivity (13 items; $\alpha = 0.76$, e.g. '*During a peekaboo game, how often did [your] baby laugh?*'). Negative affect describes an infants' tendency to express fear, sadness, anger and discomfort (12 items; $\alpha = 0.80$, e.g., '*When tired, how often did your baby show distress?*'). Regulation assesses an infants' soothability, cuddliness, attention abilities, inhibitory control and low-intensity pleasure (12 items; $\alpha = 0.77$, e.g., '*When patting or gently rubbing some part of the baby's body, how often did s/he soothe immediately?*'). Mothers responded to items on 7-point scale from never (1) to always (7) and scores were averaged within each subscale. Higher mean scores indicated greater levels of that temperament dimension.

Infant Food Responsiveness

At infant age 4 months, mothers completed the food responsiveness subscale of the Baby Eating Behavior Questionnaire (BEBQ) (4). Food responsiveness is assessed with 5 items asking about an infant's responsiveness to cues of milk and feeding, and drive to feed (e.g. '*My baby was always demanding a feed*'). Mothers responded to items on a 5-point scale from never (1) to always (5). Items were averaged to produce a mean score, with higher scores indicating greater food responsiveness ($\alpha = 0.83$).

Mothers' Use of Food to Soothe

At infant age 4 and 6 months, mothers self-reported their use of food to soothe infant distress using 12 items from a modified version of the Baby's Basic Needs Questionnaire (21, 32). Mothers responded to items (*e.g. 'How likely are you to use food (breastmilk, formula, other drinks or foods) to calm your child when you are shopping in a store?'*) on a 5-point scale from never (1) to always (5). Items were averaged to create a mean score with higher scores indicating mothers' greater use of food to soothe (4 months $\alpha = 0.87$; 6 months $\alpha = 0.85$).

Statistical Analysis

Data were analyzed using SAS 9.4 (SAS Institute, Cary, NC). Statistical significance was defined as $p < 0.05$, and all inferential tests were 2-sided. Sociodemographic characteristics and the main variables of interest were compared by study group using independent samples t-tests and χ^2 tests for continuous and categorical variables, respectively. There were no differences by study group on any sociodemographic factors or other main variables of interest (**Supplementary Table 1**). Descriptive statistics on the main variables of interest were run and assessed for normality. Pearson correlations examined bivariate associations between main study variables. General linear models were run to examine the interaction between temperament (one model for each dimension: surgency, negative affect, and regulation) and food responsiveness on mothers' use of food to soothe. Due to the small sample size and strong correlation between food to soothe at 4 and 6 months ($r = 0.78$, $p <$

0.001), cross-sectional (4 months) and prospective associations (6 months) were examined separately. Models adjusted for maternal age, education and marital status, and exclusive breastfeeding and introduction to solids. Missing data on covariates (≤6% missing) were imputed using the Markvo chain Monte Carlo multiple imputation method. Analyses were based on pooled results of 10 imputed datasets. Statistically significant interactions were probed and plotted to facilitate the interpretation of results. If an interaction was not statistically significant, the main effects of the infant temperament dimension and food responsiveness on mothers' use of food to soothe were examined using general linear models. In a sensitivity analysis, all models were rerun adjusting for study group. However, this did not significantly alter the results. Therefore, models unadjusted for study group are reported.

RESULTS

Sociodemographic characteristics of mother-infant dyads are shown in **Table 1**. Mothers were mostly white, single or divorced and high school educated (or less). Bivariate correlations between the main variables of interest are shown in **Supplementary Table 2**. Results for the main analyses are shown in **Table 2**, and are discussed by each infant temperamental trait below.

Surgency and Food Responsiveness

For both cross-sectional and prospective associations with mothers' use of food to soothe, the infant surgency × food responsiveness interaction was not statistically significant. In the main effects model, food responsiveness at 4 months was positively associated with mothers' use of food to soothe at both 4 months and 6 months, independent of surgency at 4 months, which was not statistically significant in both models.

Negative Affect and Food Responsiveness

Cross-sectionally, the infant negative affect × food responsiveness interaction on mothers' use of food to soothe was statistically significant. Simple slope analysis indicated that the slope of infant negative affect on mothers' use of food to soothe depends on infant food responsiveness. **Figure 1** presents the effect of negative affect on maternal food to soothe at 3 levels of infant food responsiveness based on the mean, mean – SD (low) and mean + SD (high). The figure shows that infants lower in negative affect and higher in food responsiveness have mothers who use food to soothe more frequently. Prospectively, the infant negative affect × food responsiveness interaction on mothers' use of food to soothe at 6 months was not statistically significant. However, the main effects model showed that both infant negative affect and food responsiveness were independently and positively associated with mothers' use of food to soothe.

Regulation and Food Responsiveness

Cross-sectionally, the interaction between infant regulation × food responsiveness was not associated with mothers' use of food to soothe. The cross-sectional main effects model showed that food responsiveness was positively associated with mothers' use of food to soothe, independent of regulation, which was not statistically significant. Prospectively, the interaction between infant regulation × food responsiveness on mothers' use of food to soothe was statically significant, and therefore simple slopes were examined. **Figure 2** presents the effect of infant regulation on mothers' use of food to soothe at three levels of infant food responsiveness. The figure shows that children low in regulation

TABLE 1 | (Non-imputed) participant characteristics ($N = 200$).

	n **(%) or mean ± SD**	***n*** **total data available**
Infant		
Male	99 (49.5)	200
Gestational age, weeks	39.2 (1.1)	200
Birth WFL *z* score	0.7 ± 1.3	198
WFL *z* score, age 6 months	0.5 ± 1.1	153
Exclusively breastfed, age 4 months	34 (17.5)	194
Exclusively breastfed, age 6 months	28 (14.6)	192
Introduced to solid foods, age 4 months	127 (65.5)	194
Introduced to solid foods, age 6 months	186 (95.9)	194
Temperament[a], age 4 months (scale 1 to 7)		
Surgency	5.0 ± 0.9	200
Negative affect	3.2 ± 1.0	200
Regulation	5.7 ± 0.7	200
Food responsiveness[b], age 4 months (scale 1 to 5)	1.8 ± 0.7	200
Mother		
Age at infant birth, years	28.1 ± 5.5	188
Marital status		189
Married and/or living with partner	92 (48.7)	
Single/Divorced	97 (51.3)	
Educational level		189
High school or less	117 (61.9)	
Some college	52 (27.5)	
College graduate or greater	20 (10.6)	
Annual household income		176
<$10,000	44 (25.0)	
$10,000–$24,999	68 (38.6)	
$25,000–$49,999	59 (33.5)	
$50,000–$74,999	5 (2.8)	
Race		200
Black	28 (13.5)	
White	137 (68.5)	
Other	36 (18.0)	
Hispanic	41 (21.8)	188
Average size of household, persons	3.2 ± 1.4	184
Food insecure	56 (29.0)	193
Food to soothe[c], infant age 4 months (scale 1 to 5)	2.3 ± 0.7	199
Food to soothe[c], infant age 6 months (scale 1 to 5)	2.2 ± 0.7	200

WFL, Weight-for-Length.
[a]Infant temperament measured via the Infant Behavior Questionnaire-R Very Short Form (31).
[b]Baby Eating Behavior Questionnaire (4).
[c]Modified version of the Baby's Basic Needs Questionnaire (21).

TABLE 2 | General linear models showing the associations between infant temperament dimension[a] and food responsiveness[b] at 4 months on mothers' use of food to soothe at 4 and 6 months[c].

	Temperament (4 months)					
	Surgency		Negative affect		Regulation	
Cross-sectional outcome: Mothers' use of food to soothe (4 months)	**B (SE)**	***p***	**B (SE)**	***p***	**B (SE)**	***p***
Temperament	0.09 (0.05)	0.09	0.34 (0.12)	0.006	0.06 (0.06)	0.37
Food responsiveness	0.43 (0.07)	<0.0001	0.85 (0.23)	0.0002	0.46 (0.07)	<0.0001
Temperament ×Food responsiveness	-	-	−0.13 (0.06)	0.03	-	-
Model R^2	0.24		0.26		0.23	
F statistic	7.54		7.53		7.22	
p value	<0.0001		<0.0001		<0.0001	
Prospective outcome: Mothers' use of food to soothe (6 months)	**B (SE)**	***p***	**B (SE)**	***p***	**B (SE)**	***p***
Temperament	0.10 (0.05)	0.07	0.14 (0.05)	0.007	0.43 (0.19)	0.023
Food responsiveness	0.35 (0.07)	<0.0001	0.34 (0.08)	<0.0001	1.75 (0.54)	0.001
Temperament ×Food responsiveness	-	-	-	-	−0.24 (0.10)	0.013
Model R^2	0.21		0.22		0.22	
F statistic	6.28		6.92		5.98	
p value	<0.0001		<0.0001		<0.0001	

Cross-sectional models adjust for maternal age, education, marital status, and exclusive breastfeeding and introduction to solids at infant age 4 months; Prospective models adjust for maternal age, education, marital status, and exclusive breastfeeding and introduction to solids at infant age 6 months.
[a] *Infant temperament measured via the Infant Behavior Questionnaire-R Very Short Form (31).*
[b] *Baby Eating Behavior Questionnaire (4).*
[c] *Baby's Basic Needs Questionnaire (21).*

and high in food responsiveness have mothers who use food to soothe more frequently at 6 months.

DISCUSSION

The current study expands the field's understanding of processes involved in the developmental origins of ASR. Our findings generally replicate previous research in middle-income families that demonstrate a positive association between infant 'difficult' temperament and mothers' use of food to soothe (21, 22). We also extend these findings by demonstrating the salient role of infant food responsiveness in this association, in a sample from low-income households. Findings highlight the independent and interrelated role of infant temperament and food responsiveness on mothers' use of food to soothe, which could ultimately shape children's development of ASR. We found that mothers respond dynamically to multiple facets of their infant's characteristics when using food to soothe infant distress. Specifically, at infant age 4 months, food responsiveness moderated the association between negative affect and mothers' concurrent use of food to soothe. Similarly, we also showed a moderating effect of infant food responsiveness on the association between regulation at age 4 months and mothers' use of food to soothe at 6 months. In addition, food responsiveness was consistently independently associated with mother's use of food to soothe. This also replicates findings in older children showing a link between food responsiveness and food to soothe (33). Future responsive parenting interventions could consider identifying 'at-risk' participants who are high on food responsiveness and difficult temperamental traits, and develop unique messaging based on these traits.

Stifter and colleagues instigated research on child temperament and mothers' use of food to soothe, and associations on child weight. Their early cross-sectional work showed that child negative affect was positively associated weight, and this association was intensified by mothers' increasing use of food to soothe (21). In the current study, the effect of infant negative affect on mothers' concurrent use of food to soothe was intensified with increasing food responsiveness. Interestingly, both negative affect and food responsiveness were independently associated with mothers' use of food to soothe at age 6 months. While the correlational nature of our analyses precludes interpretations about directionality, it is possible that the effects of temperament and food responsiveness on mothers' food to soothe evolve over time. A nuanced understanding of how infant negative affect and food responsiveness are associated with mothers' evolving use of food to soothe in the first 6 months of life is needed.

Despite no association between infant regulation and mothers' concurrent use of food to soothe, the association between regulation and mothers' prospective use of food to soothe was dependent on food responsiveness. This is also suggestive of the evolving role of mothers' responding to infant characteristics over time. While many studies have demonstrated associations between negative affect or surgency and food to soothe (21, 34), a renewed focus on regulation may be equally important at a very young age. Regulation may be precursor to later emerging effortful control (35), which is a part of general self-regulation related to top-down self-regulatory processes (3, 36). Current findings show that infants who may be lower in soothability and duration of orienting but who also respond favorably to external food cues, appear to have mothers who use feeding

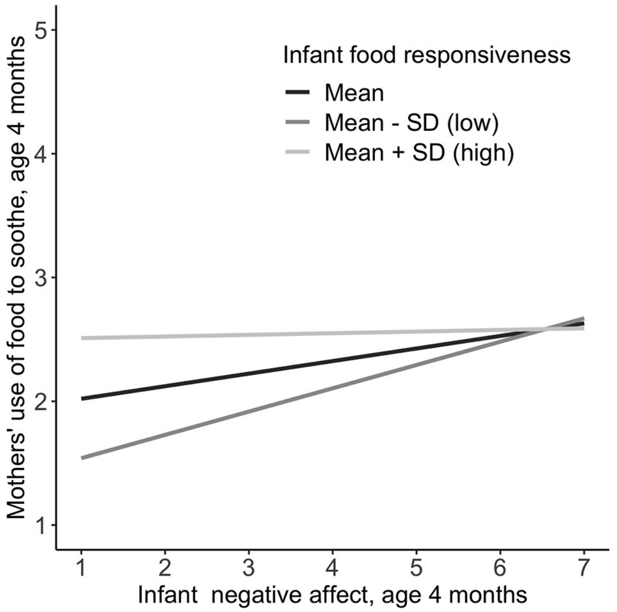

FIGURE 1 | Interaction between infant negative affect and relative levels of infant food responsiveness at 4 months on mothers' cross-sectional use of food to soothe at c months. Negative affect measured *via* the Infant Behavior Questionnaire-R Very Short Form (31); Food responsiveness measured *via* the Baby Eating Behavior Questionnaire (4). Mean = 1.8, SD = 0.7 (scale 1–5); Food to soothe measured *via* the Baby's Basic Needs Questionnaire (21).

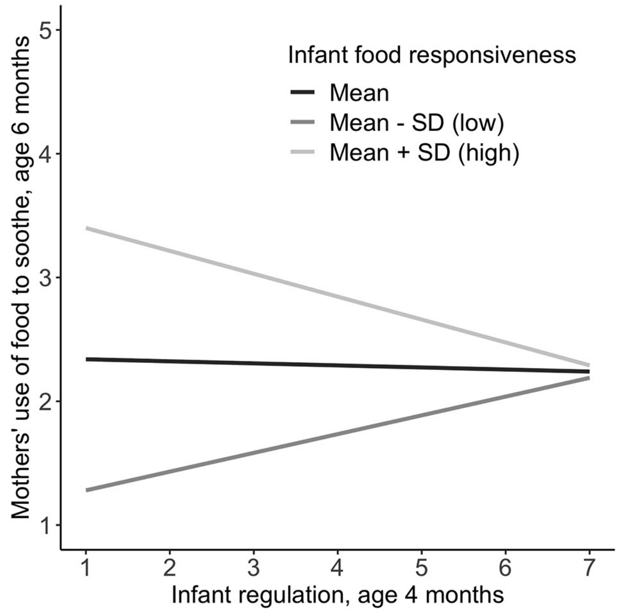

FIGURE 2 | Interaction between infant regulation and relative levels of infant food responsiveness at 4 months on mothers' prospective use of food to soothe at 6 months. Regulation measured *via* the Infant Behavior Questionnaire-R Very Short Form (31); Food responsiveness measured *via* the Baby Eating Behavior Questionnaire (4). Mean = 1.8, SD = 0.7 (scale 1–5); Food to soothe measured *via* the Baby's Basic Needs Questionnaire (21).

to calm their infants. Self-soothing abilities rapidly increase across the first year of life (37). Therefore, feeding to regulate an infants' emotional state during this period of developmental plasticity could promote maladaptive eating behaviors that contribute to appetite dysregulation later in childhood, such as emotional overeating (15). Interventions could focus on supporting mothers in identifying behaviors which indicate low orienting or regulatory capacity (e.g., difficulty in soothing or sustaining attention on an object) and high food responsiveness (e.g., frequently demanding feeds, taking feeds when offered or always preferring to be fed). For infants with these tendencies, mothers may require additional support to engage in alternative soothing strategies (38) rather than feeding.

Stifter's more recent work showed that infant surgency was prospectively associated with increased weight gain in toddlerhood when mothers used more food to soothe (34). However, we found that infant surgency was not associated with mothers' use of food to soothe cross-sectionally or prospectively when accounting for infant food responsiveness. Food responsiveness was independently associated with mothers' use of food to soothe at both 4 and 6 months. In contrast to negative affect, surgency is generally characterized by high positive affect, activity level and extraversion, which may not necessarily 'evoke' mothers' use of food to soothe when accounting for food responsiveness in infancy. It is also possible that these dynamics evolve throughout child development, with potentially adverse consequences on ASR and future weight gain (34). Therefore, further longitudinal research is required to examine how these predispositions change over time and are associated with mothers' use of food to soothe.

This research advances the understanding of one of many complex and interconnected pathways involved in the development of ASR. Based on our results, we propose two possible – and testable – mechanisms at play in the development of ASR. Firstly, our research is suggestive of an evolving and transactional infant-parent feeding processes which can potentially impinge on the infants' experiences in responding to their appetite and environmental food cues, and thus, ASR. The transactional model of development proposes that parents and infants engage in bi-directional interactions (39). In feeding, the infant plays an active role in shaping transactions through their hunger and fullness cues (i.e., appetite), which may indicate a physiological need filtered through their temperamental disposition (40). Simultaneously, the parent actively responds to the infant's cues, initiating and terminating feeding which then shapes the infant's intake and subsequent ASR. Secondly, we propose that a combination of inherent temperamental and appetitive traits (for example: regulation, negative affect and food responsiveness), may co-act as 'susceptibility factors' which are related to parents' use of food to soothe. Belsky's model of differential susceptibility (41) proposes that children with certain characteristics may be more susceptible to adverse or beneficial environmental impacts (e.g. parenting) which, in turn, influences an outcome. Applied to findings in the current study, it is possible that greater food responsiveness and more 'difficult' temperamental traits interact and render an individual more susceptible to parents' use of food to soothe, and may impede a child's developing ASR. This highlights the need for future research to examine the origins of ASR within the parent feeding context. Future research can extend this work by examining parent's feeding practices and styles, as well as their cognitions, interpretations and expectations in the realm of child eating behaviors (42).

Strengths of the current study must be considered in light of certain limitations. While much of the previous research has focused on middle income families, we examined a community sample of mothers and their infants from low-income households, who may be at greater risk of obesity. However, mothers were mostly white and additional work in needed in more racially diverse samples. This study is also a secondary data analysis of mothers recruited in a clinical trial and therefore introduces selection bias. Shared variance bias may be introduced through the use of maternal self-report of some variables. However, constructs used were derived from validated and widely-used questionnaires. For example, the BEBQ has been validated against objective measures of eating behavior (43, 44) and mothers are in a good position to report on their child's appetite over time, as opposed to a one-time observational measure (45). Due to the correlational nature of our measures and analysis, our results do not imply directionality. Future research could consider teasing apart mechanisms underlying the relationship between infant temperament, food responsiveness and mothers' use of food to soothe, longitudinally across infancy and early childhood.

Results from the current analysis reveal that both infant food responsiveness and temperament dynamically contribute to mothers' use of food to soothe. Although conceptually distinct, temperament and appetitive traits are closely intertwined factors associated with infant feeding interactions with parents. Teaching non-food soothing strategies to mothers and developing evidence-based messaging tailored to the unique characteristics of the infant could be a potential direction for future intervention. Identifying children with "high-risk" temperaments and appetitive traits may allow for opportunities to teach mothers responsive feeding strategies to prevent child weight gain across clinical and community settings in low-income populations.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Materials**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Boards of The Pennsylvania State University and Geisinger. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HAH conceptualized the study, designed the analysis, and drafted the original manuscript. AMM conducted the analysis. HAH, AMM, CFR, and JSS interpreted the results. AMM and CFR contributed to editing the manuscript. LB-D and JSS edited the manuscript, provided important intellectual content, and were involved in the funding acquisition. All authors have read and agree to take responsibility for the content of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fnut.2021.781861/full#supplementary-material

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REVIEW
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Associations Between Independent Assessments of Child Appetite Self-Regulation: A Narrative Review

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A variety of eating behaviors among children have been associated with obesity risk and are thought to broadly reflect child appetite self-regulation (ASR). While ASR is thought to occur on cognitive, emotional, motivational, biological, and behavioral levels, the inter-relatedness of ASR constructs as assessed by different methods/measures is not well-characterized. This narrative review describes the correspondence between different methods/measures of child ASR constructs as assessed by self-report questionnaires and/or observational tasks and their relationship to child standardized body mass index (BMIz). Research involving at least two different methods/measures is presented including observational tasks such as the Eating in the Absence of Hunger task, compensation trials, and eating rate, as well as various child eating behavior self-report questionnaires. Keyword searches in the PubMed and PsycINFO databases for articles published between 2000 and July 2021 identified 21,042 articles. Eighteen articles met the inclusion criteria and examined at least two of the targeted measures. Studies comparing questionnaire data with other questionnaire data showed the most evidence of significant associations (r values ranging from −0.45 to 0.49), whereas studies comparing questionnaires with observational tasks mostly showed weak (r values ranging from −0.17 to 0.19) or not significant associations, with only few studies finding moderate associations (r values ranging from −0.38 to 0.33). Studies comparing different observational tasks showed no significant associations. Overall, studies comparing self-report questionnaires showed the most correspondence, whereas those comparing observational tasks showed no correspondence. Studies across methods (questionnaires with tasks) showed less correspondence. Significant associations were found between ASR constructs and child BMIz across five studies using self-report questionnaires and two studies using observational tasks. Future research is needed to clearly define the various ASR constructs, their expected correspondence, and the strength of that correspondence, as well as the relations between ASR constructs and child weight among youth with and without overweight/obesity.

Keywords: appetite self-regulation, children, methodology, observational tasks, questionnaires, self-report

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INTRODUCTION

Child appetite self-regulation (ASR) has been identified as a central mechanism in the development of childhood obesity and has been targeted as a modifiable target in childhood obesity prevention programs (1–6). Definitions of ASR span multiple disciplines including the developmental sciences, nutrition, clinical psychology, and public health. Using a biopsychosocial framework, Russell and Russell (7) recently described ASR as multidimensional latent construct that occurs at "…cognitive, emotional, motivational, biological, and behavioral levels" and can be conceptualized in at least three ways. In the first conceptualization, top-down cognitive processes of ASR, such as inhibitory control, are thought to moderate bottom-up biologically drives toward food approach and avoidance. Top-down processes reflect effortful and executive control, whereas bottom-up processes reflect reactive, automatic processes that have neural origins. A second conceptualization included behavioral manifestations of ASR such as food choices and consumption as well as regulatory elements of hunger, satiation (during eating; brings meal to end), and satiety (after end of eating; prevents eating again before hunger). Lastly, ASR can be conceptualized as a process, a trait, or a skill (7), all of which can be measured using different methods. For example, ASR as a process or a skill can be measured using observational methods (e.g., Eating in the Absence of Hunger protocol), whereas ASR as a trait can be measured using a survey (e.g., the Children's Eating Behavior Questionnaire). While these recent theoretical advances provide a robust conceptual framework, measurement of ASR remains quite varied, and the inter-relatedness of different ASR constructs as measured by the various methods and measures is not well-characterized.

The present narrative review was undertaken to evaluate the correspondence of different methods/measures that have been used to assess common ASR constructs that are relevant to obesity risk in young children. Drawing on current multidimensional conceptualizations of ASR (7) and reviews of the extant literature on child obesogenic eating behaviors (8, 9), we focused on commonly used measures of ASR constructs that reflect multiple aspects of ASR (e.g., top-down processes, satiation) but predominantly emphasize reactive bottom-up processes. The current review focused on original research studies that included self-report questionnaires and/or observational tasks to assess common ASR constructs. Observational tasks measuring ASR constructs included compensation trials, Eating in the Absence of Hunger (EAH), and eating microstructure (i.e., eating rate and bite size). ASR self-report measures included the Children's Eating Behavior Questionnaire (parent-report), the Dutch Eating Behavior Questionnaire (parent- and child-report), the Eating in the Absence of Hunger Questionnaire (parent- and child-report), and the children's Self-Regulation in Eating scale (parent-report) by Tan and Holub. A brief description of the measures is given below to illustrate the diversity of measurement approaches and operational definitions employed in the study of ASR among children.

Among observational tasks, compensation trials have been used to assess satiation in children. Specifically, compensation protocols typically characterize the extent to which children adjust food intake at an *ad libitum* meal in response to the energy content of a compulsory preload consumed prior to the meal (10, 11). In other words, this protocol addresses whether children overeat, undereat, or accurately compensate at meals for prior intake. The EAH task assesses satiety by measuring children's intake of palatable foods (i.e., sweet and savory snacks) provided after a meal (along with a stack of toys) (12). Finally, average eating rate and average bite size are used to assess the eating microstructure, often in the context of satiation, by characterizing the number of mouthfuls eaten per minute and by gram, respectively (13, 14). Faster average eating rates and larger average bite sizes are thought to promote excessive intake by outpacing internal satiation signals (13, 14).

Among ASR self-report measures, the most commonly used are the Children's Eating Behavior Questionnaire (CEBQ; parent-report) (15) and the Dutch Eating Behavior Questionnaire [DEBQ; parent- (16) and child-report (17)]. The CEBQ measures eight appetitive traits of children 2 years old and above across 35 items using a 5-point Likert scale. Four of the eight traits are food approaching (i.e., food responsiveness or how responsive a child is to food/eating, emotional overeating, enjoyment of food, and desire to drink) and four are food avoidant (i.e., satiety responsiveness or how responsive a child is to feelings of fullness, emotional undereating, slowness in eating, and food fussiness) (15). The child-report of the DEBQ measures emotional eating, external eating, and restrained eating in children ages 7–12 years across 20 items using a 3-point scale (17). The parent-report of the DEBQ (parent report of child behaviors) measures the same constructs across 30 items on a 5-point scale (16). In addition to the CEBQ and the DEBQ, there are a number of other tools that have been used to assess ASR. For example, the Eating in the Absence of Hunger Questionnaire has two parallel versions, a parent-report of child behaviors (EAH-PC) (18), and a child-report (EAH-C) (19) used with children ages 8–18 years. Both versions assess the frequency of eating in the absence of hunger and specifically measure external eating, negative affect, and fatigue/boredom across 14 items on a 5-point Likert scale. Tan and Holub's children's Self-Regulation in Eating scale (SRES; parent-report) assesses parental beliefs regarding child's ability to self-regulate eating across 8 items on a 5-point Likert scale (20).

Considering the difficulty of operationalizing and explicitly measuring child ASR as well as the various assessment methods available, it is important for research and prevention efforts to understand how ASR constructs as assessed by different methods/measures are related (21). For example, caloric compensation, as measured by compensation trials is thought to be a behavioral analog or manifestation of satiety responsiveness, as measured by the CEBQ (22, 23). While it is not uncommon to employ multiple measures of ASR (24–27), little research to date has been undertaken with the specific goal of characterizing the correspondence of ASR constructs. Further, patterns of associations have been mixed, with some studies utilizing independent measures showing weak associations between ASR measures (25, 26) and others showing no significant associations

(24, 27). While ASR is often described in general terms, it is thought to occur at multiple levels and be manifested across a wide range of dimensions. Characterizing the inter-relatedness of ASR constructs as measured by different methods/measures is critical to advance theoretical understanding of the role of ASR in obesity risk and prevention during early childhood.

In this context, the purpose of this narrative review is to describe the correspondence of methods/measures of common ASR constructs relevant to obesity risk in children and to examine the associations between different methods/measures and child standardized body mass index (BMIz). The review focuses on original research studies that included at least two ASR assessment methods (self-report questionnaires and observational tasks) as well as measures within each methodology (i.e., a study including at least two self-report questionnaires or at least two observational tasks). Measures chosen within each methodology were those that are notably related to child obesity risk in the current literature. The review also focuses on children ages 2–12 years for two reasons: (1) eating behaviors mainly develop during this period and (2) this is the time when children are still somewhat dependent on their caregivers while becoming more autonomous and independent in their food choices (28).

METHODS

This narrative review of the literature involved an iterative process of searching for original research articles that included at least two assessments of child ASR constructs from self-report questionnaires and observational tasks. Self-report questionnaires included parent reports of child behaviors as well as child self-reports. We focused on the following constructs that are applicable to ASR: food responsiveness, satiety responsiveness, emotional overeating, external eating, eating in the absence of hunger, eating rate, bite size, slowness in eating, caloric or energy compensation, and satiation and satiety. During this process, additional constructs emerged (e.g., children's self-regulation in eating). **Table 1** provides an overview of the constructs, their definitions, and respective assessment tools.

TABLE 1 | Conceptualizations and assessment tools of constructs.

Construct	Conceptualization	Assessment tool
Food responsiveness	Responsiveness to external food cues, such as the sight or smell of food, that encourage eating, potentially to excess (8).	CEBQ
Satiety responsiveness	Ceasing consumption in response to internal signals, which may include gut hormone release and gastric distension (8).	CEBQ
Slowness in eating	Slow speed of eating (25).	CEBQ
Emotional overeating	Eating more food during negative emotional states (15).	CEBQ
Emotional eating	Excessive eating in response to emotional states such as anger, fear or anxiety (29).	DEBQ
External eating	Eating in response to food stimuli without regard to internal hunger or satiety (29).	DEBQ
Eating in the absence of hunger	Eating when exposed to palatable (sweet and savory) foods in the absence of hunger (30).	EAH protocol
Eating rate	Energy intake divided by meal duration (25).	Observed
Bite size	Energy intake divided by number of bites (13).	Observed
Caloric/energy compensation	Compensation for energy consumed in a preload during a subsequent *ad libitum* meal (10).	Observed
Satiation	Signals and processes that occur during the course of a meal that bring the meal to an end (31).	N/A
Satiety	Signals and processes that, following the end of a meal, inhibit eating before hunger returns (31).	N/A
Children's self-regulation in eating	Children's regulation of food intake based on internal cues of satiety (32).	SRES

CEBQ, Children's Eating Behaviors Questionnaire (15); DEBQ, Dutch Eating Behavior Questionnaire (29); EAH, Eating in the absence of hunger (30); SRES, Self-Regulation in Eating Scale (32).

Review Question

The focus of the review was to examine correlational data between different ASR constructs among children as assessed by at least two different methods/measures (self-report questionnaires and observational tasks). We excluded reports of correlations between subscales of the same questionnaire because they do not represent independent assessments.

Search Strategy

Keyword searches were conducted in electronic databases (PubMed and PsycINFO) in July 2021 using the following terms: (appetitive traits) OR (appetite self-regulation) OR (appetite regulation) OR (child eating behaviors) OR (bite size) OR (eating in the absence of hunger) OR (energy compensation) OR (caloric compensation) OR (food responsiveness) OR (emotional overeating) OR (satiety responsiveness) OR (slowness in eating) OR (emotional eating) OR (external eating) OR (disinhibited eating) OR (satiation) OR (satiety) OR (compensation AND eating). As the focus of the review was on correlations found in the literature, the publication type was limited to original articles, and thus systematic reviews with or without meta-analysis, conceptual articles, case-studies, and dissertations were excluded. We searched for articles published between 2000 and 2021 targeting children 2–12 years old. NM conducted the search in PubMed, which resulted in 20,593 articles. MAP conducted the search in PsycINFO, which resulted in 449 articles. A total of 373 articles in the PubMed search were also found in the PsycINFO search. Relevant articles were also hand-searched to identify any studies that were not included in our search.

Eligibility Criteria

Studies that met all the following criteria were included in the review: (1) study design (cross-sectional study, longitudinal study, randomized controlled trial), (2) population (children ages 2–12 years and/or their caregivers), (3) articles comparing results of at least two assessments that were originally designed

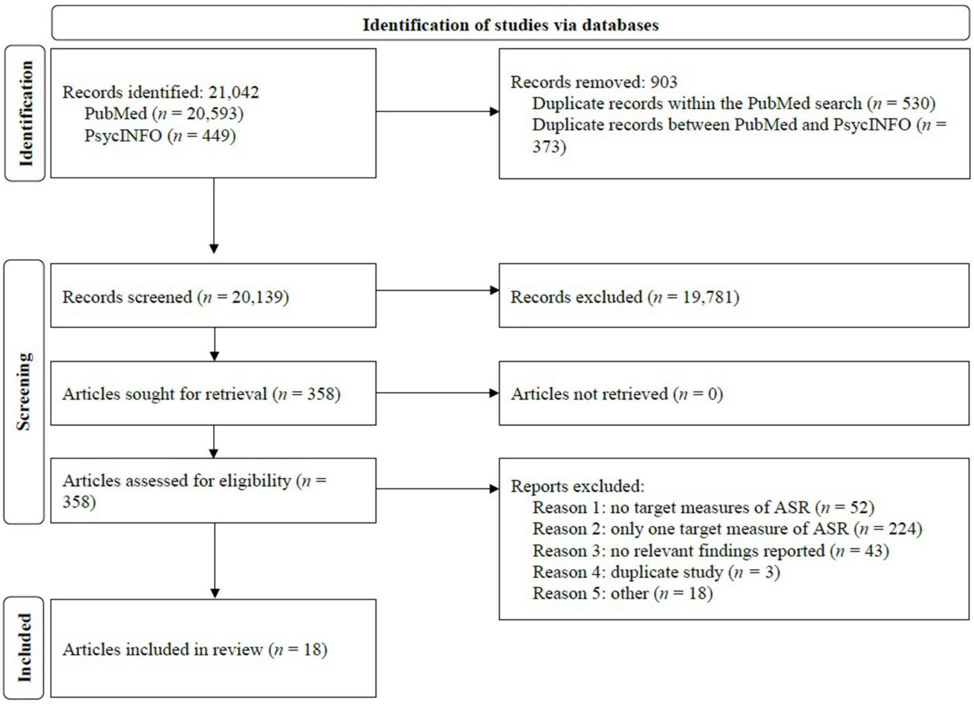

FIGURE 1 | Flow chart of the identification, selection, and inclusion of the retrieved articles.

to measure healthy ASR, and (4) article type (peer-reviewed publication). Exclusion criteria included: (1) articles focusing on children with eating disorders (e.g., loss of control of eating, binge eating) and/or developmental disorders that may affect appetite regulation (e.g., autism), (2) articles presenting research that was not original (i.e., review articles, conceptual articles, case-studies, and dissertations), (3) articles measuring child ASR constructs that are not typical/healthy (e.g., disinhibited or restrained eating due to dieting or disordered eating), (4) articles presenting data already presented in a previous publication, (5) articles that measured constructs only by a single item on a questionnaire, and (6) language (title, abstract, and/or full text not in English).

Study Selection

MAP and NM independently screened titles and abstracts of the articles identified against the study selection criteria after removal of duplicates. Specifically, MAP reviewed all articles from the PsycINFO search. NM reviewed 10,205 articles from the PubMed search, while MP reviewed the rest of the PubMed search articles. The full text of articles appearing to meet eligibility were then individually reviewed and evaluated for final eligibility by NM and MAP. To ensure quality control, approximately 37% of the articles retrieved were double coded and were in high agreement regarding inclusion or exclusion ($k = 0.83$). Any disagreements were resolved through discussion and TGP was consulted in the final selection stage. Eighteen articles met the inclusion criteria and are included in this review. The flow chart of the identification and selection of the reviewed articles is presented in **Figure 1**.

Data Extraction

A standardized data extraction form was used to gather the following information: (1) author(s) and publication year, (2) sample size, (3) age, (4) ethnicity/location, (5) assessment tools, (6) implementation, and (7) results/selected findings. This information was extracted to a spreadsheet by NM and checked by MP for accuracy. The results of the review are presented as a narrative summary below and in **Table 2**.

RESULTS

Eighteen studies were eligible for inclusion, representing studies measuring common ASR constructs as assessed by: (1) four unique self-report questionnaires, three of which included multiple versions: CEBQ (two versions: CEBQ and CEBQ for toddlers), DEBQ (three versions: parent-report for child behaviors, modified parent version for child self-report, German version for child self-report), SRES, EAH (parent-report for child behaviors and child self-report); and (2) four unique observational tasks, two of which were implemented slightly differently across studies: compensation trials/preload paradigm, EAH/Eating Without Hunger (EWH) tasks, eating rate/speed, and bite size. Implementation information and deviations from typical procedures are presented in **Table 2**.

Characteristics of the Included Studies

Table 2 also presents study characteristics and selected findings of the included articles [i.e., author(s) and publication year, sample size, age, ethnicity/location, assessment tools, assessment

TABLE 2 | Characteristics and selected findings of included studies.

References	Sample size	Age	Ethnicity/location	Assessment tools	Implementation	Results/selected findings
Questionnaire with questionnaire comparisons						
Koch and Pollatos (33)	Time 1: 1,657 52.1% female 47.9% male Time 2: 1,610 51.9% female 48.1% male	6–11 years $M = 8.38$ $SD = 0.95$	Not provided/ Germany	CEBQ DEBQ	CEBQ: parent report (EOE, FR); collected at T1 & T2 DEBQ: parent report for child (EXE); collected at T1 & T2	Time 1 FR + correlated with Time 1 EXE ($r = 0.49$, $p < 0.001$) Time 2 FR + correlated with Time 2 EXE ($r = 0.46$, $p < 0.001$) Time 2 FR + correlated with Time 1 EXE ($r = 0.38$, $p < 0.001$) Time 2 EXE + correlated with Time 1 FR ($r = 0.43$, $p < 0.001$)
Tan & Holub, (32)	95 46 females 49 males	4–9 years $M = 6.7$ $SD = 1.2$	White = 43% Hispanic = 18% Biracial = 17% Asian = 15% Black = 6% Middle Eastern = 1%	SRES DEBQ	SRES: parent report DEBQ: parent report for child (EME)	SRES−correlated with child EME ($r = -0.30$, $p < 0.01$)
Powell et al. (34)	265	2–7 years $M = 4.17$ $SD = 1.01$	Not provided for children	SRES CEBQ	SRES: parent report CEBQ: parent report (EOE, FR)	SRES−correlated with EOE ($r = -0.43$, $p < 0.001$) SRES−correlated with FR ($r = -0.45$, $p < 0.001$)
Questionnaire with observation comparisons						
Cecil et al. (35)	74 37 females 37 males	6–9 years $M = 92.1$ months $SD = 11.4$ months	Not provided/Scotland	CEBQ COMPX	CEBQ: parent report COMPX: school setting, 3 preload conditions of drink & muffin, lunch tray as meal	No significant correlations between CEBQ & deviation scores (% of deviation from perfect compensation); data not shown.
Moens and Braet (36)	52 36 females 16 males	7–13 years $M = 10.13$ $SD = 1.62$	Not provided/Europe	DEBQ EAH task	DEBQ: child self-report (adult version slightly adjusted for children); composite score of EME, EXE EAH: standard procedure; after a dinner meal satiety assessed; followed by 20 min free access to snacks	No significant correlations reported In a logistic regression (controlling for 8 other variables such as child gender, mother and child BMI, SES, & maternal feeding practices), children's report of external and emotional eating (composite score) was positively associated with greater eating in the absence of hunger ($p < 0.05$).
Munsch et al. (37)	41 23 females 18 males all overweight (BMI > 85%ile)	8–12 years females $M = 9.60$ $SD = 1.5$ males $M = 10.9$ $SD = 1.5$	Not provided/Europe	DEBQ-K Preload paradigm	DEBQ-K: German version for children, child self-report; tendency toward overeating score computed by averaging EME & EXE subscales Preload paradigm: atypical procedures, participants received a drink preload or no preload followed by 'taste test' of different flavored "crèmes"; conducted in lab; participants received only one of the preload conditions	"Children with a lower tendency toward overeating decreased their food intake after having received a preload whereas children with a higher tendency toward overeating did not alter their food intake in response to a preload (interaction between preload and tendency toward overeating, $F_{1,37} = 3.22$, $p = 0.081$)." (p. 101)
Leung et al. (26)	380 190 females 190 males	3–4 years $M = 4.1$ $SD = 0.54$	Non-Hispanic: White = 55.79% Black = 15.53% Biracial/Multiracial = 16.58% Hispanic any race = 11.32%	CEBQ EAH task	CEBQ: parent report (FR, EOE, SR) EAH: after a breakfast meal at school satiety assessed; followed by 10 min free access to snacks	EAH + correlated with FR ($r = 0.19$, $p < 0.001$) EAH + correlated with EOE ($r = 0.15$, $p < 0.01$) No significant correlation between EAH & SR ($r = 0.01$, p not provided).
Mallan et al. (38)	37 21 females 16 males	Time 1: $M = 24.1$ months $SD = 0.7$ months Time 2: 3.7-4.5 years	Not provided/ Australia	CEBQ EAH task	CEBQ: parent report (FR, SR, SE) EAH task: conducted at home by mother; meal followed by satiety rating; 15 min play then 15 min free access to snacks	No significant correlations between CEBQ at Time 1 & EAH intake at Time 2 FR + correlated with EAH ($r = 0.13$, $p = 0.45$) SR−correlated with EAH ($r = -0.02$, $p = 0.90$) SE + correlated with EAH ($r = -0.01$, $p = 0.96$)

(Continued)

TABLE 2 | Continued

References	Sample size	Age	Ethnicity/location	Assessment tools	Implementation	Results/selected findings
Hughes et al. (39)	187 89 females 98 males	4–5 years *M* = 57.4 months *SD* = 5.2 months	Hispanic	CEBQ EAH task	CEBQ: parent report (FR, SR) EAH: standard procedures, standard meal, satiety assessment, free access	No significant correlations between: EAH & SR ($r = 0.00$) EAH & FR ($r = 0.11$)
Powell et al. (40)	65 35 females 34 males	2–4 years *M* = 3.54 *SD* = 1.00	Not provided/UK	CEBQ Eating speed	CEBQ: parent report (SE, SR) Eating speed: coded from mealtime observation, mouthfuls per min	SE—correlated with eating speed ($r = -0.38$, $p < 0.001$) SR—correlated with eating speed ($r = -0.31$, $p < 0.01$)
Tan et al. (41)	91 39 females 52 males	Time 1: 26–29 months *M* = 27.33 *SD* = 0.57 Time 2: 33 months	Hispanic non-White = 40.7%	CEBQ EAH task	CEBQ: toddler version, parent report (FR, SR) EAH task: standard procedures; lunch meal at home; followed by 20 min free access to foods	No significant correlations between: Time 1 EAH & Time 1 SR ($r = -0.07$) Time 1 EAH & Time 1 FR ($r = 0.14$) Time 2 EAH & Time 1 SR ($r = 0.04$) Time 2 EAH & Time 1 FR ($r = 0.06$)
Fogel et al. (42)	195 96 females 99 males	Time 1: 4.5 years ± 2 months Time 2: 6 years ± 2 months	Chinese ($n = 105$) Indian ($n = 38$) Malay ($n = 51$) Singapore	CEBQ Eating rate Bite size	CEBQ: parent report (all subscales) Eating rate: observed lunch meal Bite size: observed lunch meal. Energy intake: *ad libitum* lunch buffet meal with parent at Time 1; vegetarian fried rice without parent at Time 2	Time 1: Eating rate & SE—correlated ($r = -0.14$, $p < 0.05$) No significant correlations between: Eating rate & FR ($r = 0.03$, *p* not provided) Eating rate & EOE ($r = -0.05$, *p* not provided) Eating rate & SR ($r = -0.06$, *p* not provided) Bite size & FR ($r = 0.07$, *p* not provided) Bite size & EOE ($r = -0.03$, *p* not provided) Bite size & SR ($r = -0.08$, *p* not provided) Bite size & SE ($r = -0.02$, *p* not provided) Time 2: Eating rate—correlated with SR ($r = -0.17$, $p < 0.05$) Eating rate—correlated with SE ($r = -0.30$, $p < 0.001$) No significant correlations between: Eating rate & FR ($r = 0.10$, *p* not provided) Eating rate & EOE ($r = 0.01$, *p* not provided) Bite size & FR ($r = -0.04$, *p* not provided) Bite size & EOE ($r = -0.02$, *p* not provided) Bite size & SR ($r = -0.13$, $p < 0.10$) Bite size & SE ($r = -0.01$, *p* not provided)
Boone-Heinonen et al. (43)	454 222 females 232 males	2–5 years *M* = 45.2 months *SD* = 9.7 months	Non-Hispanic: White ($n = 247$) Black ($n = 88$) Biracial/Other ($n = 73$) Hispanic any race ($n = 45$)	CEBQ EAH task	CEBQ: parent report (FR, SR) EAH task: cohort 1: standard procedures; after breakfast satiety assessed; followed by 10 min free access to snack; cohort 2: after lunch 10 min free access to snacks	EAH + correlated with FR ($r = 0.18$, *p* not provided) No significant correlation between EAH & SR ($r = -0.04$)
Blissett et al. (24)	62 29 females 33 males	3–5 years *M* = 46.0 months *SD* = 6.8 months	British White = 89%	CEBQ EAH task	CEBQ: parent report (FR, EOE, SR) EAH task: conducted after mood induction task; ~30 min between meal & EAH; 4 min free access	No significant correlation between: EAH kcals & FR ($r = 0.00$, *p* not provided, $n = 29$) EAH kcals & EOE ($r = 0.10$, *p* not provided, $n = 21$) EAH kcals & SR ($r = -0.23$, *p* not provided, $n = 30$)
Observation with observation comparisons						
Orlet Fisher et al. (44)	35 18 females 17 males	2.9–5.1 years *M* = 4.0 *SD* = 0.5	Black ($n = 1$) Asian ($n = 4$) Non-Hispanic White ($n = 28$) Hispanic ($n = 2$)	EAH task Bite size	EAH task: standard procedure; after one of the lunches hunger assessed; followed by small taste test of snack foods and 10 min of free access to snacks Bite Size: average bite size; total grams divided by total # of bites taken	No significant correlation between EAH & bite size ($r = 0.20$, p = not provided, $n = 23$).

(Continued)

TABLE 2 | Continued

References	Sample size	Age	Ethnicity/location	Assessment tools	Implementation	Results/selected findings
Remy et al. (27)	236 109 females 127 males	3–6 years $M = 4.5$ $SD = 0.06$	not provided/France	EAH task COMPX	EAH: standard procedure COMPX: standard procedure	No significant correlation between EAH & COMPX ($r = 0.05$; $p = 0.46$)
Questionnaire with questionnaire and observation with questionnaire comparisons						
Madowitz et al. (45)	117 62 females 55 males all overweight (BMI >85%tile)	8–12 years $M = 10.42$ $SD = 1.35$	White = 54% Black = 14% Multi-Race = 20% Other = 12%	EAH task EAH-C EAH-PC	EAH task: standard procedure; after dinner meal, satiety, hunger, & fullness assessed; followed by small taste test of snack foods & 10 min free access to snacks; EAH% calculated to get % of daily caloric needs eaten during EAH task EAH-C: questionnaire, child self-report EAH-PC: questionnaire, parent report for child.	EAH-C total score + correlated with EAH-PC total score ($r = 0.34$, $p < 0.001$) EAH-C total score + correlated with EAH-PC EXE ($r = 0.25$, $p < 0.01$) No significant correlation between: EAH% & EAH-C total score ($r = -0.04$, p not provided) EAH% & EAH-PC total score ($r = -0.12$, p not provided) EAH% & EAH-C EXE ($r = 0.01$, p not provided) EAH% & EAH-PC EXE ($r = -0.08$, p not provided) EAH-C EXE & EAH-PC total score ($r = 0.17$, p not provided) EAH-C EXE & EAH-PC EXE ($r = 0.18$, p not provided)
Observation with questionnaire and observation with observation comparisons						
Carnell and Wardle (25)	111 55 females 56 males	4–5 years	British White = 74%	CEBQ Eating rate COMPX EWH task	CEBQ: parent report (FR, SR) Eating rate: average across meals COMPX: used disguised and undisguised preloads EWH task: modified EAH by offering only 1 food during free access	No significant correlations between: Average eating rate & EWH intake ($r = 0.13$, $p < 0.10$, $n = 100$) Average eating rate & COMPX undisguised ($r = -0.23$, $p < 0.10$, $n = 68$) Average eating rate & COMPX disguised ($r = -0.17$, $n = 91$) COMPX disguised & EWH ($r = -0.06$, $n = 86$) COMPX undisguised & EWH ($r = -0.12$, $n = 61$) COMPX undisguised & COMPX disguised ($r = 0.17$, $n = 57$) Simple linear regressions: SR + associated with EWH intake ($r^2 = 0.11$, $p = 0.001$, $n = 98$) SR + associated with average eating rate ($r^2 = 0.11$, $p = 0.001$, $n = 101$) FR + associated with average eating rate ($r^2 = 0.06$, $p < 0.009$, $n = 109$) No significant correlations between: SR with COMPX disguised ($r^2 = 0.003$, $p = 0.471$, $n = 89$) SR with COMPX undisguised ($r^2 = 0.05$, $p = 0.072$, $n = 66$) FR with EWH intake ($r^2 = 0.006$ $p < 0.45$, $n = 98$) FR with COMPX disguised ($r^2 = 0.02$, $p < 0.21$, $n = 89$) FR with COMPX undisguised ($r^2 = 0.001$, $p < 0.86$, $n = 66$)

Definitions of abbreviations as they appear by column: M, mean; SD, standard deviation; BMI, Body Mass Index; CEBQ, Children's Eating Behaviors Questionnaire; DEBQ, Dutch Eating Behavior Questionnaire; SRES, Self-Regulation in Eating Scale; COMPX, % of energy compensation; EAH, Eating in the Absence of Hunger; DEBQ-K, Dutch Eating Behavior Questionnaire-Kinder; EWH, Eating Without Hunger; EAH-C, Eating in the Absence of Hunger-Child self-report; EAH-PC, Eating in the Absence of Hunger-Parent report of child; EOE, emotional overeating; FR, food responsiveness; EXE, external eating; EME, emotional eating; SR, satiety responsiveness; SE, slowness in eating.

implementation, and results/selected findings]. Most of the included studies were conducted outside the United States ($n = 10$), with eight conducted in Europe, one in Australia, and one in Singapore. Seven were conducted within the United States and one did not report location of their subjects. Of the studies conducted outside of the United States, only three reported information on race/ethnicity. Of the studies conducted within the US, most included participants from differing ethnic/racial backgrounds, although the majority was comprised of predominantly White participants. Gender distribution was approximately equal throughout all studies and child ages ranged from 2 to 13 years.

Methodologies Used to Assess ASR Constructs

Of the 18 studies that met eligibility, three studies compared data between different self-report questionnaires: Koch and colleagues (33) compared the CEBQ and the DEBQ; Tan and Holub (32) compared the SRES and the DEBQ; and Powell and colleagues (34) compared the SRES and the CEBQ. Regarding comparisons of questionnaires with observational tasks, nine studies compared the CEBQ with various tasks: compensation trials (35); eating rate/speed (40, 42) and bite size (42); or EAH (24, 26, 38, 39, 41, 43). One study compared the DEBQ (child self-report) with the EAH task (36) and another compared the DEBQ-K (child self-report; German version) with a preload paradigm (37). Three studies compared data between different observational tasks: the EAH was compared to bite size (44) and compensation trials (27); Carnell and Wardle (25) compared the following tasks to each other, compensation trials (disguised and undisguised), eating rate, and EWH. This latter study also compared all observational tasks to the CEBQ. Finally, one study conducted by Madowitz and colleagues (45), using the EAH task and EAH questionnaires (parent- and child-report), compared both versions of the EAH questionnaire to the task as well as to one another.

Inter-relatedness of ASR Constructs

Overall, the majority of significant associations were seen in cohort studies involving multiple self-report questionnaires of ASR. Specifically, in the Koch and colleagues (33) study, food responsiveness (CEBQ) was positively associated with external eating (DEBQ) at the 1st time point of the study ($r = 0.49$, $p < 0.001$) and remained significant at the 2nd time point ($r = 0.46$, $p < 0.001$). Additionally, significant positive associations were found for these constructs across time points with Time 2 food responsiveness correlating positively with external eating at Time 1 ($r = 0.38$, $p < 0.001$) and Time 2 external eating positively correlating with Time 1 food responsiveness ($r = 0.43$, $p < 0.001$). Powell and colleagues (34) also found strong associations between subscales of two questionnaires. Child eating self-regulation (SRES) was negatively associated with both emotional overeating ($r = -0.43$, $p < 0.001$) and food responsiveness ($r = -0.45$, $p < 0.001$) from the CEBQ. The SRES was also negatively associated with emotional eating from the DEBQ ($r = -0.30$, $p < 0.01$) in the Tan and Holub (32) study, but the association was moderate.

Most of the 11 studies comparing self-report questionnaires to observational tasks showed either no significant associations (4 studies) (24, 35, 39, 41) or weak and no associations (3 studies) (26, 38, 43). Two of the 11 studies showed moderate associations only between eating rate/speed and CEBQ subscales: negative association with slowness in eating ($r = -0.30$, $p < 0.001$) (42); and negative association with both slowness in eating and satiety responsiveness ($r = -0.38$, $p < 0.001$, $r = -0.31$, $p < 0.01$, respectively) (40). Between the two studies comparing observational tasks to other tasks, none showed significant associations (27, 44).

Carnell and Wardle (25) and Madowitz et al. (45) found some significant moderate associations in their studies that used mixed methods and more than one ASR observational task or self-report questionnaire. Carnell and Wardle (25) showed that satiety responsiveness was positively associated with both EWH and average eating rate ($r = 0.33$, $p = 0.001$, $r = 0.33$, $p = 0.01$, respectively), and that food responsiveness was also positively associated with average eating rate ($r = 0.25$, $p = 0.009$). However, no significant associations were shown between observational tasks. On the other hand, Madowitz and colleagues (45) found significant associations only between the parent- and child-report versions of the same questionnaire (EAH). The total scores of the child self-report were moderately associated with those of the parent-report of child behaviors ($r = 0.34$, $p < 0.001$), and weakly to moderately associated to the external eating subscale of the parent-report ($r = 0.25$, $p < 0.01$).

Within the studies comparing ASR questionnaires (32–34, 45), only Madowitz et al. (45) used different raters (i.e., parent and child) for children's behaviors with moderate and weak to moderate associations ($r = 0.34$, $p < 0.001$, $r = 0.25$, $p < 0.01$, respectively). The strength of these associations is lower than those found in the other three studies that compared data from the same rater (i.e., parent-report). Moreover, the evidence of association strength in the Madowitz and colleagues (45) study matches the strength of association strength (i.e., moderate) in three studies that compared data from self-report questionnaires and observational tasks (25, 40, 42). On the other hand, the moderate associations were found in these three studies, while the majority of the studies comparing self-report questionnaire with observational task data showed either weak or no significant associations. In contrast, within studies comparing data from several self-report questionnaires, all four studies showed significant associations.

ASR and Child BMIz

Of the 18 studies included in this review, 11 examined associations between at least one measure of ASR constructs and child BMIz or an equivalent score. Most studies used standard methods for calculating child BMIz (e.g., CDC standards) except three studies: weight-for-length z score (WLZ) (41) and similar procedures (35, 37). Henceforth, BMIz will be used to describe child weight status scores. Of the 11 studies, four used self-report questionnaires to measure ASR (32, 33, 36, 37), three used observational tasks (27, 35, 44), and four used both questionnaires and tasks (24, 38, 39, 41).

Among the four studies examining associations between self-report questionnaires and child BMIz, only two studies found associations (32, 33). Emotional overeating and food responsiveness (CEBQ) were positively associated with BMIz ($r = 0.17$, $p < 0.001$ and $r = 0.45$, $p < 0.001$, respectively) (33); external eating (DEBQ) was also positively associated with BMIz ($r = 0.21$, $p < 0.001$) (33). It should be noted that these associations were found in a larger sample [$n = 1,657$ (33)]. Self-regulation in eating (SRES) was negatively associated with BMIz ($r = -0.30, p < 0.01$) (32). The other two studies which measured external and emotional eating (DEBQ) found no associations (36, 37).

Among the three studies examining associations between observational tasks and child BMIz, only one study found an association—bite size was positively associated with BMIz ($r = 0.55, p < 0.01$) (44). No associations were found between the EAH task (27) or the compensation trials (27, 35) with BMIz.

All four studies that examined associations between both self-report questionnaires and observational tasks with child BMIz, used the CEBQ and the EAH task to measure ASR (24, 38, 39, 41). Of the four studies, three found associations: a negative association with satiety responsiveness [$r = -0.42, p = 0.015$ (38); $r = -0.24, p < 0.01$ (39); $r = -0.28, p < 0.01$ (41)] was found in all three studies; a positive association with food responsiveness ($r = 0.15, p < 0.05$) (39) was found in one study. The EAH task was associated with BMIz in one of the four studies ($r = 0.20, p < 0.01$) (39).

DISCUSSION

This narrative review was aimed at examining associations between of common child ASR constructs as assessed by at least two methods/measures. The aim was to examine these constructs both within and across self-report questionnaires and/or observational tasks. A total of 18 studies met eligibility criteria and were included in the review. The three studies comparing constructs using self-report questionnaires showed the most correspondence between different ASR constructs. In contrast, the two studies comparing ASR constructs using different observational tasks showed no correspondence. Furthermore, among the 11 studies comparing self-report questionnaires to observational tasks, two studies showed moderate correspondence and nine studies showed weak and/or no associations. As mentioned previously, the remaining two studies compared constructs within and across methodologies and showed weak and/or no associations.

Among the three studies using self-report questionnaires, three questionnaires were used to measure correspondence between constructs—emotional overeating (CEBQ) positively associated with external eating (DEBQ) (33); self-regulation of eating (SRES) negatively associated with emotional eating (DEBQ) (32); and self-regulation of eating (SRES) negatively associated with emotional overeating and food responsiveness (CEBQ) (34). That emotional overeating and external eating were positively associated could be explained by the shared elements of eating without regard to hunger and satiety cues. This correspondence is in line with the construct definitions provided in **Table 1**. Similarly, the negative association between self-regulation of eating as measured by the SRES and emotional overeating/emotional eating may reflect that responsiveness to internal cues of hunger is diminished by emotional overeating. The negative association found between SRES and food responsiveness could reflect the idea that response to external cues (e.g., sight and smell) and the response to internal cues represent opposite ends of a continuum.

However, the correspondence between these constructs, as measured by self-report questionnaires, could partly be due to method biases that can result when the data is provided by the same source/rater or by the measurement context in which the data was obtained. Apart from the Madowitz and colleagues (45) study, the studies reporting on associations within questionnaires gathered data from the same rater (32–34). When the same source provides data, an "artifactual covariance" can be created between the variables in an effort to create a consistent "story" (or *consistency motif*) between the rater's cognitions and responses (46). Additionally, the use of the same rater can generate an *implicit theory* which may "affect attention to and encoding of ratee behaviors as well as later recall" (p. 599) (47). For example, a parent completing questionnaires on their child's eating behaviors may bias their responses based on an overall view they have of their child, which may not necessarily be specific to eating. If a child is difficult, the parent may be biased to create a consistent "story" of their child's eating as being difficult. The measurement context in which the raters provide responses can also be a source of bias. For example, the current mood state of the rater as well as the time of day and location of assessment may impact responses (46). Specifically, a rater's retrieval of information may affect questionnaire completion because of the presence of "common contextual cues" influencing their memory and thus, associations between variables (46).

Among the two studies comparing constructs using only observational tasks (27, 44) and one study that examined constructs within and across methods (25), four assessments tools were used including the eating in the absence of hunger task, various types of compensation trials, and the measurements of eating rate and bite size. Across these different observational tasks, none of the constructs showed correspondence. One reason for the lack of correspondence across observations could stem from the nature of observations—the capture or snapshot of behavior at a single point in time. It is possible that observed data capture state-based behaviors, whereas self-report questionnaire data capture behaviors that parents observe or children engage in across multiple occasions and over an extended period of time—trait-based behaviors.

Among the 11 studies comparing self-report questionnaires and observational tasks of ASR, assessment tools included observations of eating rate, bite size, EAH, and compensation trials as well as the CEBQ (i.e., satiety responsiveness, food responsiveness, slowness in eating, and emotional overeating), and the DEBQ (i.e., emotional and external eating). Two additional studies examining constructs within and across methods also used most of these measures as well as the EAH questionnaire. Of these 13 studies, the most common association found was between eating rate and the CEBQ subscales of satiety responsiveness, food responsiveness, and slowness in eating (25, 40, 42). This common finding may be explained by the simplicity of the eating rate observations. Measuring eating rate can be considered fairly simple, direct, and practical compared to other observational assessments involving multiple steps over a longer period of time. In addition to the eating rate finding, mixed results (weak or no associations) were found across seven studies comparing EAH and the CEBQ subscales (24–26, 38, 39, 41, 43), while no associations were found between compensation trials (25, 35), bite size (44) and the CEBQ subscales, and between the DEBQ and a preload paradigm [a modified form of the compensation trials] (37). Interestingly, neither the parent- nor the child-report of the EAH questionnaire were associated with the EAH task.

Compensation trials did not reveal any significant associations with any ASR measures. One possible reason for this lack of findings is that the percent of compensation shown by children in these tasks usually shows a wide range of values and it is not clear how much of this variation (based on only a single pair of meals) represents stable individual differences in children's ASR vs. variability due to the many situational factors that can affect children's consumption on a single pair of occasions (time of day, child hunger, child mood, child food preferences, etc.). As part of an evaluation of a childhood obesity prevention program, Hughes and colleagues (48) found that although the COMPX scores (i.e., % of energy compensation) showed the expected relationships with child weight status, there was no significant stability in this variable over a 9- to 10-week period in either their prevention or control groups. This suggests that although this variable may be useful in the comparison of groups of children, a single pair of meals may not be sufficient to yield stable measure of individual differences in ASR. Additionally, the lack of findings with the EAH task, may stem from socialization influences that could be affecting children's behaviors during this task. Hughes and colleagues (48) have suggested that tasks, such as compensation trials and EAH, may not be effective measures of ASR with certain samples (i.e., Hispanic children from low-income backgrounds) for various reasons. For example, it is highly likely that these children experience high food insecurity at home, or the foods provided during the tasks are unfamiliar or not culturally congruent to the children. Moreover, children show wide variability in their responses to the EAH task, and individual differences may reflect both situational factors as well as individual differences in ASR. In the Hughes and colleagues (48) study, however, significant stability was shown over a 9- to 10-week period in both the prevention ($r = 0.50$) and control ($r = 0.32$) groups.

The lack of associations between ASR constructs as measured by self-report questionnaires and observational tasks has been shown in studies of adults as well (49). Interestingly, similar to the findings from this narrative review, Creswell et al. (49) found that associations between self-report questionnaires and observed computerized tasks were either weak or non-significant. Additionally, the self-report questionnaires showed associations with outcomes, whereas the computerized tasks showed weak or no associations with outcomes. This is in line with findings from the current review showing significant associations between ASR constructs and child weight outcomes across five studies using self-report questionnaires. Specifically, these studies showed significant associations between ASR constructs and child BMIz across five studies using self-report questionnaires. Specifically, satiety responsiveness, food responsiveness, and emotional overeating from the CEBQ (33, 38, 39, 41), external eating from the DEBQ (33), and child self-regulation in eating (32) were associated with child BMIz. In contrast, only two studies showed significant associations with child BMIz using observational tasks (39, 44). The findings from this review are consistent with a recent systematic review of the CEBQ subscales and child weight (50). Among studies comparing observational tasks and child BMIz, only two constructs showed associations—bite size (44) and EAH (39). Interestingly, EAH was associated with child BMIz in only one (39) of five studies (24, 27, 41, 44), despite the fact that EAH has consistently been shown to be associated with child weight status (51). These associations were specific to studies that involved more than one ASR measure and constitutes a small subset of studies looking at associations of ASR measures with weight status. The association found by Hughes et al. (39) is consistent with previous reports among these constructs in young children (51).

Findings from this narrative review should be considered in light of its limitations. Inclusion in his review required that each study assessed at least two ASR measures and reported associations. Furthermore, although many factors impact ASR in children, including biopsychological (e.g., genes, hormones, executive functioning) and family and community processes (7, 21), the current review focused on the intrapersonal factors of common ASR constructs. Moreover, only a subset of published articles (i.e., the 18 included in this review) reported associations between the measured ASR constructs with over 40 identified that did not present associations. This limits the interpretation of the findings, because if more data were available, the relationship between the targeted measures may have presented differently.

Future Research and Implications

It is thought that questionnaire-based measures have clear advantages over observational tasks for a number of reasons. Specifically, questionnaires (1) involve little participant burden for young children as parents often report on child behaviors, (2) present relatively low participant burden for parents, and (3) are more feasible to administer compared to many observational protocols that involve multiple steps administered by trained research staff. In this sense, questionnaires have obvious advantages for measurement in large epidemiological studies and interventions as well as for rapid identification of at-risk children in healthcare settings.

Future research is needed to more clearly define the various ASR constructs, their expected correspondence, as well as the strength of that correspondence. Additionally, as other scholars have suggested, current literature would benefit from studies considering the biology of the child as well as the child's immediate and more distal environments (7). The use of mixed methods comprised of existing tools, as well as conducting the same assessments over a shorter period of time (e.g., across 10 days) will better determine whether these constructs measure a state vs. a trait. Longitudinal research will provide evidence of predictability. Taken together, this additional information and identifying which ASR constructs are most effective can inform efforts toward successful childhood obesity programs that promote healthful eating behaviors in families. Further, investigating the relations between ASR constructs and child weight, among youth with and without overweight/obesity and their parents, fosters a better understanding for predicting obesity risk in children.

AUTHOR CONTRIBUTIONS

MP, SH, TP, and JF contributed to conception and design of the review. MP and NM conducted the article search and review and organized the database. TP approved the final list of articles. MP wrote the first draft of the manuscript. SH, TP, and JF wrote sections of the manuscript. All authors contributed to the revision of the manuscript and read and approved the submitted version.

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Examining the Role of Food Form on Children's Self-Regulation of Energy Intake

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Increasing childhood obesity rates in both the United States and worldwide demonstrate a need for better prevention and intervention strategies. However, little is understood about what factors influence children's ability to sense and respond to hunger and fullness cues, a critical component of self-regulation of energy intake and maintenance of a healthy body weight. Research in adults suggests that food form may influence self-regulation of energy intake. More specifically, beverages are not as satiating as solid foods when matched for factors such as energy content, energy density, and volume and therefore elicit poorer energy intake self-regulation. However, much less is known about the impact of food form on children's ability to regulate their energy intake. This report describes a study that will examine the relationship between biological, cognitive, and psychological factors and children's appetite self-regulation (ASR). In this registered report, we will examine the influence of food form on children's short-term energy compensation, a proxy indicator of energy intake self-regulation. The study will employ a within-subjects, crossover design in which children (n = 78) ages 4.5–6 years will attend five laboratory visits, each ∼1 week apart. During each visit, children will be presented with one of five possible preload conditions: apple slices, apple sauce, apple juice, apple juice sweetened with non-nutritive sweetener (NNS), or no preload. The order of preload conditions will be pseudorandomized and counterbalanced across participants. Following consumption of the preload (or no preload), children will consume a standardized *ad libitum* test meal of common foods for this age group. We hypothesize that children will demonstrate poorer short-term energy compensation (greater meal intake) in response to the liquid and semi-solid preloads compared to the solid preload. Understanding how energy in various forms affects children's ability to self-regulate intake has implications for dietary recommendations and will help identify those who are most at-risk for poor intake regulation and the development of obesity.

Keywords: pediatric obesity, energy compensation, preload, food form, self-regulation

INTRODUCTION

As childhood obesity rates continue to increase in both the United States (1) and worldwide (2) it is imperative to understand why some children eat beyond their energy needs, as this has been identified as a behavioral phenotype for obesity (3). One factor that may contribute to a positive energy balance is poor appetite self-regulation (ASR) (4), conceptualized in recent reviews as a multi-faceted construct characterizing the ability to regulate energy intake in response to biological, social, and psychological influences (5). Early studies that primarily assessed homeostatic influences on energy regulation found that infants can upregulate their energy intake in response to energy deficits (6, 7). However, this ability declines with age (8) and by the time children reach preschool (i.e., 3–5 years), they are less able to regulate energy intake in response to environmental perturbations (e.g., portion size, energy density, parenting practices) (9–13). These more recent studies reinforced the notion that ASR is influenced by more than just homeostatic signals coming from the gut and periphery. The current registered report describes the methods for a study intended to examine the interplay between social, psychological, and biological factors on children's ASR.

In developing this study, we drew inspiration from reviews by Russell and Russell (4, 14) to develop a dual-process model of ASR in children (see **Figure 1**). In this model, ASR is influenced by bottom-up signals from the gut and periphery that send information about hunger and satiety and by top-down processes that enable children to appropriately respond to these signals by controlling the amount of energy consumed. It is likely that many factors, including child-level individual differences (e.g., sex/gender, appetitive traits, general self-regulation, social desirability) and food characteristics (i.e., portion size, food form) can either enhance or disrupt children's ASR. In order to develop a more comprehensive picture of children's ASR, we operationalized it as a combination of (1) energy compensation (i.e., the ability to regulate energy intake in response to food form and energy content), (2) eating in the absence of hunger (EAH), and (3) food-specific delay of gratification. Energy compensation was selected as the primary outcome because it is the gold-standard for measuring satiety in response to manipulations in food form or energy content, and it captures the interplay between top-down and bottom-up processes. EAH and food-specific delay of gratification were added as secondary outcomes to allow for characterization of a more complete ASR phenotype. EAH has been characterized as a measure of bottom-up approach tendencies toward food, while delay of gratification depicts top-down control over food intake (4). While outcomes related to the broader construct of ASR will be published in other reports, the current registered report will focus only on outcomes related to children's ability to regulate in response to food form and energy content, referred to as "energy compensation" ability.

The energy compensation paradigm is thought to measure children's ability to eat in response to satiety signals (14). In this paradigm, short-term energy compensation is measured by providing children with a preload that varies by some attribute, often energy density, and assessing subsequent intake at an *ad libitum* meal following a predetermined interval (15). Using this procedure, energy compensation can be quantified by comparing energy intake following the various preload conditions. Most often, preloads vary in energy content by using a non-nutritive sweetener (NNS) in the low-energy preload to match the taste, volume, and orosensory attributes of the high-energy preload. The energy content of the preloads is then masked from participants to determine how well they sense and respond to the energy content by regulating their subsequent intake at a meal. Those with "good" compensation adjust their subsequent meal intake commensurate with the energy intake from the preloads. The appeal of this approach is that the ability to regulate energy intake can be quantified in an objective manner.

Most common in the children's literature, energy compensation has been depicted as a linear transformation of the difference in intake across two preload conditions that vary by energy content (i.e., compensation index; COMPx) (3, 16–19). Studies using this approach have found that COMPx varies widely between children and differs by certain characteristics such as satiety responsiveness (20), food responsiveness (21), BMI z-score (9), age (8), and sex (16, 19, 22, 23). However, these findings are not consistently observed across studies, and relatively little is understood about the influence of other physiological, cognitive, and environmental factors on children's energy compensation, and ASR more generally.

Research conducted in adults has found a consistent effect of food form on satiety such that beverages, when matched for key factors such as weight and energy content, produce weaker satiety than solid foods (24, 25). Notably, Flood-Obbagy and Rolls (26) conducted a preloading study in which adults consumed apples in various forms (apple slices, apple sauce, and apple juice) or no preload prior to a standardized *ad libitum* meal. They found that apple slices produced greater satiety and reduced subsequent meal intake relative to both apple sauce and juice. This was despite preloads being matched for weight, fiber, energy content, energy density, and ingestion rate (26). These results align with other preloading studies that find poorer energy compensation following consumption of beverages compared to solid foods (24, 25). Additionally, one RCT in adults found that healthy-weight participants gained weight over an 8-week period when

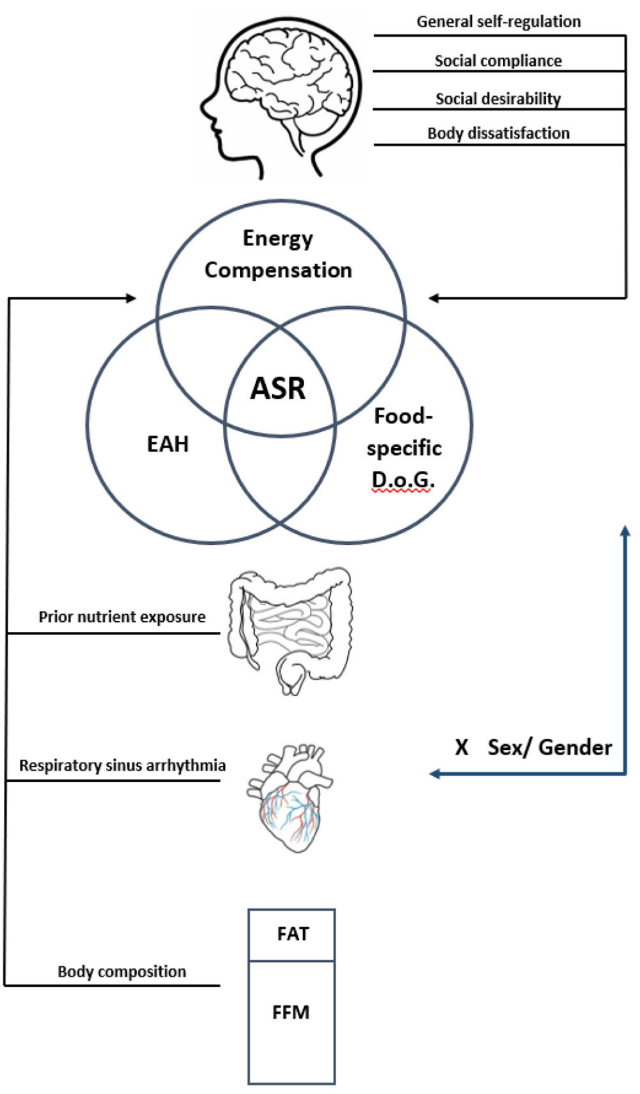

FIGURE 1 | Dual-process model of psychosocial and physiological factors hypothesized to influence ASR. This study posits that ASR involves both bottom-up and top-down processes that may be influenced by a variety of factors. ASR itself is to be operationalized using common paradigms to assess energy compensation, eating in the absence of hunger (EAH) and food-specific delay of gratification (D.o.G). The factors hypothesized to influence bottom-up processes include previous exposure to non-nutritive sweeteners, respiratory sinus arrythmia, and body composition, specifically the ratio of fat mass to fat-free mass (FFM). Top-down influences to be tested include measures of general self-regulation including social compliance and social desirability, as well as body dissatisfaction. We also hypothesize that child sex, which may play a role in ASR, may also be associated with differences in both top-down and bottom-up influences on ASR.

fruits and vegetables were given as a liquid compared to an 8-week period when these foods were given as solids (27). This suggests that food form may influence ASR and subsequent weight gain over longer periods of time than is typically measured in a laboratory. Several physiological mechanisms have been proposed that may help explain these findings. Relative to liquids, solid foods increase gastric distension (28) and decrease gastric emptying rate (29–31), both of which may increase satiety. Additionally, solid foods require greater mastication and oral exposure time than liquids, which may increase satiation (32, 33). Though more research is needed to understand the underlying mechanisms, the effect of food form on satiation and satiety has been consistently demonstrated in adults.

Whereas a substantial body of research in adults suggests that solid foods provide greater satiety than beverages, little is known about when these differences develop. To date, only one study has examined the impact of food form on satiety in children. Schwartz and colleagues (34) compared apple slices to apple sauce (matched for energy and energy density) and found no effect of food form on subsequent food intake in 8- to 10-year-old children (34). This study, however, did not include a liquid (beverage) preload, which is a limitation, as much of the adult literature examining the effect of food form employs the use of beverage preloads as a comparator to solid preloads. Caloric beverages (e.g., fruit juices, sports drinks) are ubiquitous in children's diets (35) and contribute ∼175 kcal/day to total energy intake (36). Despite this, the effect of beverages on children's satiety relative to solid and semi-solid foods is understudied. Additionally, neither Schwartz et al. (34) nor existing adult literature has controlled for the effect of perceived volume on satiety. Solid foods appear greater in volume and thus are expected to be more satiating than beverages (37, 38), and adults have demonstrated that expected satiety before a meal may influence self-reported fullness after the meal (38). By masking volume, this study reduces the potential cognitive influences in order to better isolate the sensory and physiological effects of food form on satiety.

This study aims to address these gaps by examining the effect of food form on children's short-term energy compensation. In an effort to capture the developmental window where children are becoming less responsive to internal cues (39–41) and more responsive to external cues (9–13), we are conducting this study in 4.5- to 6-year-old children. Additionally, although oral development such as mastication efficiency shows a general increase across childhood, it appears to plateau between the ages of 4–6 years (42). This suggests that studying the effect of food form in this age group will be less confounded by age differences in oral development. Apples will be presented to children in various forms (i.e., apple slices, apple juice, and apple sauce) prior to a standardized *ad libitum* test meal. Apple preloads will be matched for weight, energy content, energy density, and total consumption time, and volume will be disguised. In addition to the apple preloads, a low-calorie apple juice sweetened with non-nutritive sweetener (NNS apple juice) and a no preload condition will be included. The first aim of this study is to examine the effect of apples in various forms on children's subsequent energy intake at a standardized test meal. Specifically, we hypothesize that the regular apple juice will elicit the poorest energy compensation relative to both apple sauce (semi-solid) and apple slices (solid). Additionally, we hypothesize that apple sauce will result in greater satiety than apple juice. The second objective of this study is to examine energy compensation within the same food form by comparing meal intakes following the regular apple juice and NNS apple juice. We hypothesize that children will consume less

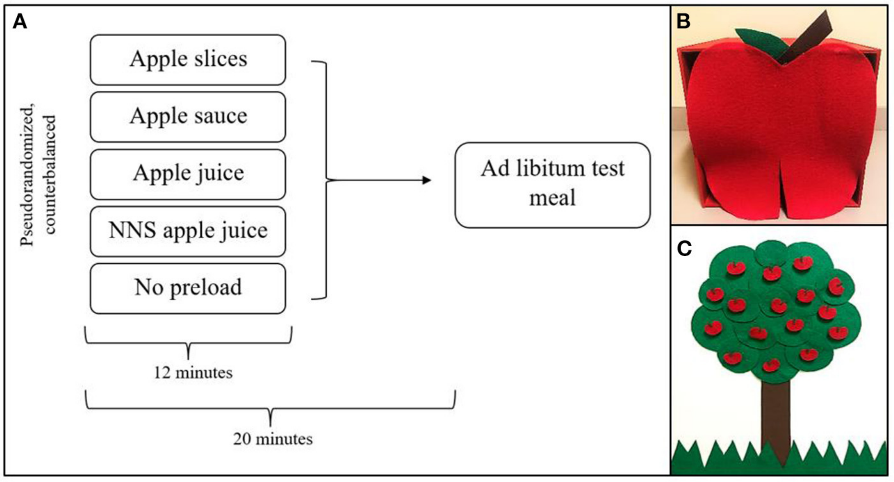

FIGURE 2 | Overview of preload protocol **(A)**, child-friendly box to mask preload volume **(B)**, and game board to encourage children to finish preloads **(C)**.

following the regularly sweetened apple juice than the apple juice sweetened with NNS.

METHODS

Experimental Design

This study will use a within-subjects, crossover design with repeated measures. Children will visit the laboratory once a week over an approximate 5-week period, for a total of five, one and a half hour sessions. Families will attend either lunch or dinner meals based on availability, but meal times will be kept consistent within families. Children will be fasted for 3 h upon arrival to each visit. On each test session, children will be served one of five preload conditions: apple slices, apple sauce, regular apple juice, NNS apple juice, or no preload. The same standardized test meal will then be served ∼20 min after the start of preload consumption, a timeframe chosen based on previous research in preschool-aged children (16, 43) and to account for the rapid pace in which liquids are emptied from the stomach (44). On the final visit, children's EAH will be assessed following their test meal. Therefore, the order in which preloads will be delivered to children will be pre-established from a limited number of possible orders so that one of the three caloric preloads is delivered prior to children's EAH assessment. These orders will be counterbalanced across participants. **Figure 2A** provides an overview of the preloading protocol. This study was approved by the Institutional Review Board of The Pennsylvania State University (IRB #13957) in accordance with the Declaration of Helsinki. On visit 1, parents give informed consent to allow their children to participate in the study.

Participants

Inclusion criteria for the study will be children between the ages of 4.5–6 years-old who are physically healthy, with no food allergies or medical conditions that affect appetite or ability to follow study protocol. Excluded medical conditions include children with autism or developmental delays, many of whom are prone to feeding difficulties (45). Children must also like and be willing to consume apple slices, apple sauce, and apple juice in addition to at least four of the five *ad libitum* test meal foods, according to parental report on a screening questionnaire. The legal parent or guardian primarily responsible for child feeding decisions must be able to attend all visits with the child. While no recruitment restrictions will be based on children's weight status or race/ethnicity, we expect the majority of children to be white, non-Hispanic or Latinx, and of healthy weight status (BMI-for-age percentile <85) based on recent census data from where the study will be conducted (46). Based on the same census data, we expect children to come from relatively affluent families, as median household income for families with children ranges from ∼$93,00–107,000 per year (46). As child sex may play an important role in ASR (12, 16, 19, 22, 23, 47), and our study aims to further examine these sex differences, even numbers of boys and girls will be recruited.

Energy Compensation

Energy compensation will be examined by comparing meal intake following each preload condition. According to the pre-established order, children will consume one of four preloads or no preload (five possible conditions) at the beginning of each visit. A no preload condition will be included to assess children's usual intake without a pre-meal snack; the four remaining preloads will be apple slices, applesauce, regular apple juice, and apple juice sweetened with NNS. Apple slices, applesauce, and regular apple juice will be matched for energy content (63.8 kcal), weight (133.0 g), and energy density (0.48 kcal/g). The NNS preload will be matched for weight with the other preloads but, by design, will not be matched for energy content or energy density (**Table 1**).

Apples were chosen as they are widely accepted by children and are commonly consumed in various forms (48). In addition, this choice will allow comparison with prior studies done in

TABLE 1 | Weight, energy content, energy density, and macronutrient composition of preloads and standardized *ad libitum* test meal foods.

	Weight (g)	Energy (kcal)	Energy density (kcal/g)	Carbohydrate (g)	Fiber (g)	Fat (g)	Protein (g)
Preloads							
Apple slices, peeled	133.0	63.8	0.48	15.3	1.7	0.0	0.0
Applesauce with peeled apples	133.0	63.8	0.48	15.3	1.7	0.0	0.0
Regular Apple juice	133.0	63.8	0.48	14.9	0.5	0.0	0.0
NNS Apple juice	133.0	16.5	0.12	3.8	0.0	0.0	0.0
No preload	–	–	–	–	–	–	–
***Ad libitum* test meal (first serving)**							
Macaroni and cheese	100.0	198.0	1.98	27.2	1.1	6.2	5.7
Broccoli	61.0	26.5	0.43	1.8	1.8	0.0	0.9
Baby carrots	35.0	12.3	0.35	1.9	1.0	0.0	0.0
Grapes	113.0	75.7	0.67	18.4	1.0	0.0	0.7
Graham crackers	~23.0	97.5	4.24	17.3	0.8	2.6	1.5
Water	226.8	0.0	0.00	0.0	0.0	0.0	0.0

adults (26) and children (34). Preload amounts were selected based on the average weight of apples consumed per eating occasion in a similar age group using a nationally-representative sample (49). Apple sauce and apple juice recipes were developed based on Flood-Obbagy and Rolls' study in adults (26). Apple slices (133 g) will be served to children without the skin in order to increase acceptance and avoid additional fiber that could impact satiety. Apple sauce will be prepared using 133 g peeled, sliced apples heated for 20 min at 350 degrees Fahrenheit. Once cooked, the apples will be puréed and any water lost during heating will be added back to ensure consistent weight between preload conditions. Apple juice (133 g) will be 120.4 g of Mott's 100% Apple Juice (Mott's® Mott's Inc., Plano, TX) and 12.6 g water to match the weight and energy density of the apple slices and apple sauce. Lastly, NNS apple juice (133 g) will be prepared with 66.5 g Mott's Light Apple Juice (Mott's® Mott's Inc., Plano, TX) and 66.5 g Old Orchard Healthy Balance Diet Apple Juice Cocktail (Old Orchard Brands LLC® Lassonde Industries Inc., Sparta, MI). This was done because informal taste testing among 14 research assistants revealed that the diet juice cocktail alone was not palatable; however, a mixture of the diet juice cocktail and regularly sweetened apple juice improved palatability. In order to create a product that was both palatable and low in energy compared to the regular apple juice, the diet juice cocktail was combined with the "light" version of the same brand of apple juice used in the regular apple juice condition.

Energy compensation by food form will be assessed by comparing meal intake following each of the caloric preloads (apple slices, apple sauce, regular apple juice), discussed in more detail in the "Data Analysis" section. Additionally, in order to better compare these findings to the broader literature, COMPx (3, 16–19) will be calculated using data from the regular and NNS apple juice conditions. The equation to calculate COMPx is:

$$\frac{\text{Meal kcal following NNS juice} - \text{Meal kcal following regular juice}}{\text{Regular juice kcal} - \text{NNS juice kcal}} \times 100$$

Using this equation, a COMPx of 100% indicates perfect compensation (adjustment) for the energy in each preload, meaning children reduced their meal intake commensurate with the energy in each preload. A COMPx above 100% indicates that children overcompensated (underate) at the meal following the regular apple juice compared to the NNS apple juice, and COMPx below 100% indicates that children undercompensated (overate) at the meal following the regular apple juice compared to the NNS apple juice.

Preload Administration

In addition to matching the preloads for attributes of weight and energy content, we also aim to control perceived volume and ingestion time of each preload, both of which can impact satiety. Without standardizing ingestion time, the beverages would likely be consumed more quickly than the other preloads, and this would impact the interval between the preload and subsequent meal. As the time interval is an important driver of energy compensation (24) we would not be able to disentangle effects of food form from that of eating rate. Similarly, because volume or amount served can influence expected satiety, we developed methods to disguise the volume of the preloads. By doing this, we hope to reduce the impact of visual volume cues on subsequent satiety. As a result of these design choices, we expect the see less robust, but still significant, influences of food form on satiety than what have been reported in other studies (24). This outcome will help to isolate potential mechanisms whereby food form influences satiety that can be targeted in future studies.

To address differences in perceived volume across the various conditions, preloads will be disguised under a colorful, child-friendly, apple-themed box (**Figure 2B**). This box reduces the amount of time children spend looking at the preload and prevents them from seeing the entire volume to be consumed at once. To standardize ingestion time, an audio recording of a story will be played for the children during preload consumption. These stories were developed to mention a key word ("apple") once every 45 s which serves as a cue for children to reach into the box and pull out a soufflé cup containing one pre-portioned amount of the preload. Each story mentions the key word 16 times, for a total of 16 equal-weight preload portions across 12 min. To encourage children to finish each preload, a research assistant will show the child an apple tree-themed game board (**Figure 2C**) while the audiobook plays. Each time the child consumes one of the preload portions, the research assistant will remove an apple from the tree on the game board and place it into a small basket. Children will be instructed that they must collect all of the apples from the tree in order to earn a sticker. During the no preload condition, children will listen to an audiobook that also mentions the key word "apple" 16 times, once every 45 s. However, the storyline follows a boy who is missing apples, so the children will be instructed to reach into the box to see if any apples are there. During this condition, children will also have a chance to earn stickers by collecting all of the apples from the apple tree game board. This will mimic the timing and protocol of the other preload conditions to control for these factors.

Ad libitum Test Meal

Approximately 20 min after the start of preload ingestion, a standard *ad libitum* test meal will be served consisting of the following familiar, commercially-available foods: macaroni and cheese (Kraft®, Kraft Heinz Co., Chicago, IL), frozen broccoli florets (Birds Eye®, Conagra Brands, Chicago, IL), red grapes (Wegmans®, Wegmans Food Markets, Rochester, NY), baby carrots (Wegmans®, Wegmans Food Markets, Rochester, NY), graham crackers (Nabisco Original®, Nabisco, East Hanover, NJ), and water. Amount (in grams) and energy content of each test meal food are displayed in **Table 1**. Children will be given 30 min to eat until comfortably full and may request additional portions of any of the five test foods, if desired. Each additional portion will weigh the same as the first portion (see **Table 1**). Weights will be taken before and after the child's meal in order to determine total consumption of each food in grams.

Liking and Hunger Ratings

In order to capture other factors that may influence children's intake, including how much they like the foods and variable hunger levels, we will assess liking of each preload and test meal food using a five-point hedonic scale (50). Perceived hunger ratings will be collected before and after each preload, and before and after each test meal using a four-point silhouette scale depicting varying degrees of stomach fullness (51).

Other Measures

As this study posits that successful ASR requires both bottom-up and top-down regulatory processes, other measures of ASR as well as child-level characteristics that may either enhance or disrupt these processes will be tested and reported in future publications. These measures are summarized below and are modeled in **Figure 1**.

Eating in the Absence of Hunger (EAH)- Following their *ad libitum* test meal on visit 5, children's EAH will be assessed using a widely-accepted protocol (52). Twenty min after the end of their test meal, children will be presented with 6 palatable snack foods: potato chips (Lay's® original, PepsiCo, Harrison, NY), cookies (Chips Ahoy!® chocolate chip cookies, Nabisco, East Hanover, NJ), fruit candy (Starbursts® original chews, Mars Inc.®, McLean, VA), M&M's (Mars Inc.®, McLean, VA), corn chips (Fritos® The Original corn chips, PepsiCo, Harrison, NY), and brownies (Entenmann's® Little Bites Fudge Brownies, Bimbo Bakeries, Horsham). Children will also be presented with several toys and will be left alone for 10 min to eat and/or play with whatever they would like, but will not be told how long they have to do so. EAH is a common method used to assess children's food approach behaviors and tendency to eat when satiated, an aspect of ASR (4).

Delay of gratification (D.o.G.)- Children's food-specific delay of gratification will be assessed using a waiting task (53). During this task, a research assistant will first ask the child to choose which snack they would most like to play for from three possible choices: coated chocolate candies, animal crackers, or pretzels. The child will be given instructions to wait until the researcher enters the room in order to receive a larger portion of the snacks, or the child may eat the smaller portion of the snack before the researcher enters the room. The child will not be told, however, how long they must wait in order to earn the larger portion and they may ring a bell if they would like to end the task early. The researcher will exit the room after giving instructions, and this task will end when either (a) the child ends the task by eating the food or ringing the bell or (b) 7 min have passed. While performance on this task does not specifically measure energy intake regulation, it may be related to cognitive efforts to control what or how much is consumed. It is therefore implicated in the pre-consumption phase of ASR (14) and may also be related to eating cessation.

Child sex- A demographics questionnaire will be administered to parents to assess biological sex. Due to the age of the children, we are not asking parents to report gender, which is a sociological construct (54). However, as detailed in our model (**Figure 1**), we hypothesize that many of the psychological and social influences likely to impact ASR may also differ by or interact with child sex/gender. Several studies assessing children's energy compensation have found that boys demonstrate better COMPx than girls (16, 19, 22, 23). However, these findings are not consistent (12, 17, 18, 20, 41) and to our knowledge, no studies have been designed and powered *a priori* to examine these sex differences. An aim of this study, therefore, is to examine whether children's COMPx, calculated by comparing meal intake following the regular apple juice compared to the NNS apple juice, differs by child sex.

Anthropometrics and Body Composition- Children's height and weight will be measured at the beginning of their first laboratory visit after removing shoes, socks, and jackets. Weight will be measured to the nearest tenth of a kilogram using a digital body scale and height will be measured to the nearest half of a centimeter using a stadiometer. Each measurement will be taken in duplicate, and averaged values will be used for data analysis. BMI percentiles and z-scores will be calculated using the Center for Disease Control (CDC) age- and sex- specific BMI cutoffs. Body fat percentage (adiposity), lean body mass (fat-free mass; FFM), and bone mineral density will be measured using dual-energy X-ray absorptiometry (DXA) at the Clinical Research

Center at Penn State. Lean body mass is a determinant of energy needs and has been hypothesized to be a key determinant of the ability to regulate appetite (55), and may therefore be an important bottom-up process involved in ASR.

Previous Exposure to NNS- Previous exposure to NNS will be assessed using the Beverage Questionnaire for Preschoolers (BEVQ-PS), a parent-reported measure of beverage intake that has been validated in this age group (35). Additionally, a version of the Artificial Sweetener (Non-nutritive Sweetener) Intake Questionnaire adapted to measure children's NNS intake will be collected from parents. Children with a greater exposure to non-nutritive sweeteners (NNS) may be at greater risk of overweight and obesity (56). A possible hypothesis for this could be that these children demonstrate poorer ASR, potentially due to an "uncoupling" of energy signaling and energy intake (56), but this has not yet been tested in children.

Respiratory sinus arrhythmia (RSA)- To better understand if ASR in children is dictated by physiological, and therefore subconscious, processes, respiratory sinus arrhythmia will be measured during the children's meals. RSA can be used to approximate vagal nerve activity, which could provide insight into the physiological responses to various food forms and potentially ASR more generally.

Social desirability- Two measures will be collected to approximate children's social desirability. First, a Do/Don't task (57) will be conducted on the first visit to assess children's compliance with the researcher. Following the test meal, the researcher will present the child with an assortment of age-appropriate, attractive toys from a basket and will dump the contents of the basket onto a table in front of the child. The child will have 5–10 min of free play, after which the research assistant will ask the child to put away the toys that were set out. The research assistant will then leave the room. The task ends when either (a) 3 min have passed or (b) the child has finished putting all the toys away. Once this "do" task is complete, children will complete the "don't" task. The research assistant will re-enter the room with a wrapped box containing a small toy. The child will be asked not to touch the gift box until the researcher returns, and the research assistant will leave the room. This task will last 3 min and, similarly to D.o.G, children will not be told the length of time that they must refrain from touching the gift box. After 3 min, the research assistant will re-enter the room and the task will end. Additionally, the Social Desirability Questionnaire for Children (58) will be collected. These measures approximate children's social desirability, which may increase as children's general self-regulation increases. ASR appears to decrease as general self-regulation increases (4); however, few studies have systematically examined both in children. Understanding more about the relationship between general self-regulation and ASR may provide insight into how to improve ASR.

Portion sorting task- A novel portion sorting task developed in our lab will be performed to assess children's ability to match pictures of foods of varying portion sizes. Children will be presented with 16 cards and asked to match the two cards with identical portion size. Children will play two rounds of this game (for a total of 32 cards) and will be timed on how long it takes to make all 8 matches each round. Following the matching task, children will be presented with a deck of 40 cards depicting various foods of different portion sizes and three baskets labeled "too much," "just right," and "too little." Children will be instructed to imagine eating the food and place the picture in the appropriate basket based on how they think their bellies would feel after they finish that portion. Children will complete this task on Visit 1 prior to their meal, during a fasted state. This task may provide insight on children's abilities to discriminate visual food cues during the pre-consumption phase of ASR.

Body dissatisfaction- Three measures of children's body dissatisfaction will be collected following EAH on visit 5: The Weight Concerns Scale (59), Body Esteem Scale (60), and Body Image Scale (61). Eating in order to achieve a desired body type, rather than in response to homeostatic signals, may lead to poorer ASR, though this has not yet been tested in children.

Data Analysis

Based on a power analysis conducted with GPower version 3.1, testing 78 children will be sufficient to achieve 80% power to detect significant differences ($P < 0.05$) between preload conditions. A small effect size ($f = 0.2$) was chosen to be conservative, and the correlation among repeated measures ($r = 0.24$) was based on previous data from our laboratory that used a preloading design in a similar age group (62). Given these specifications, the sample size needed to examine the main effect of food form (1 group, 3 measurements) was smaller than the sample size needed to examine interactions between experimental condition and sex/gender on children's COMPx following the two apple juice preloads (2 groups, 2 measurements). We therefore chose the larger sample size of 78 children and will recruit even numbers of boys ($n = 39$) and girls ($n = 39$) in order to examine sex differences.

Energy intake from the preloads and test meals will be calculated by multiplying gram intake by the energy densities outlined in **Table 1**. To test the hypothesis that food form affects subsequent energy intake at the test meal, a mixed linear model with repeated measures will be used to analyze the main outcomes of meal energy intake (in kilocalories) with preload type (solid, semi-solid, liquid) as the fixed factor and participant as a random factor. Additionally, mean COMPx in response to the apple juice preloads will be calculated using the aforementioned COMPx equation (43). If preload type is a significant predictor of meal energy intake, Tukey's test will be conducted to determine which condition(s) are driving these differences. To test the hypothesis that children will eat less at the meal following the regular apple juice preload compared to the NNS apple juice preload, a similar mixed linear model with repeated measures will treat preload type (high- or low-energy density) as the fixed factor and participant as a random factor. Both models will control for child sex, age, and body weight as well as preload order. Additionally, a separate model that adds pre-meal hunger as a covariate will be conducted for each hypothesis. Because differences in perceived hunger are related to our primary outcome, we will run the analyses with and without adjusting for pre-meal hunger to see if there is an independent effect of food form or energy density on subsequent intake independent of physiological hunger. Similarly, a separate model that adds food liking as a covariate will be conducted for each hypothesis as well to test the independent effect of children's liking of the test foods on energy intake. Significance will be set at $\alpha = 0.05$ and all analyses will be conducted using the most recent version of the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

This study was reviewed and approved by the Institutional Review Board of The Pennsylvania State University (IRB #13957) in accordance with the Declaration of Helsinki. The parents give informed consent to allow their children to participate in the study.

AUTHOR CONTRIBUTIONS

NR and KK were responsible for experimental design and manuscript preparation. BR, LF, KB, JH, MH, KM, and SK were responsible for experimental design and manuscript editing. All authors contributed to the article and approved the submitted version.

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Profiles of Behavioral Self-Regulation and Appetitive Traits in Preschool Children: Associations With BMI and Food Parenting Practices

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Appetitive traits that contribute to appetite self-regulation have been shown to relate to non-food-related regulation in general domains of child development. Latent profile analysis (LPA) was used to identify typologies of preschool children's behavioral self-regulation (BSR) and appetitive traits related to appetite self-regulation (ASR), and we examined their relation with children's BMIz and food parenting practices. Participants included 720 children and their parents (90% mothers), drawn from the baseline assessment of a childhood obesity preventive intervention. BSR measures included teacher reports of children's inhibitory control, impulsivity and attentional focusing, as well as an observed measure of inhibitory control. ASR was assessed using parents' reports of children's appetitive traits related to food avoidance (*e.g.,* satiety responsiveness, slowness in eating) and food approach (*e.g.,* enjoyment of food, food responsiveness). Children's body mass index z-score (BMIz) was calculated from measured height and weight. Parents' BMI and food parenting practices were also measured. Four profiles were identified that characterized children with dysregulated behavior, higher food approach and lower food avoidance (16%), dysregulated behavior but lower food approach and higher food avoidance (33%), regulated behavior but highest food approach and lowest food avoidance (16%), and highly-regulated behavior, lowest food approach and highest food avoidance (35%). Children's BMIz was highest in the profile consisting of children with dysregulated behavior, higher food approach and lower food avoidance. BMI was similar in the profile with children with regulated behavior but highest food approach and lowest food avoidance; children in this profile also had parents who reported the highest levels of controlling food parenting practices, and the lowest levels of parental modeling of healthy eating. Compared to all other profiles, children in the profile characterized by highly-regulated behavior, lowest food approach and highest food avoidance had the lowest BMIz and had parents who reported food parenting practices characterized by the highest levels of child control in feeding and the lowest

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levels of pressure to eat. These findings provide evidence of differing patterns of relations between self-regulation across behavioral and eating domains, and children's obesity risk may vary based on these different patterns.

Keywords: self-regulation, appetitive traits, food approach, food avoidance, childhood obesity, food parenting practices, latent profile analysis

INTRODUCTION

Childhood obesity is a major public health challenge in the U.S. and across the world (1). Approximately 12% of U.S. children ages 2–5 were classified with obesity between 2013 and 2016 (2). Children from low-income households are more likely to have obesity, compared to children from middle- or high-income households (3, 4). Deficits in self-regulatory capacity, the ability to control an impulse or behavior, in general domains of development have been implicated in the development of obesity (5–9). General self-regulation is a broad term that is used to describe a number of behavioral, emotional, and cognitive processes related to one's ability to plan and structure behaviors, focus attention, and inhibit impulses to pursue long-term goals (10). Self-regulatory behavior can be measured across multiple domains of development (e.g., biological, behavioral, emotional, eating), and are essential for biobehavioral health and successful development throughout childhood (11). Evidence linking self-regulation to childhood obesity suggests that greater deficits in children's early self-regulatory capacity (∼age 3 or 4 years) may be linked to rapid weight gain and obesity through adolescence, (6, 8) and into adulthood (12).

As described by Nigg (13), self-regulation includes both top-down and bottom-up processes that co-act. Bottom-up processes are automatic, and require little effort to enact, whereas top-down processes are deliberate, goal-based and require cognitive effort and control. Executive function processes, which represent neurocognitive processes related to problem solving, planning, reasoning and goal-directed behaviors (14), are top-down components of self-regulation that have been implicated in the development of obesity (15, 16). Although executive function processes related to behavioral inhibition (*e.g.,* inhibitory control and impulsivity) have been the most widely-researched processes in studies linking executive function to obesity (15), the exact mechanisms through which executive function is linked to the development of obesity in childhood are not yet fully understood. However, inhibitory control and impulsivity are thought to be implicated in the etiology of obesity, in part, through their influence on children's appetitive traits related to appetite self-regulation.

Appetite self-regulation, as described by Russell and Russell (17), refers to neurocognitive, social and biobehavioral processes or skills involved in an individual's ability to regulate energy intake. Appetitive traits include several domains of eating behaviors, most of which are bottom-up processes that contribute to appetite self-regulation, although some include an interplay of top-down and bottom-up processes (e.g., satiety responsiveness) (18). Appetitive traits have been conceptualized as traits that may explain individuals' differential susceptibility to food, which may confer differential levels of risk for or resilience from obesity (19). Several appetitive traits are conceptualized as a set of eating behaviors that indicate children's tendency toward food approach (i.e., responsiveness to food stimuli, such as the presence of food) and food avoidance (*e.g.,* responsiveness to cues that signal fullness). These traits have been associated with young children's appetite self-regulation and weight status (20–27), and show a small to moderate degree of stability from early (ages 3–5) to late childhood (ages 9–11) (28, 29).

Food approach behavior is described as a movement toward or desire for food, which includes traits such as a preoccupation with food, and eating in response to external or emotional cues. Food avoidance behavior is described as a movement away from food, and includes traits such as picky eating/food fussiness, a slow eating rate, and satiety responsiveness, which is a sensitivity to cues that signal fullness (22, 30). These appetitive traits have consistently been shown to be related to preschool children's obesity risk (31–33), with a higher risk in children who exhibit greater tendencies toward food approach behavior and lower risk in children with greater tendencies toward food avoidance behavior. Findings from multiple studies provide evidence for an interplay between appetitive behaviors and neurocognitive and behavioral systems related to general self-regulation, although there may be underlying processes that are domain specific (18). In a study of 187 low-income, Hispanic preschool children, Hughes and colleagues (23) found that general self-regulation was associated with children's satiety responsiveness, but not with objectively-measured eating regulation (e.g., eating in the absence of hunger) or BMIz; only eating-related regulation measures were associated with child BMIz. In a study with a predominantly white, middle- and upper-income sample of children ages 3–6 years, Giuliani and Kelly (34) assessed children's delay of gratification on a food-based task, which measured whether children chose to wait for a larger snack portion over receiving an immediate, smaller snack portion. The authors found that children's inability to delay gratification (choosing the immediate, smaller portion) was related to greater, objectively-measured eating in the absence of hunger, but it was not related to tasks measuring general, Non-food self-regulation (attentional and inhibitory control) or BMIz. Neither eating- or Non-eating-related regulation was related to child BMIz in the Guiliani et al. study. Additional studies are needed that elucidate the ways in which self-regulation may be linked across domains (*i.e.,* food and Non-food related), and the extent to which various combinations of regulation-related individual, family and household factors increase risk for or confer protection from obesity in children.

One such factor may be coercive food parenting practices, including Non-responsive, controlling attempts to alter children's food intake. Such food parenting practices may undermine children's ability to regulate their intake, and influence the development of obesity in young children (35). Conversely, child-focused, responsive food parenting practices have been shown to promote healthy eating and weight outcomes in children (35). The combined effects of appetitive behaviors, general self-regulation and food parenting practices on children's obesity risk have been examined in several studies (36–41). Although the findings are somewhat mixed, there is evidence to suggest that the effects of coercive food parenting practices on children's obesity risk appear to be exacerbated in children who exhibit appetitive behaviors associated with deficits in eating regulation. Rollins et al. (37) found that the effects of maternal controlling food parenting practices on 5-year-old girls' eating regulation and BMI was most pronounced in girls with low inhibitory control. There are also findings that show that food parenting practices may moderate the association between children's appetitive behaviors and obesity risk. Vollmer et al. (42) interviewed 150 racially- and socioeconomically diverse fathers of children ages 3–5 years and found that the inverse relation between satiety responsiveness and preschool children's BMIz was only significant in children with fathers who used coercive food parenting practices.

Given the multifactorial nature of obesity, there is a confluence of factors across multiple levels of influence that impact children's risk for obesity. Russell and Russell (43) highlight the need for a biopsychosocial approach to research on the development of obesity in children, and call for integrated models that examine links between individual factors across multiple domains of development (e.g., children's appetitive traits and behavioral self-regulation) and parent-related (e.g., food parenting practices) factors, and their interactive roles on children's risk for obesity. This approach formed the basis of the conceptual framework for the present study, along with the dual processing model that conceptualizes self-regulation as involving interplay between top-down regulatory processes (i.e., inhibitory control) and bottom-up regulatory processes (i.e., food approach/avoidance) (18). The objectives of the current study were to use a person-centered approach, latent profile analysis, to explore typologies of preschool children's behavioral self-regulation (BSR), food approach and food avoidance, and their relation with children's BMIz, parents' BMI and parents' food parenting practices. We hypothesized that (a) distinctive profiles of BSR and appetitive traits would be identified; (b) profiles characterized by high BSR, low food approach and high food avoidance would be associated with lower child BMIz and more responsive food parenting practices; and (c) profiles characterized by low BSR, high food approach and low food avoidance would be associated with higher child BMIz and more coercive food parenting practices. To account for the potential genetic and environmental influence of parental weight status on study outcomes, we also examined relations with parental BMI. We hypothesized that higher parental BMI would predict children's membership in the most dysregulated profiles, characterized by combinations of weaker top-down regulatory control (lower inhibitory control and attentional focusing and higher impulsivity), high food approach and low food avoidance.

MATERIALS AND METHODS

Participants

All data were drawn from the Healthy Bodies Project, a 28-week childhood obesity preventive intervention conducted in center-based childcare programs in Central and Southcentral Pennsylvania; 57% of participating centers served predominantly low-income families. Only data collected at baseline (before the intervention began) between 2017 and 2020 were utilized in the current study. To be included in analyses for the current study, surveys from teachers and parents were required; out of the 1397 eligible children, 720 met those criteria. Mothers (90%) represented the majority of parents who completed the parent survey; 9% of parents were fathers, and the remaining respondents were stepmothers and related caregivers. All procedures were approved by the Pennsylvania State University Institutional Review Board.

Measures

Behavioral Self-Regulation (BSR)

Children's behaviors related to self-regulation were assessed using the Children's Behavior Questionnaire–Teacher's Short Form (CBQ-TSF) (44) and the Walk a Line Slowly behavioral task (45, 46). On the CBQ-TSF, teachers reported each child's level of inhibitory control, impulsivity, and attention focusing. Inhibitory control (reported by the teacher) refers to the capacity to plan actions and inhibit inappropriate responses (e.g., "Can easily stop an activity when s/he is told 'no'"; $\alpha = 0.85$). Impulsivity refers to the speed of initiating a response, or acting without thinking (e.g., "Often rushes into new situations"; $\alpha = 0.78$). Attentional focusing refers to the ability to maintain attention and focus on a task (e.g., "When drawing or coloring in a book, shows strong concentration"; $\alpha = 0.87$). Each subscale consisted of 6-items; response options were on a 7-point scale ranging from 1 (extremely untrue of your child) to 7 (extremely true of your child). Teachers are also given the option to select "Not applicable (N/A)." An adapted version of the Walk a Line Slowly behavioral task, or "Turtle Race," provided a measure of inhibitory control (observed in the classroom). In the original version of this task, each child is asked to slowly walk down a "path" consisting of a 2.5-inch x 12-foot strip of colorful tape. Due to concerns about classroom space constraints, a 6-foot line of green-colored tape was used in the current study. As in the original task, a baseline trial was followed by two trials in which children were asked to walk down the line as slowly as they can and then even slower; the length of time (in seconds) it took for the child to walk the line was recorded for each trial, and the two Non-baseline trials were averaged to comprise an observed measure of inhibitory control. Both the teacher-reported and classroom observed measures of inhibitory control were moderately related in this sample ($r = 0.25, p < 0.001$).

Appetitive Traits

Children's appetitive traits were measured using parent reports on the Child Eating Behavior Questionnaire (47). Reliability estimates have been found to be satisfactory with low-income samples of parents of preschoolers (48–51). For the purposes of this study, we included two subscales that indicate *food avoidance behaviors* (movement away from food), and three subscales that indicate *food approach behaviors* (movement toward food) (22). These subscales have been widely reported in the literature to be associated with young children's weight status, objectively-measured eating self-regulation, and food parenting practices, among other relevant outcomes (19, 30, 33, 51, 52). From the *food avoidance* domain, we included the satiety responsiveness subscale, referring to the ability to stop eating in response to satiety cues (e.g., "My child leaves food on his/her plate at the end of a meal"; $\alpha = 0.69$) and slowness of eating subscale (e.g., "My child takes more than 30 min to finish a meal"; $\alpha = 0.72$). From the *food approach* domain, we included the enjoyment of food subscale (e.g., "My child loves food"; $\alpha = 0.85$), the food responsiveness subscale (e.g., "Even if my child is full up s/he finds room to eat his/her favorite food"; $\alpha = 0.74$), and the emotional overeating subscale (e.g., "My child eats more when worried"; $\alpha = 0.76$). Each subscale consisted of 3- to 5-items, and response options were on a 5-point scale ranging from 1 (never) to 5 (always). For the purposes of this study, we conceptualize food avoidance and food approach behaviors as processes that contribute to children's appetite self-regulation. For the purposes of this study, children higher on food avoidance and lower on food approach are characterized as higher in appetite self-regulation, and children higher in food approach and lower on food avoidance are characterized as lower in appetite self-regulation.

Sociodemographics

In the parent survey, parents reported on their child's age, sex (0 = male, 1 = female), and race (recoded as 0 = white Non-Hispanic, 1 = child of color). Parents also self-reported on their age, education levels (recoded as 0 =< college; 1 = completed college or more), and household income (1 = "<$20,000", 2 = "$20,000 to 34,999", 3 = "$35,000 to 49,999", 4 = "$50,000 to 75,000", 5 = over $75,000).

Anthropometrics

Children's height and weight were measured in triplicate using standardized procedures by trained research assistants in the preschool setting. Height was measured to the nearest 0.1 cm and weight was measured to the nearest 0.1 kg; shoes and heavy clothes were removed. Height and weight were used to calculate age- and sex-specific body mass index (BMI; kg/m^2), and BMI percentiles and z-scores based on standardized reference criteria recommended by the Centers for Disease Control and Prevention (53). Weight status classifications included: Non-overweight (BMI < 85th percentile), overweight (BMI ≥ 85th percentile), and obesity (≥95th BMI percentile). Parents were asked to self-report their current height (inches) and weight (pounds) in the online parent survey. These data were used to compute parents' BMI scores (weight[kg]/height[m^2]).

Food Parenting Practices

Parents reported their food parenting practices on the Comprehensive Feeding Practices Questionnaire (54), a 49-item measure of parenting in the feeding domain. For the purposes of this paper, we included subscales measuring feeding constructs that have been shown to support or undermine children's self-regulation (35, 55, 56). Responsive feeding subscales included the child control subscale (e.g., "Do you let your child eat whatever s/he wants?"; $\alpha = 0.67$), which measures autonomy-granting in feeding or the degree to which parents allow children to control their own eating; modeling (e.g., "I model healthy eating for my child by eating healthy foods myself"; $\alpha = 0.83$); and monitoring (e.g., "How much do you keep track of sweets?"; $\alpha = 0.88$). Coercive feeding subscales included food as reward (e.g., "I offer my child his/her favorite foods in exchange for good behavior"; $\alpha = 0.69$); emotion regulation (e.g., "Do you give this child something to eat or drink if s/he is upset even if you think s/he is not hungry?"; $\alpha = 0.80$); pressure to eat (e.g., "My child should always eat all of the food on his/her plate"; $\alpha = 0.66$); restriction for health (e.g., "I have to be sure that my child does not eat too many sweets"; $\alpha = 0.74$); and restriction for weight control (e.g., "I restrict the food my child eats that might make him/her fat"; $\alpha = 0.80$). Internal consistency estimates are similar to those reported by others, (54, 57, 58) including lower estimates on the food as reward and child control subscales. Each subscale consisted of 3 to 8 items, and response options ranged from 1 (never/disagree) to 5 (always/agree).

Statistical Analysis

To address the study research questions, first, we examined bivariate relations among children's BSR, food approach and food avoidance traits. Second, we utilized latent profile analyses to identify profiles of BSR and these appetitive traits that capture the interactive relation between these variables. Third, we investigated whether individual differences in child BMI, and parent-reported food parenting practices and BMI were related to membership in the identified profiles.

Pearson correlations were computed to examine bivariate relations among the measures of behavioral self-regulation and appetite self-regulation. To accommodate the small amount of missing data (1% of data points affecting 30 participants), 25 multiple imputations were performed in SAS 9.4 (SAS Institute Inc., Cary, NC, USA) (59). All study variables were included in the imputation model.

Latent profile analysis (LPA) was conducted in Mplus 8.0 (Muthen & Muthen, Los Angeles, CA) following the approach outlined by Ferguson et al. (60); missing data were handled using full information maximum likelihood (61, 62). Ferguson et al. (60) conclude that a minimum sample size for LPA ranges from 300 to 500 participants, which we exceed. LPA was used to identify distinct groups or "profiles" of children in the sample, based on relations among the indicators of BSR, food approach and food avoidance. Each of the four BSR measures (e.g., inhibitory control, attention control, impulsivity, and Walk a Line Slowly) and five appetitive traits (e.g., slowness in eating, satiety responsiveness, enjoyment of food, food responsiveness, and emotional overeating) were entered into the LPA. Variables that did not differentiate between the profiles were removed from the analyses to improve model fit. Models with 1–8 profiles of children were estimated and compared to one another. Model

TABLE 1 | Inter-correlations between measures of behavioral self-regulation (BSR) and appetite self-regulation (ASR).

	1	2	3	4	5	6	7	8	9
1. Attention control	1.00								
2. Inhibitory control (observed)	0.28***	1.00							
3. Inhibitory control (reported)	0.78***	0.25***	1.00						
4. Impulsivity	−0.36***	−0.12***	−0.57***	1.00					
5. Satiety responsiveness	0.04	0.02	0.10**	−0.13***	1.00				
6. Slowness in eating	−0.03	0.03	−0.01	−0.03	0.45***	1.00			
7. Enjoyment of food	−0.04	−0.11**	−0.08*	0.11**	−0.50***	−0.31***	1.00		
8. Food responsiveness	−0.07	−0.07	−0.06	0.03	−0.18***	−0.04	0.43***	1.00	
9. Emotional eating	−0.02	−0.06	−0.02	−0.00	0.04	0.05	0.09*	0.54***	1.00

*$p > 0.05$.
**$p > 0.01$.
***$p > 0.001$.

fit was assessed using the Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC), in which lower scores are better, as well as the Lo-Mendell-Rubin Likelihood Ratio Test (LMR-LRT) and Bootstrap Likelihood Ratio Test (BLRT), in which the fit of a model is compared with the fit of a model with one fewer profiles. We also evaluated entropy, interpretability, and latent class size.

Once the preferred LPA model was determined, we tested whether the children in each profile differed by child and parental BMI, parental feeding practices, and sociodemographics, using the Bolck-Croon-Hagenaars (BCH) method, in which the probability that each child was in each profile was used as a weight to account for uncertainty in profile assignment and reduce bias in point estimates and standard errors of profile means. Models testing profile associations with child and parental BMI included covariates to adjust for child sex and age, parent age and college education, and household income.

RESULTS

Sample Demographics

Children were, on average, 4.4 years old, ranging from 3 to 5 years; 48% of children were female and 86% were Non-Hispanic, white. Approximately 53% of parents reported a college education or higher. Slightly more than one-quarter of parents reported a household income of $49,999 or less, 24% reported an income between $50,000 and $75,000, and 48% reported an income exceeding $75,000.

Intercorrelations

Bivariate relations among measures of behavioral self-regulation and appetite self-regulation are shown in **Table 1**. As expected, correlations among the measures of child behavioral self-regulation were moderately to strongly related. Children's attentional focusing and inhibitory control (reported and observed) indices were positively correlated, and both were inversely associated with impulsivity. Similarly, parent reports of children's appetitive traits on the CEBQ were correlated in the expected direction. Children's satiety responsiveness was positively associated with slowness in eating, and both measures were inversely associated with enjoyment of food. Children's food responsiveness was inversely associated with satiety responsiveness, and positively associated with enjoyment of food and emotional overeating. Enjoyment of food was also positively associated with emotional eating.

Few relations between the behavioral self-regulation measures and appetitive traits reached statistical significance (as shown in **Table 1**). Children's satiety responsiveness was positively associated with inhibitory control (reported) and inversely correlated with impulsivity. Children's enjoyment of food was inversely associated with inhibitory control (reported and measured), and positively correlated with impulsivity. There were no relations between attentional focusing and appetitive traits.

Behavioral Self-Regulation (BSR) and Appetitive Traits Profiles

When a series of LPA models with 1–8 profiles was estimated to identify patterns of BSR and appetitive traits, emotional overeating did not appear to differentiate the profiles. In general, parents reported very low levels of emotional overeating among their preschool children ($M = 1.6$ out of 5.0; $SD = 0.6$; range = 1.0 to 3.75). Therefore, this variable was removed and the LPA models were rerun. Fit statistics of the subsequent models are presented in **Table 2**. As shown, the LMR-LRT index indicated that the 2-profile model was superior to the 1-profile model and the 3-profile model was superior to the 2-profile model, but there was little improvement in model fit when additional profiles were added. Plots of BIC and AIC indicated two elbows at the 2-profile and 6-profile models, with smaller reductions in subsequent values. In contrast, the BLRT suggested that there was always a benefit of adding more profiles. Entropy was comparable across all models, suggesting high differentiation among profiles, with high likelihoods that children could be classified in a single profile. When interpretability was examined, it appeared that new and important profiles were emerging in the 3-profile and 4-profile model, but not in models with more than 4 profiles. Moreover, the number of children in subsequent profiles was becoming quite small, suggesting that some profiles would be considered rare and unlikely to replicate. Given this pattern of findings, the 4-profile model was selected as representing the best balance between parsimony and model fit, with profiles that were distinct, easy to interpret, and not rare.

The four profiles were labeled based on mean differences in the BSR indices and appetitive traits; means and standard errors (SEs) are provided in **Table 3** and visually depicted in **Figure 1**. For the sake of simplicity, we refer to food approach and food avoidance as appetite self-regulation (ASR) in the abbreviations of the profiles. As described below, two profiles displayed concordant patterns in BSR indices and appetitive traits; the remaining two profiles had discordant patterns.

Concordant Profiles

- *Profile 1, Dysregulated Behavior and Appetite* (16% of the sample); children in this profile exhibited the lowest attentional focusing and inhibitory control and the highest impulsivity, as well as lower food avoidance and higher food approach (Lowest BSR/Lower ASR).
- *Profile 2, Highly-Regulated Behavior and Appetite* (35% of the sample); children in this profile exhibited the greatest attentional focusing and inhibitory control and the lowest impulsivity, along with higher food avoidance and lower food approach (Highest BSR/Highest ASR).

Discordant Profiles

- *Profile 3, Dysregulated Behavior but Regulated Appetite* (33% of the sample); children in this profile exhibited low attentional focusing and inhibitory control and high impulsivity, but high food avoidance and low food approach (Lower BSR/Higher ASR). Children in Profile 3 scored similarly to the Highest BSR/Highest ASR profile on two out of 4 of the ASR indices.
- *Profile 4, Regulated Behavior but Highly Dysregulated Appetite* (16% of the sample); children in this profile exhibited high attentional focusing and inhibitory control and low impulsivity, but low food avoidance and high food approach (Higher BSR/Lowest ASR). Children in Profile 4 scored similarly to the Highest BSR/Highest ASR profile on measured inhibitory control, but were the most dysregulated on all four of the ASR indices.

Sociodemographics

Mean differences in sociodemographics across the four profiles are shown in **Table 4**. Both high BSR profiles had greater proportions of female and older children than the other two profiles. Children in the Highest BSR/Highest ASR profile had the highest household income levels and proportion of parents with a college education. The low ASR profiles had the lowest household incomes, and children in the Lowest BSR/Lower ASR profile were least likely to have parents with a college education.

Child BMI

Mean differences in child and parent BMI indices are shown in **Table 4**. Children in the two low ASR profiles had the highest (and similar) BMI indices, compared to children in the two high ASR profiles, who had similar, low BMI index scores. No other associations with child BMI indices were found.

Parent BMI and Food Parenting Practices

Mean differences in parent BMI and food parenting practices are also shown in **Table 4**. The highest parent BMI was observed among children in the Lowest BSR/Lower ASR profile; this profile also had parents who reported the lowest levels of modeling healthy eating with their child. On average, children in the two high BSR profiles had parents with the lowest BMI scores, but who diverged in their reported food parenting practices. Specifically, children in the Highest BSR/Highest ASR profile had parents who reported the highest levels of child control—i.e., a measure of autonomy-granting in feeding, and lowest pressure to eat. In contrast, children in the Higher BSR/Lowest ASR profile had parents who reported using the lowest levels of child control, and the highest levels of parental modeling and pressure to eat. Lastly, children in the Lower BSR/Higher ASR had parents who reported high pressure to eat, a score that was similar to the Higher BSR/Lowest ASR profile. There were no other significant associations with food parenting practices.

DISCUSSION

Children's appetitive traits tap into food approach and food avoidance behaviors that are related to behavioral inhibition and approach constructs in general domains of development. General behavioral inhibition and approach behaviors have been shown to be related to biological dysregulation (63) and dysregulated eating behaviors (22, 64) in preschool children, suggesting that important processes underlying self-regulation may be common across food and Non-food-related domains. We sought to examine patterns of relations between preschool children's self-regulation in general developmental domains (e.g., inhibitory control and impulsivity) and appetitive traits related to self-regulation in the eating domain. The results from the present study confirm evidence of a clustering of regulatory behaviors across behavioral and eating domains, although the patterns did not provide clear evidence of a dichotomy (e.g., dysregulated vs. regulated). In addition to profiles of children who were either higher or lower in both BSR and appetitive traits related to ASR, we identified profiles of children with lower BSR who exhibited lower food approach and higher food avoidance, and vice versa. Profiles with children who were regulated in only one domain were not rare; ∼33% of children in the sample showed dysregulated behavior but lower food approach and higher food avoidance patterns, and 16% of children in the sample showed the opposite pattern. Along with findings from other studies with preschool children (23, 34, 65), our findings provide only partial evidence for a commonality in regulation across domains of development.

Within each BSR and appetitive traits construct, there was evidence of a consistent (and expected) pattern of domain-specific self-regulation that emerged among indicators. On BSR indicators, children were either high on attention control and inhibitory control and low on impulsivity, or they were low on attention control and inhibitory control and high on impulsivity. On appetitive traits, children were either high on food approach and low on food avoidance, or they were low on food approach

TABLE 2 | Model fit statistics.

Latent classes	BIC	AIC	Convergence	LMR-LRT	BLRT	Entropy	Log likelihood	% of children in smallest class
1	14,967	14,990	YES	–	–	1.00	−7467.9	100.0%
2	14,393	14,279	YES	0.000	0.000	0.81	−7114.6	38.1%[a]
3	14,248	14,092	YES	0.055	0.000	0.73	−7012.2	23.1%[b]
4	14,150	13,953	YES	0.225	0.000	0.76	−6933.8	15.7%[c]
5	14,087	13,848	YES	0.311	0.000	0.76	−6872.4	9.4%[d]
6	14,030	13,751	YES	0.214	0.000	0.77	−6814.6	9.7%[e]
7	14,029	13,708	YES	0.159	0.000	0.78	−6784.4	4.6%[f]
8	14,025	13,663	YES	0.182	0.000	0.79	−6752.8	4.0%[g]

[a]*Proportions for the 2-profile solution were as follows: 61.9 and 38.1%.*
[b]*Proportions for the 3-profile solution were as follows: 41.0, 36.1, and 22.9%.*
[c]*Proportions for the 4-profile solution were as follows: 35.2, 32.9, 16.4, and 15.5%.*
[d]*Proportions for the 5-profile solution were as follows: 35.0, 30.1, 12.7, 12.6, and 9.4%.*
[e]*Proportions for the 6-profile solution were as follows: 29.4, 26.8, 13.4, 10.4, 10.1, and 9.7%.*
[f]*Proportions for the 7-profile solution were as follows: 30.5, 25.8, 12.9, 10.2, 9.6, 6.2, and 4.6%.*
[g]*Proportions for the 8-profile solution were as follows: 30.5, 25.0, 11.7, 10.2, 7.6, 6.1, 4.7, and 4.0%.*

TABLE 3 | Distribution of standardized scores (mean ± SE) of behavioral self-regulation (BSR) and appetite self-regulation (ASR) indices by profile membership.

(Percent of sample)	Lowest BSR/ Lower ASR (15.7%)	Highest BSR/ Highest ASR (35.1%)	Lower BSR/ Higher ASR (32.8%)	Higher BSR/ Lowest ASR (16.4%)
Behavioral self-regulation (BSR)				
Attention control	−1.3[a]	0.8[d]	−0.5[b]	0.5[c]
Inhibitory control (measured)	−0.5[a]	0.2[b]	−0.1[a]	0.3[b]
Inhibitory control (reported)	−1.6[a]	0.9[d]	−0.4[b]	0.5[c]
Impulsivity	1.0[a]	−0.6[d]	0.2[b]	−0.2[c]
Appetite self-regulation (ASR)				
Satiety responsiveness	−0.3[a]	0.4[d]	0.1[b]	−0.9[c]
Slowness in eating	−0.1[a]	0.2[b]	0.2[b]	−0.5[c]
Enjoyment of food	0.4[a]	−0.5[d]	−0.2[b]	1.1[c]
Food responsiveness	0.2[a]	−0.3[b]	−0.2[b]	0.7[c]

Different superscript letters indicate significant differences between groups at $p < 0.05$. Higher scores on attention and inhibitory control, and lower scores on impulsivity indicate higher levels of behavioral self-regulation. Higher scores on food avoidance measures (satiety responsiveness and slowness in eating), and lower scores on food approach measures (enjoyment of food and food responsiveness) indicate higher levels of appetite self-regulation. The Lowest BSR/Lower ASR profile exhibited both dysregulated behavior and appetite; the Highest BSR/highest ASR profile exhibited both highly-regulated behavior and appetite; the Lower BSR/Higher ASR profile exhibited dysregulated behavior but regulated appetite; the Higher BSR/Lowest ASR profile exhibited regulated behavior but highly-dysregulated appetite.

and high on food avoidance. This indicates that there was a reliable level of regulation or dysregulation within each self-regulation construct, highlighting the contribution of this study's findings to our understanding of the domain specificity of self-regulation, and the potential ways in which variations in BSR-appetitive trait patterning may confer risk for obesity in young children. The finding that both concordant and discordant profiles confer varying levels of risk for obesity lends support to the need for more research that examines the interplay between bottom-up and top-down regulatory processes that are implicated in the development of obesity (17).

We found partial support for our hypothesis that children who exhibited the greatest degree of dysregulation–characterized by lower BSR, higher food approach and lower food avoidance–would have the highest BMIz. Children in profiles with higher food approach and lower food avoidance had the highest BMIz, however, these profiles varied in BSR. That is, BMIz of children in the profile characterized by lower BSR, higher food approach and lower food avoidance were not significantly higher than those of children in the profile characterized by higher BSR, higher food approach and lower food avoidance. Regardless of BSR levels, children higher in food approach and lower in food avoidance had significantly lower BMIz than children in profiles characterized by lower food approach and higher food avoidance. That is, appetite-related appetitive traits appeared to be a stronger factor in uncovering individual differences in child BMIz than BSR. This suggests that eating-related regulation may be a more potent correlate of children's weight status than behavioral self-regulation, which may have implications for obesity resilience downstream. In similar findings, Rhee

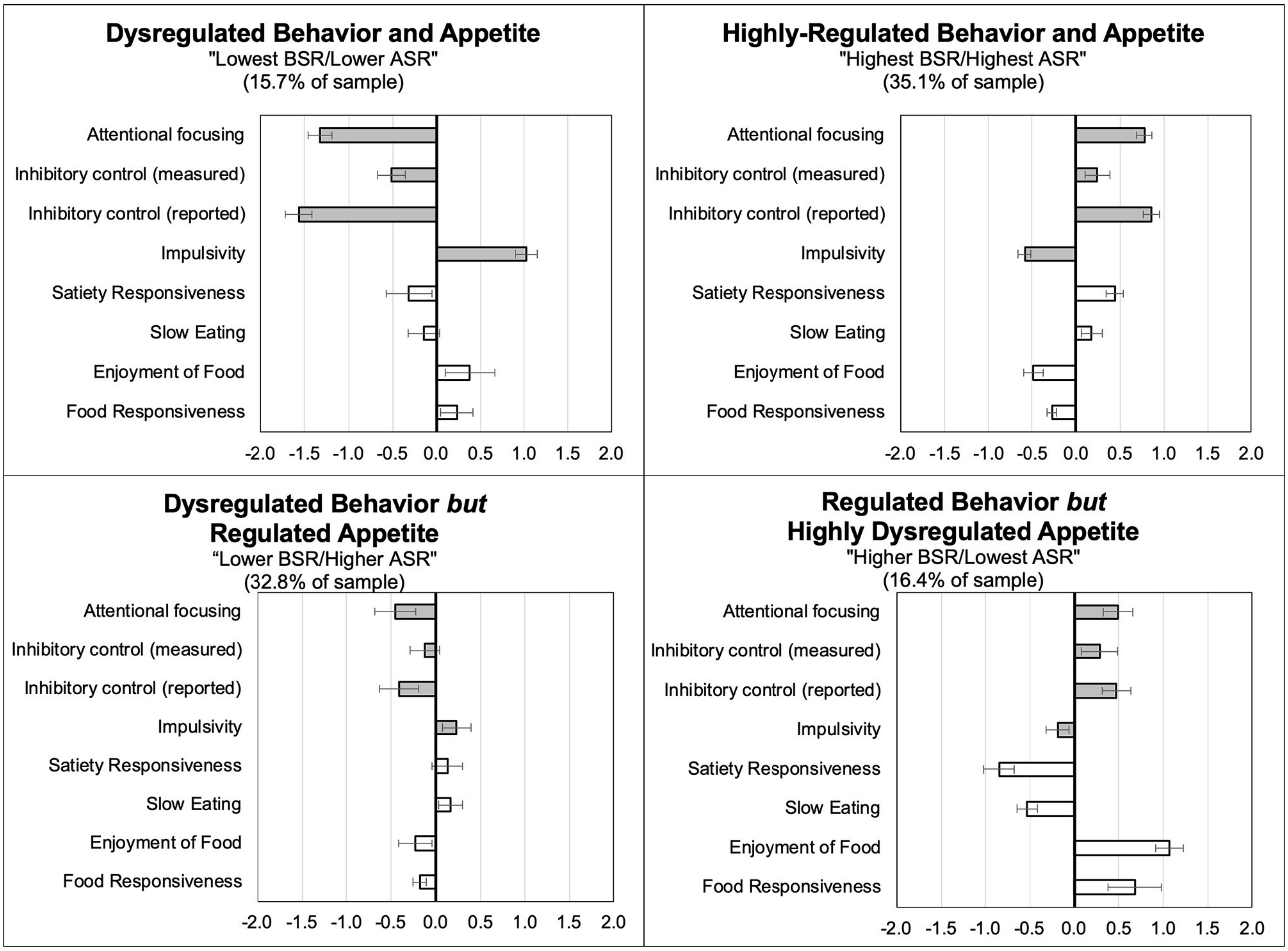

FIGURE 1 | Distribution of standardized behavioral self-regulation indices (BSR; shaded bars) and appetitive traits that contribute to appetite self-regulation (ASR; white bars) by profile membership.

et al. (26) found that low-income preschool children's BMI percentiles were higher among children with lower executive function skills, who also exhibited high food responsiveness (i.e., high food approach) and low satiety responsiveness (i.e., low food avoidance). In our sample of preschoolers, higher levels of behavioral self-regulation did not appear to add additional protection against obesity risk in children with higher food approach and lower food avoidance. Tan and Holub (24) found that parent reports of 3- to 9-year-old children's eating regulation and weight status were related, but inhibitory control was not related to children's weight status. They recommended that interventions focus on eating-related, self-regulation training. Our findings suggest that appetitive traits may be an important target for obesity prevention, given that even among children with poor BSR, those with lower food approach and higher food avoidance had lower BMIz. Additional research is needed to better understand the mechanisms by which these relations exist, including links with objective measures of eating behaviors and dietary patterns, and other obesity correlates.

We also hypothesized that parent factors known to increase children's obesity risk, including parental BMI, would be higher in children who exhibited lower behavioral and appetite self-regulation. The highest parental BMIs were evident in parents of children in the most dysregulated profile, characterized by both lower BSR, higher food approach and lower food avoidance. Children in the profiles characterized by high BSR had parents with the lowest BMIs. This pattern differs slightly from the BMI findings for children: children's BMIz was lowest among children in the profiles characterized by higher ASR (lower food approach and higher food avoidance). This suggests that parental weight status may influence a number of unmeasured family/household environmental factors (*e.g.*, dietary patterns, activity and sleep patterns, parents' eating style) that may be related to deficits in self-regulation. Additional research is needed to better understand these potential factors. Furthermore, obesity prevention and treatment programs may need to be tailored based on children's risk due to parental weight status.

Our findings also revealed different patterns of relations with food parenting practices by profile. There is extensive

TABLE 4 | Mean (± standard error) distribution of behavioral self-regulation (BSR) and appetite self-regulation (ASR) indices by profile membership.

(Percent of sample)	Lowest BSR/ Lower ASR (15.7%)	Highest BSR/ Highest ASR (35.1%)	Lower BSR/ Higher ASR (32.8%)	Higher BSR/ Lowest ASR (16.4%)	Total Sample (100.0%)
Demographics					
Child sex, % female	31.4[a]	58.1[b]	40.9[a]	59.9[b]	48.1
Child age, years	4.2 ± 0.1[a]	4.5 ± 0.0[b]	4.3 ± 0.0[a]	4.6 ± 0.1[b]	4.4 ± 0.00
Parent education, % college	0.37 ± 0.1[a]	0.63 ± 0.0[c]	0.55 ± 0.0[b,c]	0.42 ± 0.0[a,b]	0.53 ± 0.0
Household income[1]	3.5 ± 0.2[a]	4.3 ± 0.1[c]	4.0 ± 0.1[b]	3.6 ± 0.2[a]	4.0 ± 0.5
Child weight status					
BMI[2]	17.0 ± 0.2[a]	16.1 ± 0.1[b]	16.2 ± 0.1[b]	16.8 ± 0.2[a]	16.4 ± 0.1
BMI z-scores[2]	0.9 ± 0.1[a]	0.4 ± 0.1[b]	0.4 ± 0.1[b]	0.8 ± 0.1[a]	0.6 ± 0.0
BMI percentile[2]	73.2 ± 2.6[a]	62.7 ± 2.0[b]	63.2 ± 2.2[b]	69.9 ± 2.9[a]	65.8 ± 1.0
Food parenting practices					
Modeling	3.9 ± 0.1[a]	4.2 ± 0.1[a,b]	4.2 ± 0.1[a,b]	4.3 ± 0.1[b]	4.2 ± 0.0
Monitoring	4.1 ± 0.1	4.0 ± 0.1	4.1 ± 0.1	4.2 ± 0.1	4.1 ± 0.0
Food as reward	2.5 ± 0.1	2.5 ± 0.2	2.6 ± 0.1	2.5 ± 0.1	2.5 ± 0.0
Emotion regulation	1.7 ± 0.1	1.7 ± 0.1	1.6 ± 0.0	1.7 ± 0.1	1.6 ± 0.0
Pressure to eat	3.1 ± 0.1[a,b]	3.0 ± 0.1[b]	3.2 ± 0.1[a]	3.3 ± 0.1[a]	3.2 ± 0.0
Restriction for health	3.1 ± 0.1	3.3 ± 0.1	3.4 ± 0.1	3.4 ± 0.1	3.3 ± 0.0
Restriction for weight	1.7 ± 0.1	1.7 ± 0.0	1.7 ± 0.0	1.7 ± 0.1	1.7 ± 0.0
Child control	2.6 ± 0.1[a,b]	2.7 ± 0.1[b]	2.6 ± 0.1[a,b]	2.4 ± 0.1[a]	2.6 ± 0.0
Parental weight status					
Parent BMI	29.4 ± 0.8[a]	27.9 ± 0.5[b]	28.8 ± 0.6[a,b]	27.3 ± 0.9[b]	28.4 ± 0.2

BMI, body-mass-index; BSR, behavioral dysregulation; ASR, appetite self-regulation. The Lowest BSR/Lower ASR profile exhibited both dysregulated behavior and appetite; the Highest BSR/highest ASR profile exhibited both highly-regulated behavior and appetite; the Lower BSR/Higher ASR profile exhibited dysregulated behavior but regulated appetite; the Higher BSR/Lowest ASR profile exhibited regulated behavior but highly-dysregulated appetite.

Different superscript letters indicate significant differences between groups at $p < 0.05$.

[1]*Reported as 1 = "< $20,000", 2 = "$20,000 to 34,999", 3 = "$35,000 to 49,999", 4 = "$50,000 to 75,000", 5 = over $75,000.*

[2]*Adjusted by child age (years), sex (1 = female), and race (1 = white), household income (1 = "< $20,000", 2 = "$20,000 to 34,999", 3 = "$35,000 to 49,999", 4 = "$50,000 to 75,000", 5 = over $75,000), parent education (1 = 4-year college completed), and parent age (years).*

evidence confirming relations between food parenting practices, children's dysregulated eating behaviors (55) and obesity risk (35). Responsive food parenting practices, including lower levels of coercive feeding (pressure to eat) and higher levels of respect for children's autonomy in feeding (child control), were associated with the most highly-regulated profile, characterized by higher BSR, lower food approach and higher food avoidance. The lowest levels of parents' modeling of healthy eating were reported by parents of children in the most dysregulated profile, characterized by lower BSR, higher food approach and lower food avoidance. Coercive food parenting practices, coupled with children's poor inhibitory control, have been shown to have a compound effect on children's dysregulated eating behavior (37, 38). Programs focused on improving food parenting practices may hold promise for improving children's eating behaviors, which may reduce future obesity risk.

We found a greater proportion of girls and older children in the 2 profiles characterized by high BSR, with varying levels of food approach and avoidance. These findings align with those showing evidence of developmental, age-related increases in BSR, with reports of higher proficiency in girls compared to boys (66, 67). In addition, girls have been shown to follow developmental trajectories characterized by attainment of self-regulatory proficiency at younger ages compared to boys (68, 69). There is also a growing body of literature that shows evidence of sex differences in young children's appetitive behaviors. Studies described in a review by Keller et al. (70) show that the relation between appetitive traits and weight status varies by sex, with a stronger association in girls. In contrast, several studies show that self-regulation of eating (71, 72), as well as the relation between BSR and obesity risk (73, 74) varies by sex; relations appear to be more pronounced in boys. The analyses in the current study did not test whether associations between the profiles and children's BMI varied by sex. There is a need for studies that examine the combined influence of BSR and appetitive traits on children's obesity risk, and how these relations may vary by sex.

Unlike variable-centered statistical modeling approaches (e.g., multiple regression) that provide information on patterns of relations among variables, LPA allowed us to identify profiles that best represent subgroups of preschool children with similar patterns of relations among BSR indicators and appetitive traits. In fact, an examination of correlations between individual BSR indicators and appetitive traits in our sample revealed very few significant associations between individual measures of BSR and individual appetitive traits. LPA yielded unique groups of children based on similarities in their varying levels of BSR and appetitive traits, and membership in these groups was differentially associated with BMIz and obesity risk factors. Few studies have used person-centered approaches to examine BSR-ASR relations. More research is needed to better understand the way in which top-down and bottom-up regulatory processes interact and coact to form self-regulation phenotypes associated with the development of obesity. In a review of food and Non-food self-regulation, Russell and Russell (18) conclude that there are "important parallels" between general self-regulation and appetite regulation, but that they also "involve unique components and processes." Person-centered approaches are useful tools for unpacking these common and unique components and processes, and is an area ripe for inquiry.

Study Strengths and Limitations

This study has notable strengths. It included a large sample of preschool children, and the majority of participating childcare centers served predominantly low-income families. It collected teacher reports, parent reports, direct testing, and biometric measures to assess constructs. And, it relied on latent profile analysis to model the interplay of those constructs. For studies of complex developmental phenomena and health outcomes, such as eating behavior and obesity, person-centered approaches can answer questions about how risk and protective factors are jointly associated with outcomes. In addition, the ability to add covariates to the models affords researchers the ability to further characterize individuals in each profile, which may provide information on potential targets for prevention and treatment. These approaches will expand the literature on the interplay of general self-regulation and appetite self-regulation processes, and may provide useful information on underlying factors linking these constructs (see the paper by Russell, Leech and Russell in this special section).

However, this study is not without limitations. First, although the sample is fairly large, there was evidence of response bias; just over 50% of childcare centers included in the study served a majority of low-income families, however, the response rate for parent surveys was low (52%), and parents who completed surveys were, on average, highly educated (53% college-educated) and from higher income households. The findings may have differed (including the proportion of children identified in the various profiles) if a greater proportion of parents completed surveys. Furthermore, parent reports are subject to bias, particularly for reports related to parenting and demographics. In addition, parents' height and weight were self-reported; this may explain the trends in associations between parental BMI and the profiles. We also did not include an objective measure of eating regulation or energy intake. We are also limited in our ability to make inferences about causation or bidirectionality, given the cross-sectional study design. The racially, ethnically and socioeconomically homogenous sample limits us to generalizing the findings to preschool children in predominantly rural, Northeastern U.S. settings. In addition, we only modeled patterns of self-regulation across two distinct domains of development: behavior- and appetite-related domains. There remains a need to examine self-regulation across multiple domains of development (e.g., biological, behavioral, emotional and appetitive). There are also likely a number of potential confounding variables that were not measured in this study. Lastly, there is clear value in the use of LPA. However, there is usually some judgment involved in determining the number of subgroups and describing the characteristics of those subgroups. Confidence in the existence of particular groups will be enhanced once replicated in further studies.

Summary and Implications

The findings from this study provide evidence of differing combinations of self-regulation across behavioral and eating domains, and the potential influence on children's obesity risk varies across self-regulation profiles. Obesity tracks from childhood through adolescence (75) and adulthood, (76) and based on the current prevalence of obesity in U.S. children, it is estimated that nearly 60% of children with obesity will become adults with obesity (77). The development of obesity in children and adolescents is particularly troubling given its links with a multitude of negative physical health outcomes, (78, 79) and psychosocial and behavioral challenges (80). Early intervention and prevention efforts should focus on improving children's regulation across developmental domains. In a review of studies linking general self-regulation to appetite-related regulation in children, Russell and Russell (17) conclude that general self-regulation increases as children age, while appetitive self-regulation appears to decrease with age. If general self-regulation is malleable, and is thought to drive regulatory behaviors in other domains of development, there is a pressing need to intervene during early childhood (2–5 years), a sensitive period when general self-regulation is rapidly developing (11, 14). Appetitive traits appear to change with age as well, with a shift toward more dysregulated traits (decreased satiety responsiveness and increased food responsiveness) as children age (28, 31). Furthermore, although there is a high degree of heritability in appetitive traits related to eating regulation, the behaviors associated with these traits are thought to be malleable (33, 81).

Findings from promising behavioral interventions and observational studies provide evidence that programs designed to improve self-regulation skills in general behavioral domains may play a role in decreasing adiposity, (82) as well as improve children's appetitive behaviors (83, 84). There is also evidence that preschool children can be taught to regulate their food intake, and focus attention on cues that signal hunger and fullness (71, 85). Lastly, interventions focused on improving general parenting and food parenting practices can impact children's behavioral self-regulation and eating behaviors in ways that reduce obesity risk (86–88). Taken together, there is evidence that behavioral and eating-related regulation factors are malleable targets for prevention and early intervention. However, our findings suggest that programs designed to improve regulation in these domains may need to be targeted based on differing patterns of children's self-regulation across developmental domains.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Penn State University Office for Research Protections. Written informed consent to participate in this study was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

LF and BR conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript. BR conducted all analyses. LF provided critical oversight for the development of the analytical approach. KK, RN, and JS contributed to the interpretation of the results and preparation of the manuscript. All authors contributed to the article and approved the submitted version.

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Infant Distress in a Food Delay Task Changes With Development and Predicts Amount Consumed

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Objective: Eating behavior regulation emerges during early development and involves general self-regulation (emotional, behavioral), appetite regulation (homeostatic metabolic need) and appetite self-regulation (including both Bottom-Up Food Approach and Bottom-Up Food Avoidance and top-down purposeful self-control of eating). Limited research has investigated developmental trajectories of the regulation of eating behavior before the preschool years. The current study used a novel food delay task to assess infant distress as an early emerging marker of eating behavior regulation constructs across early infancy and examine associations with amount of milk consumed.

Method: Mother-infant dyads (n = 179) completed the Ability to Delay Gratification for Food in Infants Task (ATDG-FIT) at 2 weeks, 8 weeks, and 16 weeks of age. The ATDG-FIT required infants to wait before being fed while their bottle was present, but not accessible (3-min Pre-Feeding Delay). After this, the infant was fed for 1 min, then the feeding was paused for 30 s (Mid-Feeding Delay). Infant distress was coded during each feeding delay period and the amount of milk consumed was measured.

Results: The mean proportion of distress during the Pre-Feeding Delay period decreased from 8 to 16 weeks of age ($F(2,230) = 15.02$, $p < 0.001$), whereas the mean proportion of distress during the Mid-Feeding Delay increased from 2 to 8 weeks of age ($F(2,230) = 27.04$, $p < 0.001$). There was a positive interaction between distress during Mid-Feeding Delay and infant age predicting the amount consumed in the protocol ($\beta = 0.30$, $p = 0.022$), suggesting that the association between distress during this part of the task and amount consumed strengthens as infants get older.

Conclusion: The ATDG-FIT may be an effective method to assess emerging eating behavior regulation constructs during early infancy.

Keywords: delayed gratification, appetite, distress, infants, ATDG

Abbreviations: ATDG, ability to delay gratification; CCK, cholecystokinin; ITNR, income-to-needs ratio; WLZ, weight-for-length z-score; MLM, multi-level model.

INTRODUCTION

Obesity established during early childhood is often sustained (1), and difficulties with regulation of eating behavior are hypothesized to promote rapid weight gain (2). For example, it has been proposed that individuals who are more successful at delaying gratification are better able to resist eating tempting foods, thus reducing their risk of overweight and obesity over time (3). The ability to delay gratification (ATDG), defined as the ability to postpone immediately available rewards in order to attain a desired outcome (4), has thus been studied extensively among preschool-aged children, most often using food stimuli (3, 5, 6). A longitudinal study of 805 children found that those who demonstrated poorer ATDG for food at 4 years of age were more likely to be overweight at 11 years of age (6), and a separate longitudinal study of 164 children found that poorer ATDG for food at 4 years of age was associated with higher BMI 30 years later (3). Limited research has investigated ATDG prior to age 3 years (7). Of studies that have done so, poorer ATDG (for a gift, not food) at age 2 years was associated with higher BMI at age 5 years (8) and age 10 years (9). Another study found that greater ATDG for food at age 2 years was associated with lower concurrent BMIz (10). Yet, very little is known about early precursors of ATDG for food or how younger children and infants may respond to ATDG-for-food tasks.

The regulation of eating behavior involves a nuanced interplay between homeostatic, hedonic, and cognitive control factors, and is not well-characterized prior to age 12 months (11, 12). Yet, infancy is an important developmental period during which to identify indicators of emergent eating behavior regulation, as it is a time of rapid development and changes in eating and growth. Behaviors that can be measured during infancy may be relevant for understanding, predicting, and ultimately shaping later eating behavior regulation. For example, Neale et al. (13) used a spoon grasping task with 12-month-olds which required inhibiting their response to grasp a spoon facing the wrong direction, and instead grasp the spoon handle in order to obtain food. Responses on this task at 12 months predicted ATDG for food at 24 months. Assessing infant responses to tasks that are designed to elicit early indicators of eating behavior regulation may inform efforts to identify early emerging individual differences that may signal later poor eating behavior regulation and possible risk for obesity.

In their recent overviews of the literature, Russell and Russell (2, 11) provided an overarching framework for considering developmental changes in capacity to regulate one's eating that included both general self-regulation (e.g., cognitive control) and self-regulation of appetite specifically (including homeostatic need and hedonic factors). They also noted a lack of consistency in the terms used to describe key constructs in the field. We use the term "eating behavior regulation" to capture the conceptual domain of eating regulatory capacity and expand on their framework by considering how relevant constructs emerge early in development and whether they may be assessed in ATDG-for-food task (see **Table 1**). The framework distinguishes General Self-Regulation (GSR), which includes regulation of emotions, cognition, and behavior (for infants, these are co-regulated with a caregiver), from Appetite Regulation (AR), which includes metabolic or homeostatic needs such as hunger and thirst, and Appetite Self-Regulation (ASR), which is comprised of the factors of appetitive traits characterized by propensity for food reward or "Bottom-Up Food Approach" and avoidance of food or "Bottom-Up Food Avoidance" and Top-Down regulation (i.e., goal-directed behavior to inhibit food intake). Traditional ATDG-for-food tasks (2) are thought to potentially measure GSR, Bottom-Up Food Approach, Bottom-Up Food Avoidance, and Top-Down ASR, but are not thought to measure AR. Although young infants do not yet have the developmental capacity for intentional choice to delay gratification (Top-Down ASR; 14), AR is highly significant in young infants for whom homeostatic need is a critical driver of eating behavior (15). Therefore, using ATDG-for-food tasks to assess eating behavior regulation in infants must consider not only the task stimuli (i.e., food vs. non-food) but also relevant infant developmental capacities.

The developmental capabilities of infants younger than 6 months require that responses to ATDG tasks are captured through infant negative affect or frustration, as such tasks involve tolerating the typically unpleasant state of waiting for a desired outcome (16, 17). Regulation of negative affect in infancy, in coordination with a caregiver, is an important indicator of emerging GSR (18). For instance, a longitudinal study from ages 18 to 48 months found that a shorter duration of anger during a gift delay task was associated with a longer duration of distraction, a GSR strategy, at all timepoints (19). Distraction may aid in ATDG by allowing children to strategically shift their attention away from the desired object and reduce expression of negative affect associated with the frustrating situation. In contrast, toddlers who are unable to shift their attention away from the immediate desire are less able to tolerate the frustrating situation without negative affect (19, 20). As affect and attention regulation are closely connected during infancy (21), investigating infant distress during a delay task can give insight into an infant's ability to cope with a frustrating situation and capacity for ATDG. With regard to implications for eating and appetite, although researchers have found that infants who are reported by parents to display distress in response to (non-food) limitations gained weight faster (22) and gained more body fat (23), no research has considered infants' observed negative affect during a food delay task.

Considering responses to an ATDG-for-food task in infants younger than age 6 months also requires consideration of the fact that while infant distress is a very early indicator and precursor of later GSR, it is also an essential indicator of hunger, an aspect of AR (15) and a fundamental element of the mammalian system that maintains energy homeostasis (2). Distress vocalizations that elicit caregiving and feeding behaviors are essential to survival and are therefore tightly regulated by physiologic indicators of caloric need (i.e., hunger and satiety). In human infants and animal models, a low blood glucose reliably initiates feeding, generally through the onset of crying (24), while cholecystokinin (CCK), released from the small intestine in response to milk feeding, suppresses feeding, reduces seeking of feeding-related stimuli, pacifies crying, and causes sedation (25–28). These

TABLE 1 | Constructs relevant to emerging eating behavior regulation; adapted from Russell and Russell.

Construct	Definition and examples [from Russell and Russell (2, 11)]	Could ATDG-FIT index?
General Self Regulation (GSR)	Capacity to self-regulate emotions, cognition, and behavior in relation to food (or non-food) stimuli (e.g., executive functioning; emotion regulation). Includes early infant self-soothing capacity and co-regulation with parent.	Yes
Appetite Regulation (AR; Russell and Russell)	Homeostatic need (e.g., long-term energy reserves, nutrient sensing and availability, metabolic requirements; short- and long-term energy homeostasis; hunger)	Yes
Bottom-Up Appetite Self Regulation (ASR) – Food Approach	Appetitive traits characterized by food-approach (e.g., food responsiveness, reward sensitivity, enjoyment)	Yes
Bottom-Up Appetite Self Regulation (ASR) – Food Avoidance	Appetitive traits characterized by food-avoidance (e.g., picky eating, food fussiness, slowness in eating)	No
Top-Down Appetite Self Regulation (ASR)	Purposeful inhibitory control of food intake (i.e., cognitive control of food intake for purposes of health, weight control; intentional choice; goal directed)	No

biological pathways result in a tight integration of hunger, satiety, and distress (29, 30).

Finally, individual differences in Bottom-Up Food Approach and Bottom-Up Food Avoidance, or appetitive traits such as food reward and avoidance have been studied in older children and identified as promoting or reducing risk for obesity, respectively (31–33). Russell and Russell (11) suggest that in older children, Bottom-Up Food Approach and Bottom-Up Food Avoidance processes could drive some of the mixed findings observed between Top-Down ASR and weight outcomes. Although less research has been conducted in infants, there is emerging evidence that appetitive traits, or Bottom-Up Food Approach indicators (e.g., food responsiveness) are associated with eating in the absence of hunger (34) as well as weight (35) within the first year of life. It is therefore also important to consider how Bottom-Up Food Approach could be a driver of infant response to ATDG-for-food tasks during very early infancy.

Current Study

The goal of the current study was therefore to examine infant distress in a novel ATDG-for-food task – the ATDG-FIT – as a marker of early eating behavior regulation, specifically GSR, AR, and Bottom-Up ASR. We developed the ATDG-FIT to parallel ATDG-for-food tasks in older children so we could determine how infant responses in the ATDG-FIT would evolve across the first year of life and lay the groundwork to test whether they would relate to later ATDG performance. As noted in **Table 1**, we anticipate that the ATDG-FIT in early infancy (prior to 6 months of age) may assess GSR, AR, and Bottom-Up food approach, but not Top-Down ASR, given infants' limited cognitive capacity for choice to delay (14). We used a longitudinal design and assessed infant distress while waiting to consume milk under two conditions (Pre-Feeding and Mid-Feeding Delay) across three timepoints (infant age 2, 8, and 16 weeks). The ATDG-FIT included both Pre-Feeding and Mid-Feeding Delay on the premise that differences in energy homeostasis (i.e., AR) under these two conditions may account for possible differential associations between distress and milk intake. We hypothesized that infants would show less distress during the delay periods as they grew older, reflecting improving GSR, and that decreased distress during the Pre-Feeding Delay specifically could reflect reduced acuity of metabolic need (i.e., changes in AR). We did not have specific hypotheses about change in Bottom-Up Food Approach across development. We also examined whether infant distress during the delay periods predicted the amount of milk infants consumed in the protocol and whether this association changed across early development. Overall, we hypothesized that there would be positive associations between distress during either feeding delay and amount of milk consumed across all three ages, reflecting the possibilities that more limited GSR could drive increased consumption as a soothing mechanism, that greater metabolic need (AR) could drive increased consumption, and that higher Bottom-Up Food Approach could drive greater demand and increased consumption.

MATERIALS AND METHODS

Recruitment and Participants

Mother-infant dyads were recruited from a community in the Midwest United States through flyers, postcards, and social media. Mothers provided written informed consent for themselves and their infants. The study was approved by the University of Michigan Medicine Institution Review Board (IRB MED). Inclusion criteria for the study consisted of the following: (1) Child was born at 37.0 – 42.0 weeks gestation with weight appropriate for gestational age, and no significant perinatal or neonatal complications. Participants were excluded from the study if they met any of the following criteria: (1) Mother is not fluent in English; (2) infant is not the biological child of the mother; (3) mother < 18 years old; (4) medical problems or diagnosis affecting current or future eating, growth, or development; (5) child protective services involvement in the neonatal period; and (6) infant does not consume at least two ounces in one feeding from an artificial nipple and bottle at least once per week. Dyads were recruited to begin the study when infants were 2 weeks of age. To facilitate recruitment, families could also enter the study at infant age 8 weeks (2 months) or 16 weeks (4 months). Data were collected for each family at the infant's first assessment point (termed "baseline") and as described at each timepoint thereafter. Infants who were breastfed at all three timepoints were dropped from study analyses because there were no available objective measurements of amount consumed. Infants excluded from analyses for this reason ($n = 106$) did not significantly differ from those included in the analyses on any of the study variables of interest (all p's ≥ 0.05). Infants who were bottle-fed for at least one of the three timepoints were retained as the analytic sample for the current study ($n = 179$).

Procedure

Research assistants visited families' homes and mothers completed several questionnaire-based measures at baseline. Mothers and infants also completed the ATDG-FIT in their home at baseline and subsequent timepoints (i.e., 2-, 8-, and 16-weeks), which was video recorded for observational coding. The ATDG-FIT was conducted at the point during the home visit when mothers indicated that they thought the infant was hungry based on the infant fussing or crying, which have been identified as relatively reliable indicators of infant hunger in prior literature (15). The time of day at which the ATDG-FIT was also recorded.

Ability to Delay Gratification for Food in Infants Task

The goal of the ATDG-FIT was to assess infant behaviors when the infant is not allowed to eat immediately (see **Table 2**, for task elements and sequence). Mothers were instructed to prepare to feed the infant their usual milk (either breast milk or formula) and usual bottle, prepared as they usually would, or prepare to breastfeed. Research assistants instructed the mothers, "we will ask you to prepare a bottle for [infant's name]. Once the bottle is prepared, we will ask to set the bottle on the table or in the baby's view for the first few minutes of the protocol. We want to make sure that [infant's name] can see the bottle but not reach it. If [infant's name] become upset, you can use any non-feeding method you'd like to soothe them." Mothers who chose to breastfeed were instructed to hold but not feed their infant for this segment. Mothers were also instructed that they could have a pacifier nearby, which they could use only during the pacifier period of the protocol, if desired. The research assistant stayed behind the video camera and did not engage with the dyad during the protocol. Research assistants asked the mother when their infant was hungry and the protocol began when the mother indicated that the baby was hungry. The mother then held their infant for 3 min while the bottle was present and visible to the infant but not reachable (Pre-Feeding Delay). If the mother elected to breastfeed, then the mother held their infant without feeding. After the 3-min Pre-Feeding Delay, if the mother had a pacifier, the research assistant told the mother, "you can offer [infant's name] the pacifier now." The mother was given 2 min to offer the pacifier or continue holding the baby. Mothers without a pacifier continued to hold their baby. After 2 min, the mother was instructed, "you can feed [infant's name] now for 1 min." The research assistant then timed the infant feeding for 1 min. After the 1-min feeding period, the mother was asked to stop feeding for 30 s (Mid-Feeding Delay) by giving the bottle to the research assistant or covering access to their breast. The research assistant then placed the bottle where it was visible to the infant but not reachable. After the 30-s Mid-Feeding Delay, the mother was asked to continue feeding as she typically would until the feeding was complete. For infants who were bottle-fed, the bottle was weighed before and after the protocol to measure the amount consumed by the infant during the protocol.

TABLE 2 | Ability to delay gratification for food in infants task (ATDG-FIT).

Segment	Length of time
Pre-Feeding Delay (bottle present/visible, but no access)	3 min
Bottle visible, but no access, pacifier optional	2 min
Bottle given	1 min
Mid-Feeding Delay (bottle removed to pause feeding)	30 s
Feeding until completion	Until dyad completes feeding

We analyzed infant distress during the "Pre-Feeding Delay" and "Mid-Feeding Delay" segments.

Measures

Distress

Infant distress, defined as displays of negative affect, was coded in 10-s intervals as none (0), mild (1), or moderate/intense (2) based on facial, vocal, and body movement indicators. Mild distress included instances of whimpering, mild fussing, and facial expressions or body movements indicating distress or frustration (e.g., downturned mouth, mild squirming). Moderate/intense displays of negative affect included stronger displays of distress such as hard crying, active squirming or arching back while crying, or screaming. In the current study we considered any distress as an indicator so we created a composite code to indicate distress present (1; mild or moderate/intense distress) or not present (0; no instances of distress). Undergraduate research assistants, who did not administer the protocol, were trained to achieve interrater reliability ($\kappa > 0.70$) on coding at each of the three timepoints prior to coding the videos. Approximately 20% of videos were double-coded throughout the coding process to assess interrater reliability at the 2-week ($\kappa = 0.73$), 8-week ($\kappa = 0.75$), and 16-week ($\kappa = 0.78$) timepoints. For data analysis purposes, we calculated the proportion of distress in each segment (i.e., the total number of intervals with distress present divided by the total number of coded intervals). We analyzed infant distress during the 3-min Pre-Feeding Delay (i.e., bottle visible, but no access) and 30-s Mid-Feeding Delay (i.e., bottle removed to pause feeding) periods, as these two segments required infants to wait without milk or a pacifier being offered. Hereafter, we refer to these variables as Pre-Feeding Delay Distress and Mid-Feeding Delay Distress.

Amount Consumed

Amount of breastmilk or formula consumed by the infant in grams was calculated by subtracting weight of the bottle and contents remaining from the initial weight of the bottle and contents. Bottles were weighted using a Taylor TE32FT digital scale (2lb $\times$ 0.01oz/1 kg $\times$ 0.5 g; accurate to $\pm$ 0.5 g). It was only possible to directly calculate the amount consumed variable in this manner for infants who were bottle-fed. Values for amount consumed were imputed for any timepoints when infants were breastfed, but this was true only for those infants who were bottle-fed for at least one of the three study timepoints.

Covariates

Infant weight-for-length z-score (WLZ) was included as a covariate, given associations with infant consumption amount (36). Infant weight and length were measured at all timepoints twice during the same visit and averaged; if the two measurements differed by >0.1 kg for weight or >0.2 cm for length, then a third measurement was obtained and averaged. Measurements were used to calculate WLZ based on the World Health Organization growth charts (37). Infant feeding mode (breast or bottle-fed), and milk type (breast milk or formula) used in the ATDG-FIT were also included as covariates. Infant feeding mode was coded as breastfed or bottle-fed (breastfed = 0; bottlefed = 1) at each timepoint. Infant milk type was coded as breast milk or formula (breast milk = 0; formula = 1) at each timepoint. Time elapsed since last feeding was also included as a covariate, given well-established associations between feeding intervals and amount consumed (38–40). Mothers reported the time of the infant's last feeding prior to the start of the ATDG-FIT, from which time elapsed since last feeding was calculated.

Demographics

Mothers reported whether they were Hispanic or not, as well as their race, choosing from United States Census categories White, Black, American Indian or Alaska Native, Asian, Native Hawaiian or Pacific Islander, Multiracial (and if so, which races), and Other; categories were collapsed to indicate race/ethnicity (White non-Hispanic, Black non-Hispanic, Hispanic any race, and other non-Hispanic [American Indian/Alaskan Native, Asian, Native Hawaiian/Pacific Islander, Multiracial]. Mothers reported on family income, number of individuals living in the household, and infant sex at baseline. Income to needs ratio (ITNR) was calculated by dividing income by the poverty income threshold for a household of that size in the given year; an ITNR of 1.0 indicates that a household is living at the poverty level, with higher values indicating greater income-to-needs (i.e., lower poverty) (41).

Analysis Plan

Descriptive statistics were used to characterize the sample and bivariate statistics were used to assess associations among key variables. To examine developmental change, analyses of variance (ANOVAs) using repeated measures were used to assess differences in Pre-Feeding Delay Distress and Mid-Feeding Delay Distress) across the 3 ages. Repeated measure ANOVAs were also used to assess differences in mean amount consumed across the 3 ages.

To examine whether Pre-Feeding Delay Distress or Mid-Feeding Delay Distress related to amount consumed and whether the association changed with age, multilevel modeling (MLM) in Stata 17 (42) was used to examine time-variant predictors (see below) of amount consumed over time while accounting for possible correlation between repeated measures (43). MLM analyses also accounted for the fact that the number of weeks differed between assessment timepoints by using infant's exact age at the time of the assessment. Predictors of interest were infant age, Pre-Feeding Delay Distress, and Mid-Feeding Delay Distress. Covariates were time varying infant WLZ, feeding mode (breast- vs. bottlefed), milk type (breast milk vs. formula), and time elapsed since last feeding that occurred prior to the ATDG-FIT.

Multi-level model was used to examine predictors of the amount consumed across development (i.e., trajectory of amount consumed) for Pre-Feeding Delay Distress or Mid-Feeding Delay Distress. This MLM included an infant age by distress interaction term in order to test whether the association between Pre-Feeding Delay Distress or Mid-Feeding Delay Distress and amount consumed changed as infants grew older. A positive interaction between infant age and either distress variable would indicate that the strength of the association between distress and amount consumed increased as infants grew older. The model to predict amount consumed was estimated including time variant independent variables using the following equation:

$$y_{it} = \beta_0 + \beta_1(\text{Infant age}) + \beta_2(\text{Pre-Feeding Delay Distress}) + \beta_3(\text{Mid-Feeding Delay Distress}) + \beta_4(\text{Pre-Feeding Delay Distress*Infant age}) + \beta_5(\text{Mid-Feeding Delay Distress*Infant age}) + \beta_6(\text{Feeding mode}) + \beta_7(\text{Milk type}) + \beta_8(\text{WLZ}) + \beta_9(\text{Time elapsed since last feeding}) + u_{0i} + e_{it}$$

Missing Data Imputation

Missing values for amount consumed at the timepoints when infants were breastfed were handled alongside all other missing data using multiple imputation with covariates (44–46). Imputation was conducted based on the values of other independent variables included in the statistical model, following recommended methods (46). Amount consumed and milk type had between 20 and 72% missing data, with breastfeeding accounting for most missingness, as expected. Other variables had between 11 and 45% missing data. Twenty imputed datasets were created and then simultaneously analyzed in accordance with recommendations for the number of imputations (47). Regression coefficients and standard errors were averaged across regression models (44).

RESULTS

Descriptive Statistics and Bivariate Associations

The total sample recruited consisted of 285 mother-infant dyads. Of these, 179 had data from at least one ATDG-FIT assessment at infant age 2 weeks (timepoint 1; n = 99), infant age 8 weeks (timepoint 2; n = 155), and/or infant age 16 weeks (timepoint 3; n = 157) and were included in the analytic sample for the current study (see **Table 3**). Of this sample, more than half of the infants were girls (53%) and 66% of mothers were White, non-Hispanic. The mean ITNR was 3.46 (SD = 2.23) for this sample, where values of 1.0 indicate that a household is living at the poverty level and higher values indicate greater income-to-needs (41). At 2 weeks, 41% of infants were bottle-fed

TABLE 3 | Sample demographics and covariates of interest ($N = 179$).

Sample demographics collected at study entry for each family	M(SD)/%		
Infant sex (girls)	53%		
Mother race/ethnicity			
White, non-Hispanic	66%		
Black, non-Hispanic	17%		
Hispanic, any race	6%		
Other (American Indian/Alaskan Native, Asian, Native Hawaiian/Pacific Islander, Multiracial)	11%		
Income to needs ratio (ITNR)	3.46 (2.23)		
Covariates of interest collected at each study wave	**Timepoint 1 (2 Weeks) n = 99 M(SD)/%**	**Timepoint 2 (8 Weeks) n = 155 M(SD)/%**	**Timepoint 3 (16 Weeks) n = 157 M(SD)/%**
Infant age (weeks)	3.23 (0.98)	9.25 (1.47)	17.73 (1.83)
Infant weight to length z-score (WLZ)	−0.12 (1.07)	0.04 (1.03)	0.12 (0.96)
Feeding mode (Bottle)	41%^{a}	52%^{b}	64%^{c}
Food type (Breast milk)	61%^{a}	55%^{a}	47%^{b}
Pre-Feeding Delay distress (proportion of segment)	0.60 (0.34)^{a}	0.58 (0.36)^{a}	0.40 (0.38)^{b}
Mid-Feeding Delay distress (proportion of segment)	0.32 (0.36)^{a}	0.62 (0.40)^{b}	0.60 (0.42)^{b}
Amount consumed in grams	72.39 (38.31)^{a}	85.12 (54.79)^{b}	109.36 (62.91)^{c}
Time elapsed since last feeding (minutes)	149.57 (63.49)^{a}	164.50 (70.41)^{ab}	172.29 (82.10)^{b}

Differing superscripts denote within-row significant differences. Different n's denote the number of dyads with data for that study wave. Descriptives are presented on data prior to imputation. Income to needs ratio (ITNR) was calculated by dividing income by the poverty income threshold for a household of that size in the given year. ITNR is a commonly used metric to indicate the financial situation a family is in relative to needs. In terms of interpretation, an ITNR of 1.0 indicates a household is living at the poverty level; higher values indicate greater income (41).

during the ATDG-FIT; at 8 weeks, 52% were bottle-fed; and at 16 weeks, 64% were bottle-fed. The majority of dyads completed the ATDG-FIT protocol midday (*mean start time* = 12:46 PM, *SD* = 2 h and 20 min).

Bivariate analyses of the data prior to imputation indicated that covariates (feeding mode [breast- vs. bottlefed], and milk type [breast milk vs. formula] during the ATDG-FIT) were associated with key study variables of Pre-Feeding Delay Distress, Mid-Feeding Delay Distress, and/or amount consumed for at least one timepoint; for example amount consumed was positively associated with being bottlefed and consuming formula, and distress was positively associated with being bottlefed. Bivariate analyses also indicated that Pre-Feeding Delay Distress, Mid-Feeding Delay Distress, and amount consumed were all positively associated (all *p*'s reported < 0.05). Specifically, infant distress during Pre-Feeding Delay was positively associated with amount consumed at 16-weeks of age ($r = 0.28$, $p < 0.001$), and positively but not significantly associated with amount consumed at 2-weeks ($r = 0.25$, $p = 0.09$) or 8-weeks ($r = 0.11$, $p = 0.26$). Infant distress during Mid-Feeding Delay was positively and significantly associated with amount consumed at all timepoints (2-week $r = 0.34$, $p = 0.02$; 8-week $r = 0.19$, $p = 0.04$; 16-week $r = 0.36$, $p < 0.001$).

Means and standard deviations for all study variables at each measurement occasion prior to multiple imputation are summarized in **Table 3**. One-way repeated measures ANOVAs were conducted prior to multiple imputation to assess mean differences in key variables across timepoints (significant differences across timepoints noted in **Table 3**). Observed distress at both Pre-Feeding and Mid-Feeding Delay ranged from 0 to 1, reflecting large individual differences. Amount consumed differed across timepoints (F (2,130) = 22.31, $p < 0.001$). Infants consumed significantly more at 16 weeks compared to 8 weeks ($t = 4.61$, $p < 0.001$), at 16 weeks compared to 2 weeks ($t = 6.25$, $p < 0.001$), and at 8 weeks compared to 2 weeks ($t = 2.87$, $p = 0.013$). The percentage of infants who were breastfed and fed breastmilk declined across the three ages (see **Table 3**).

Association of Pre-Feeding Delay Distress and Mid-Feeding Delay Distress With Age

ANOVA results revealed a difference in Pre-Feeding Delay Distress across timepoints ($F(2,230) = 15.02$, $p < 0.001$; see **Figure 1** and **Table 3**). A Tukey *post-hoc* test revealed significantly lower Pre-Feeding Delay Distress at 16 weeks compared to 8 weeks ($t = -4.79$, $p < 0.001$) and at 16 weeks compared to 2 weeks ($t = -4.47$, $p < 0.001$). No significant difference was found between 8 and 2 weeks. There was also a difference in Mid-Feeding Delay Distress across ages ($F(2,230) = 27.04$, $p < 0.001$; see **Figure 1** and **Table 3**). A Tukey *post-hoc* test revealed significantly higher Mid-Feeding Delay Distress at 16 weeks compared to 2 weeks ($t = 6.21$, $p < 0.001$) and 8 weeks compared to 2 weeks ($t = 6.99$, $p < 0.001$). No significant difference was found between 16 and 8 weeks.

Association Between Distress and Amount Consumed Across Ages

Results from MLM analysis (see **Table 4**) revealed a significant interaction between Mid-Feeding Delay Distress and infant age

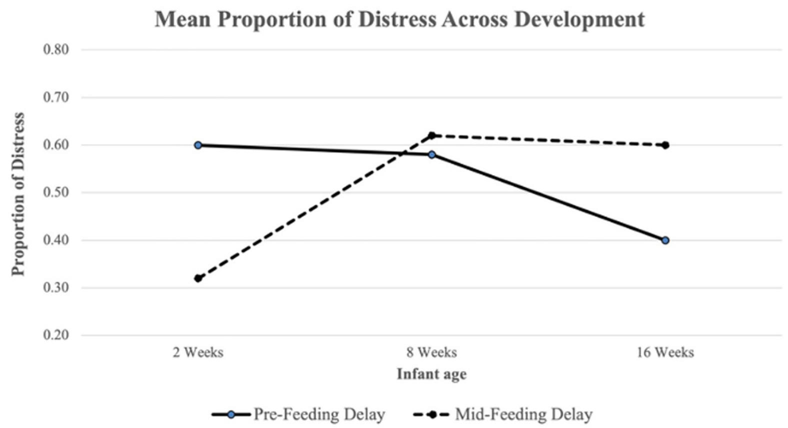

FIGURE 1 | Mean proportion of Pre-Feeding and Mid-Feeding Delay distress across development. The proportion of distress in each delay segment was calculated as the total number of intervals with distress present divided by the total number of coded intervals.

TABLE 4 | Multilevel model estimating amount of milk consumed over time.

Fixed Effects	ß	SE	*t*	*P*-value	[95% CI]
Infant age	0.101	0.94	1.14	0.254	[−0.78, 2.93]
Pre-Feeding Delay distress	0.097	21.22	0.74	0.458	[−26.23, 57.84]
Infant age * Pre-Feeding Delay distress	0.005	1.50	−0.04	0.967	[−3.02, 2.90]
Mid-Feeding Delay distress	−0.101	19.51	−0.74	0.460	[−53.24, 24.27]
Infant age * Mid-Feeding Delay distress	0.298	1.35	2.31	0.022	[0.45, 5.79]
Infant weight for length	−0.156	3.29	−2.72	0.007	[−15.41, −2.48]
Milk type (breast milk = 0, formula = 1)	0.228	6.50	3.88	0.000	[12.45, 38.06]
Feeding mode (breast = 0, bottle = 1)	−0.064	9.73	−0.90	0.369	[−28.15, 10.58]
Time elapsed since last feeding	0.199	0.04	4.88	0.000	[0.11, 0.26]
Intercept	–	18.77	1.20	0.237	[−15.14, 60.05]
Random effects	**Estimate**		**SE**		**[95% CI]**
Person level variance	27.38		4.11		[20.37, 36.79]
Residual variance	40.76		2.66		[35.82, 46.39]

ß = Standardized Beta; SE = Standard Error; CI = Confidence Interval.

(ß = 0.298, p = 0.022, 95% CI = [0.45, 5.79]). The association between Mid-Feeding Delay Distress and amount consumed became stronger as infants grew older. **Figure 2** illustrates that at infant age 2 weeks and 8 weeks, the amount consumed was not associated with Mid-Feeding Delay Distress, whereas at 16 weeks the amount consumed was positively associated with Mid-Feeding Delay Distress (see unstandardized beta values for each age in **Figure 2**). In this model, amount consumed was significantly associated with infant WLZ (ß = −0.156, p = 0.007, 95% CI = [−15.41, −2.48]), formula feeding during the protocol (ß = 0.228, $p < 0.001$, 95% CI = [12.45, 38.06), and time elapsed since last feeding (ß = 0.199, $p < 0.001$, 95% CI = [0.11, 0.26]), but not significantly associated with infant age, Pre-Feeding Delay Distress, age by Pre-Feeding Delay Distress interaction, Mid-Feeding Delay Distress, or feeding mode.

DISCUSSION

The current study sought to investigate infant responses hypothesized to reflect emerging eating behavior regulation in a novel protocol – the ATDG-FIT. Specifically, we tested whether distress during a Pre-Feeding and a Mid-Feeding Delay changed with infant age, and whether distress would predict the amount of milk infants consumed during the protocol across early development. First, we found that infants showed distress in the ATDG-FIT as early as 2 weeks after birth. Second, we found that Pre-Feeding Delay distress decreased from 8 to 16 weeks, whereas Mid-Feeding Delay distress increased from 2 to 8 weeks of age. Third, the association between distress during Mid-Feeding Delay – but not Pre-Feeding Delay – and amount consumed became stronger with age such that it was present at 16 weeks, but not at 2 or 8 weeks. This association was present independent of infant WLZ, feeding mode, or milk type, and time elapsed since last feeding.

Emergent Eating Behavior Regulation in the Ability to Delay Gratification for Food in Infants Task

Despite significant research on ATDG during early childhood, little work has examined responses to food delay tasks during

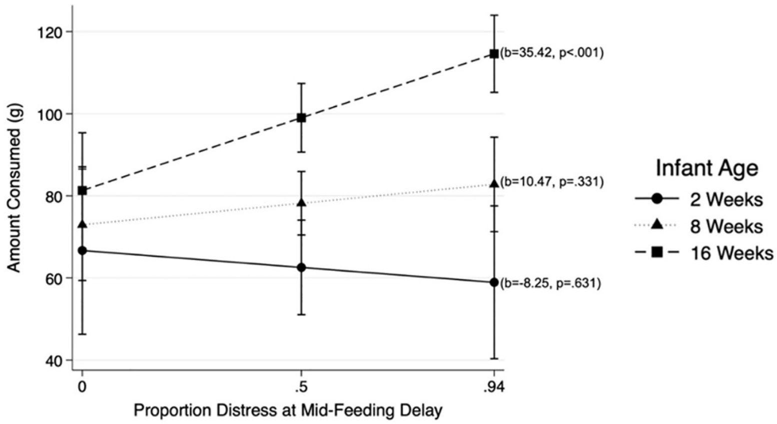

FIGURE 2 | Associations between distress at Mid-Feeding Delay and amount consumed at different infant ages: 2, 8, and 16 weeks.

infancy (48). Prior research has used familiar and motivating objects to test infant delay capacity (13), but researchers interested in the development of eating behavior regulation have emphasized the importance of using food-specific tasks (2, 10). The ATDG-FIT was therefore designed to mirror ATDG-for-food tasks in older children by using milk and a familiar object (bottle or breast) to elicit infant responses while waiting to be fed. We considered infant distress observed during specific sections of the protocol–Pre-Feeding Delay (i.e., when bottle was present, but not accessible) and Mid-Feeding Delay (i.e., when bottle was removed)–as indicating emergent eating behavior regulation, specifically GSR, AR, and Bottom-Up Food Approach. The infant distress observed during Pre-Feeding Delay may have indicated physiological hunger, or AR; indeed, distress is a critical infant hunger cue for caregivers during the earliest weeks of life that helps to ensure an infant will not starve (15, 24). In contrast, Mid-Feeding Delay captured infant behavior while waiting for food under different circumstances, after the infant has started feeding and may be less hungry (26, 49). Distress in this segment may have signaled greater frustration with the removal of the bottle and the need to wait for more milk, thus could be interpreted as implicating GSR rather than AR. Distress in either segment may also have indexed Bottom-Up Food Approach, or propensity for food reward. Thus, in addition to examining associations between ATDG-FIT responses and amount of milk consumed in the protocol as we did in the current study (see discussion below), it will be an important direction for future work to examine associations between individual differences in infant ATDG-FIT responses and other hypothesized early life indicators of eating behavior-related constructs, for example response to sweet taste (50) or sucking behavior in young infants (51), or reinforcing behavior paradigms in older infants (52, 53).

Developmental Change in Responses to the Ability to Delay Gratification for Food in Infants Task

In terms of developmental change, consistent with our hypothesis, we found that distress during the Pre-Feeding Delay decreased as infants aged. There are several possible explanations for this observation, mostly related to changes in energy homeostasis with age (i.e., AR), suggesting infants may be more able to tolerate hunger while waiting for milk as they get older. Between ages 2 weeks and 3 months, infant adiposity nearly triples [from about 11 to 30% body fat; (54)]. Blood glucose correlates closely with adiposity (55), and declines in blood glucose initiate eating (24). Younger infants also have very high glucose turnover and less ability to mobilize hepatic stores efficiently (56). Due to this glucose physiology, younger infants experience a more acute and urgent need for feeding than do older infants. Declining Pre-Feeding Delay distress with age could also be explained by operant conditioning. CCK mediates learning of food cues in human infants and animal models (28, 49, 57) – calming in response to feeding cues is conditioned by the linking of the CCK-induced pacifying effects with feeding in very early infancy. The ability of the older, but not younger, infants to calm in response to milk cues may represent their greater exposure to and learning of food and feeding cues. Finally, this change could be due to the manner in which homeostatic states initiate feeding in older vs. younger infants. Specifically, in animal models, motivation to suck occurs from birth in response to presentation of a feeding cue, regardless of nutritional state; the association between motivation to suck and homeostatic caloric need only emerges in later infancy (58). Thus, while 2-week-old infants will invariably demonstrate distress (i.e., emitting vocalizations to cue feeding from the caregiver) simply at exposure to a feeding cue, older infants are more likely to demonstrate distress only when they are exposed to a feeding cue *and* have caloric need (26, 58, 59); isolating the roles of hunger, response to feeding cues, and how Bottom-Up Food Approach may relate to each of these processes would be interesting to examine further in future research.

In contrast to Pre-Feeding Delay, and somewhat counter to our hypothesis, distress during Mid-Feeding Delay significantly increased between 2 and 8 weeks of age. Potential explanations for this observation could relate to GSR, AR, and Bottom-Up Food Approach. First, this finding may in part reflect the development of object permanence throughout the first several months of infancy, a fundamental cognitive achievement that underlies later GSR capacities such as delay of gratification skills (60). In the current study, 2-week-old infants may have not been fully aware of the bottle continuing to exist after it was removed and, in turn, were less distressed than older infants after the bottle was removed. With ongoing cognitive development, however, it is possible that the infants became more aware of the bottle's continued existence once it was removed, resulting in more Mid-Feeding Delay distress at older ages. Another explanation related to GSR could be due to changes in the nature of infant affect expression in response to violations of expectations across this developmental period. Anger and frustration can be elicited by goal blockage and are first detectable in response to goal blockage (e.g., arm restraint) by 2 months of age (61, 62). Goal blockage due to a feeding interruption may therefore simply not evoke this type of affective response until age 8 weeks, as infants may have limited awareness of their lack of control over the expected event (feeding) prior to this age (62). Thus, infants' increasing cognitive and emotional capacity may result in greater, rather than lesser, distress in response to delay in this early period.

Additional explanations of the increase in Mid-Feeding Delay distress with age may involve AR. For example, as noted above, CCK is released in response to milk feeding, suppresses feeding, reduces seeking of feeding-related stimuli, pacifies crying, and causes sedation (25–28). Yet, CCK levels decline across infancy [CCK is 10 times higher in the newborn period than at age 9 months (63)] such that the sedating and pacifying effect of CCK released in response to milk feeding declines with infant age. Thus, while 1 min of milk ingestion at 2 weeks leads to immediate CCK release (28), with potent sedating and pacifying effects that maintain a calm behavioral state in the 2-week-old even during a 30-s feeding interruption, the CCK release in the 8-week-old and 16-week-old infant is less robust, and milk ingestion is not associated with potent calming effects during a mid-feeding interruption. Therefore, compared to the 2-week-olds, older infants may not have been as physiologically soothed by their milk intake during the Mid-Feeding Delay. In animal models, distress occurs when a schedule of positive reinforcement is interrupted (64). When expected delivery of food to a hungry animal is intermittent or interrupted, an increased level of activation is produced, which is channeled to other responses (65). When an animal is engaged in ingestive behavior under high-drive conditions (e.g., hunger), the animal's high drive becomes directed to a displacement activity (64) – perhaps in this case, crying. It is possible that 2-week-old infants have not been exposed to the positive reinforcement schedule of feeding for enough duration or consistency to sufficiently evoke a response when that reinforcement schedule does not occur as anticipated; in contrast, by 8 weeks, the infant may have become accustomed enough to the positive reinforcement schedule of feeding that when it is unexpectedly interrupted, the infant becomes distressed.

Finally, it is also possible that distress during Mid-Feeding Delay may reflect Bottom-Up Food Approach factors such as food responsiveness (66). Milk feeding releases opioids (28), and the nature of opioid-mediated responses to sweet taste evolve across infancy (50). Infants have also been shown to "work" for milk by continuing to suck from a nipple with a smaller aperture as young as age 2 months (51), and by pressing a computer mouse button repeatedly as young as age 9 months (35). The greater infant distress exhibited at 8 and 16 weeks, compared to 2 weeks, may therefore reflect emergent reward sensitivity to food in early infancy, an aspect of Bottom-Up Food Approach.

Distress and Milk Consumption in the Ability to Delay Gratification for Food in Infants Task

Regarding associations between ATDG-FIT distress displays and amount consumed, we found that distress during Mid-Feeding Delay associated with amount consumed only as infants grew older. Potential explanations for this observation may also reflect GSR, AR, and Bottom-Up Food Approach. Distress during Mid-Feeding Delay could indicate infants who are less able to tolerate delayed gratification (i.e., with poorer GSR) and who may become more likely to consume excess calories in response to frustration. Becoming reliant on food to soothe could establish links between behavioral distress and amount consumed and disrupt infant recognition of their own AR needs. Over time, this could translate to emotionally driven eating behaviors, such as eating in response to stress rather than hunger cues, and disrupted eating later in development (2). Infant negativity may result in parents' overfeeding in attempts to soothe and quiet the infant (67, 68) resulting in heavier infant weight, especially for infants who are high in temperamental negativity (69). Although we found minimal associations with WLZ in the current study, such behaviors could promote excessive weight gain over time (2).

AR-related explanations for this association may also operate through a few different pathways. In animal models, although feeding releases CCK from early infancy, CCK causes calming and reduces the incentive salience for food in the earliest days of infancy, but does not affect volume intake; volume intake is only affected by CCK later in early infancy (26, 28). The dissociation of CCK with amount consumed in very early infancy is theorized to be due to either an unknown physiologic mechanism or that associative learning has not yet occurred (26). Second, in animal models, eating in the earliest stage of infancy is opportunistic – sucking occurs in response to opportunity; only later in infancy does the feeding system emerge as specifically regulated by peripheral feedback (49, 58, 59). Thus, the emergence of a linkage between distress and amount consumed in later infancy, but not early infancy, may reflect maturation of this system.

The association between Mid-Feeding Delay distress and amount consumed may also reflect changes in the reward value of food with development, an aspect of Bottom-Up Food Approach. Animal models have demonstrated that the components for reward-driven eating can change over time (70), reflecting sensitization of the dopamine system in response to repeated consumption of pleasurable foods. As the system becomes more sensitized, motivational drive (i.e., "wanting") for food increases and can drive greater intake (70). The administration of smaller "priming" doses of a reward can further amplify motivational drive for more of the rewarding substance (71).

Thus, the milk initially consumed prior to the Mid-Feeding Delay may prime the "wanting" system for more milk, increase distress, and drive greater intake when milk again becomes available. With development the reward system may become sensitized and this behavior may therefore become more evident in older infants who have had more opportunities to repeatedly experience food reward.

Strengths and Limitations

The current study used a novel protocol and a longitudinal design to examine distress in response to a food delay and at an earlier age than has previously been considered. Such contextually specific, observational work is essential for understanding emerging eating behavior regulation and how GSR, AR, and Bottom-Up Approach may interact and underlie early individual differences in this domain. Prior research in this area has heavily relied on parent-reports, for example of general infant temperament [e.g., (22, 23)]. In contrast, the ATDG-FIT allowed us to objectively assess infant distress in a food-specific delay. Our finding of increased associations between amount consumed during the ATDG-FIT and distress during the Mid-Feeding, but not the Pre-Feeding Delay segment at older ages suggests that distress during each segment may reflect different aspects of emerging eating behavior regulation capacity. It will be important to track these behaviors over the first year of infancy in order to determine, for example, whether infant ATDG-FIT responses predict later ATDG for food. Further research is also needed to understand the integration of the affect regulation, nutritional homeostasis, and food reward systems in early infancy. As described, explanations for the observed phenomena include the development of cognitive capacity and affective and behavioral self-regulation (GSR), nutritional homeostatic controls (AR), and food reward sensitivity (Bottom-Up Food Approach) across early infancy. The manner in which these systems interact and potentially influence the development of one another is an important area for future work.

Despite the aforementioned strengths, there were several study limitations. It is possible that distress observed during the ATDG-FIT relates to dyadic processes that also shape infant response to food delays. Mothers were allowed to use any non-feeding/non-pacifier method to soothe the infant, hence the protocol likely captured variation in the mother's ability to soothe their child without feeding or pacifier use. Given the resources required to conduct observational coding, we were unable to assess potentially confounding variables such as maternal attempts to soothe infant distress. Mothers were also instructed to complete the ATDG-FIT when they perceived their infants to be hungry, which could lead to bias, but we elected to do so to preserve ecological validity and based on findings that mothers are reasonably able to identify hunger (at least as compared to satiety (15). Furthermore, although distress during Mid-Feeding Delay became a stronger predictor of amount consumed in the protocol as infants aged, we did not objectively measure how it related to infant consumption outside of the protocol. We objectively measured amount consumed and parents were instructed to feed the infants as long as they deemed necessary, but we did not have data on whether the infants finished the bottle, so it is possible that the amount consumed variable could have been truncated and some infants may have even consumed more, if offered. Finally, although our multiple imputation approach was a strength, it is important to note that there was a substantial amount of missing data on the outcome variable (amount consumed), as it was not possible to measure amount consumed from infants who breastfed during the ATDG-FIT. Our exclusion criterion that the infant had not yet taken a feeding from an artificial nipple also may not generalize to all infants, although the majority of United States mothers who breastfeed expressed milk and feed their infant from a bottle at some point during early infancy (72).

CONCLUSION

This study sought to investigate early emerging eating behavior regulation by examining distress during a novel food delay protocol, the ATDG-FIT, and whether distress predicted the amount of milk infants consumed in the protocol across early development. Findings highlighted the unique roles of both context and development, identifying different patterns of distress in the ATDG-FIT across time. Of note, the positive association between distress during Mid-Feeding Delay and amount consumed strengthened as infants grew older, suggesting that infant distress in this food delay context, even within the first 2 months of life, could signal possible risk for excessive consumption across early development. Our findings suggest that observing infant distress during the ATDG-FIT may be an important context in which to assess the interplay of infant GSR, AR and Bottom-Up Food Approach in order to characterize emerging regulation of eating behavior during early infancy.

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 University of Michigan Medicine Institutional Review Board (IRB MED). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SS: contributed to drafting the initial manuscript, conducted the statistical analyses, and approved the final manuscript.

HR: contributed to drafting the initial manuscript and approved the final manuscript. NK, JS, and AG-K: reviewed the statistical analyses and approved the final manuscript as submitted. KR and JL: conceptualized and designed the study, provided critical review of the manuscript, and approved the final manuscript. AG: provided critical review of the manuscript and approved the final manuscript. AM: conceptualized and designed the study, contributed to drafting the initial manuscript, provided critical review of the manuscript, and approved the final manuscript. All authors contributed to the article and approved the submitted version.

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Associations Among Food Delay of Gratification, Cognitive Measures, and Environment in a Community Preschool Sample

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Much of the work on the development of appetite self-regulation in early childhood employs tasks assessing Delay of Gratification (DoG). While this skill is thought to rely on "cool" cognitive processes like effortful control, executive functioning, and self-regulation, demonstration of how laboratory measures of food DoG relate to common assessments of those cognitive processes in community samples of children is needed. This study presents secondary data investigating the associations between two laboratory tasks of food DoG, the Snack Delay and Tongue Tasks, and an array of laboratory and parent-report cognitive measures in a sample of 88 children ages 3-6 (*M* age = 4.05, SD = 0.76), as well as how four measures of the child's environment were associated with food DoG. Results indicated that both measures of food DoG were positively correlated with performance on the cognitive tasks, with stronger associations observed for the Tongue Task. Family income was positively associated with food DoG as measured by the Tongue Task, and child negative life events in the past year were negatively correlated with food DoG as measured by the Snack Delay Task. These findings present the pattern of associations between cognitive tasks and food DoG, the development of which may be meaningfully affected by specific aspects of family environment.

Keywords: delay of gratification, cognitive measures, executive function, preschool, environment

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INTRODUCTION

Delay of gratification (DoG) refers to an individual's ability to forego an immediate reward in favor of a later, larger reward. While DoG can be applied to various rewards, many behavioral paradigms use food stimuli to measure this construct in preschool-aged children (1–3). This is referred to in the literature as food-related, or appetite, self-regulation (2). While some of the main cognitive mechanisms that enable successful food DoG in early childhood have been identified in previous studies [e.g., effortful control, executive function; see (1, 4)], the measures used to assess these mechanisms vary. Indeed, a wide array of assessment tools are used in the literature to measure these constructs in early childhood; it remains unclear the degree to which these measures capture those constructs and how they relate to DoG performance. To address this gap in the literature, the present study employed data collected as part of a larger study to investigate the associations between multiple measures of food DoG and tasks assessing theoretically relevant cognitive constructs.

Delay of Gratification

In the decades of work that have been done on DoG, researchers have separately conceptualized it as measuring (a) sensitivity to reward value, (b) impulsivity, and (c) top-down regulatory control (5). While many models of self-regulation situate top-down, cognitive processes in dynamic interaction with bottom-up reactions to stimuli [e.g., (6–9)], it may be that DoG itself represents the entire process. Specifically, DoG behavior captures the degree to which top-down, cognitive processes are engaged with the goal of regulating bottom-up reactions to a reward, such that delay behavior results from the balance achieved between the two systems. Indeed, DoG depends on "the cognitive and attentional mechanisms that help execute goal directed behavior" (7). Many such cognitive mechanisms have been evoked with regard to successful DoG, including effortful control [EC; (10, 11)] and executive function [EF; (12–14)]. Interestingly, while EF and EC stem from different traditions, they are thought to represent overlapping processes (15) and the same tasks are used to assess them [e.g., Day/Night, Go/NoGo Tasks; (16, 17)].

However, other conceptualizations of EF may get closer to capturing the type of cognitive processes engaged during DoG. Much of the recent work on DoG treats it as a form of "hot" EF (18), which is "involved in social and affective situations that generate emotion and motivation, as well as tension between immediate gratification and greater long-term reward" (19). Use of DoG in food contexts can be particularly evocative, as food can be rewarding, induce impulsive behavior, and be emotional for many people (2, 20). There is some evidence that, compared to non-food rewards, food DoG is uniquely associated with weight in early childhood (21), supporting the investigation of food DoG in this age range. Indeed, hot and cool forms of EF are thought to follow distinct but related trajectories in middle childhood (19), but it remains unclear the degree to which successful food DoG is associated with measures of cool EF earlier in childhood.

Delay of Gratification in Context

Ecological systems models stress the importance of interactions between biological and environmental factors in explaining development (22). To this end, a large body of literature demonstrates the effect that the family environment has on EC and EF development [e.g., (23–26)], as well as on food DoG [e.g., (3, 27)]. Indeed, this literature suggests that the resources and stressors in the child's environment have a meaningful effect on DoG development. However, there are relatively few places in the literature presenting simple associations between different aspects of family environment and multiple measures of food DoG in preschool-aged children. The present data set provides us with the opportunity to address this gap in the literature.

In the literature on environmental influences on the development of food DoG, several candidate measures emerge. First, socioeconomic status (SES) is positively associated with better performance on DoG tasks [e.g., (3, 28)] and other measures of food-related self-regulation [e.g., (29)]. As such, both family income and maternal education—common measures of SES—should positively correlate with delay time. Second, environmental stressors beyond low SES are also associated with the development of EF and DoG (1, 30, 31). Two measures of environmental stress in the present dataset, maternal depression and negative life events experienced by the child, are risk factors for high weight in children (32–35) with food-related self-regulation proposed as a mechanism (36). Extant research suggests that maternal depression is negatively associated with food DoG in children [e.g., (37)]. Similarly, experiencing stressful life events such as losing one's housing to an earthquake has been associated with decreased DoG (38). This is consistent with a "fast life history strategy," where environmental uncertainty promotes seeking immediate gratification (39).

The Present Study

The present study uses data collected as part of the Parent-Child Self-Regulation study (40). While the main focus of the original study was to quantify associations between parent and child measures of food-related DoG and attentional and inhibitory control, we also gathered additional measures that have not yet been published.

Here, we present secondary analyses addressing the aforementioned gaps in the literature regarding the associations among (1) food DoG and cognitive measures, and (2) food DoG and measures of family income, maternal education, maternal depression, and recent child negative life events in a community sample of typically-developing 3-6 year old children.

METHODS

Participants

Families were recruited via 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 assessment. Non-inclusion criteria were if mothers had less than half-time custody of the child, had a history of significant neurological disorder(s), 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. All study procedures were approved by the University's Committee for the Protection of Human Subjects.

TABLE 1 | Demographic information.

Demographics	*M* (SD)	%
Child demographics		
Age (years)	4.05 (0.76)	
FemaleRace or Ethnicity		49%
White		87.23%
Asian		2.13%
Hispanic		0%
Multiracial		8.51%
Native American/Indian		2.13%
Preschool attendance		61.7%

This study presents data from 88 children ages 3–6 (*M* age = 4.05, SD = 0.76; **Table 1**). These data are from a larger study designed to investigate self-regulation in parents and children, parent-child interactions, parent feeding practices, and child eating behavior. Data from this sample have been described in Giuliani and Kelly (41) and Giuliani et al. (40).

Protocol

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. Measures relevant to the present analyses are described below. Families were paid $60 for their time.

Measures

Food Delay of Gratification Tasks

Snack Delay Task

In this task (40, 41), children were asked to choose a preferred snack (choices: fruit snacks, M&Ms, goldfish crackers). The experimenter placed the snack on a napkin in front of the child and asked them to wait until the experimenter 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 snack before bell is lifted), 1 (eats snack after bell is lifted), 2 (touches bell/snack before bell is lifted), 3 (touches bell/snack after bell is lifted), or 4 (waits for bell to ring before touching snack/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. This task has a 1–2 week test-retest reliability of 0.5 (42).

Tongue Task

As in the Snack Delay Task, the Tongue Task started with the child choosing a preferred snack. The child was then asked to place the snack on their tongue, and were told to wait until a bell was rung to eat it. Four trials were administered (10, 20, 30, 15 s), and coded to reflect the length of time before the child ate the snack. The final score was the average score across the four trials. Preschool-aged Fall-Spring academic year test-retest reliability as part of a larger hot EF composite was estimated at 0.58 (43).

Cognitive Tasks

Flanker Task

The Flanker Task was administered via the NIH Toolbox (44). 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 and a block of 20 arrow trials, shown only if the participant scored >90% on the fish stimuli. The NIH Toolbox uses a two-vector method to compute performance, which incorporated both accuracy and reaction time for participants who maintained a high level of accuracy (>80% correct), and accuracy only for those who did not meet this criterion. This computed score was used to represent performance (40). This task has a 7–21 day test-retest reliability of 0.89 (44).

Go/NoGo Tasks

Two GNG tasks were administered to children. First, children performed the Zoo Game (45). The task asks 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 the monkey helping the zookeeper [NoGo (NG) trials]. It begins with three practice blocks in which children can practice (1) pressing the laptop button when they see an animal, (2) pressing the button within a certain time limit, and (3) inhibiting their response when they see the monkey. Feedback at the end of each trial presented children with 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. Each trial consisted of a 500–700 ms jittered fixation cross, 1200 ms stimulus presentation, 500 ms black screen, and 1,000 ms feedback. Responses could be made while the stimulus was on 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. Two-to-four week test-retest reliability of a similar task was 0.58 (46).

We also asked children to complete the Fish GNG Task from the Early Years Toolbox (47). The task asks children to respond to G trials ("catch fish," 80%) and withhold responding on NG trials ("avoid sharks," 20%). The task begins with go instructions followed by 5 practice G trials, NoGo instructions followed by 5 practice NG trials, combined GNG instructions followed by a mixed block of 10 practice trials (80% G), and a recap of instructions prior to the task commencing. Auditory feedback was provided on all practice trials. The task itself did not contain feedback, and was comprised of 75 stimuli over three blocks. Stimuli were presented in pseudo-random order, such that a block never began with a NG stimulus and no more than two successive trials were NG stimuli, separated by a 1,000 ms inter-stimulus-interval. Percent correct was calculated across both types of trials. Due to computer error, data from 15 participants were not recorded. The split-half reliability of this task was 0.84 in the original validation sample (47).

We originally planned on combining across the two GNG tasks in previous analyses using these data (40). However, the relatively modest correlation between the two tasks ($r = 0.44$, $p < 0.001$) suggests that they may index related but separate processes. Therefore, we opted to consider the two tasks separately.

Day/Night Stroop Task

In this task (16), the child was shown a total of 16 pictures in a random sequence that depict either a moon on a dark background or a sun on a white background. When the child was shown the picture of the sun or moon, they were instructed to say the opposite time of day. For instance, if the child was shown a picture of the sun, they should have said "night." The total number of correct responses was recorded, and percent correct was calculated. This task has a 2-week test-retest reliability of 0.84 (48).

Balance Beam Task

In this task (49), which is sometimes called "Walk-a-Line-Slowly," a 12 ft piece of tape was placed on the floor. The child was instructed to walk along the tape, once at regular speed, and twice slowly. This experimenter recorded and coded the times for each trial in seconds. Difference scores between the average of the two slow times and the regular time was calculated. This task has a Fall-Spring academic year test-retest reliability of 0.42 (43).

Tower Task

In this task (50), the child was asked to take turns with the experimenter in building a tower. Twenty wooden blocks were used, with 10 blocks allocated to each person. The experimenter deliberately waited to place their block until the child explicitly signaled that they were giving a turn. The child earned 1 point for each time they appropriately gave a turn to the experimenter. If the child gave the experimenter all their due turns, the child earned up to 10 points. The child could also gain one point for arranging the tower to prevent it from collapsing, and for waiting 10 s after placing their block even if they did not explicitly signal that they were giving a turn to the experimenter. Points were summed to create a final score for this task. This task has a 1–2 week test-retest reliability of 0.85 (42).

Head-Toes-Knees-Shoulder Task

In this task (51), children were provided with paired behavioral rules (e.g., touch your head/touch your toes) and then asked to do the opposite. First, the child completed 10 trials where they were asked to touch their head or their toes. If the child responded correctly to 5 or more items, then the second set of paired rules (touch your shoulders/touch your knees) was introduced. If the child produced the correct response immediately, the item was scored 2. If the child self-corrected without prompting, the item was scored 1. If they did not touch the correct part of their body, the item was scored 0; all points summed to create a final score. This task has a Fall-Spring academic year test-retest reliability of 0.6 in a pre-kindergarten sample (52).

Family Demographics

Mothers were asked to report the birth date, sex, race, and 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 in US$ and her highest level of educational attainment by degree. Degree earned was then transformed into years of education, where high school diploma or GED = 12, Associate = 14, Bachelor's = 16, Master's = 18, and Doctoral = 22.

Mother-Report Surveys

Mothers completed the Devereux Early Childhood Assessment for Preschoolers–Second Edition [DECA; (55)], from which we used the Self-Regulation (SR) subscale ($\alpha = 0.87$). We also administered the Child Behavior Questionnaire–Very Short Form [CBQ-VSF; (56)], from which we used the Effortful Control (EC) subscale ($\alpha = 0.64$).

Mothers also completed the Center for Epidemiological Studies Depression [CESD; (57)] scale ($\alpha = 0.91$) and a modified version of the Coddington Life Events Questionnaire (58) to report their depressive symptoms and their child's negative life events in the past year, respectively.

Analyses

For all variables, outliers were Winsorized (59) at 3 standard deviations from the mean (noted in **Table 2**) and then assessed for skew and kurtosis. Gross family income; maternal depressive symptoms; performance on the Snack Delay, Tongue, Zoo Go/NoGo, Flanker, Day/Night Stroop, Balance Beam, Tower, and HTKS Tasks; and child negative life events in the past year were identified as non-normally distributed (skewness and/or kurtosis $> \pm 1$). To maximize sample size and statistical variance, we opted to retain Winsorized values and use non-parametric statistical tests that did not assume normality. Analyses of both the raw data and the data with outlier cases removed did not meaningfully change the results, indicating that extreme but plausible values did not drive the study's findings.

All analyses were run using R (60). For both aims, associations were measured using Spearman's correlations. All analyses were adjusted for multiple tests by hypothesis, using the Benjamini-Hochberg correction (53); adjusted p-values are presented. Correlations were also disattenuated to account for varying measure reliability using the reliability estimates provided in the measures descriptions above (61). Formal comparisons of the strength of the correlations values were evaluated using https://www.psychometrica.de/ (62).

RESULTS

Descriptive statistics for task variables and measures of family environment are presented in **Table 2**.

Zero-Order Associations

After adjusting for multiple comparisons, zero-order correlations (**Table 3**) revealed that performance on the Snack Delay and Tongue DoG Tasks was significantly positively correlated, $r_{(85)} = 0.43$, $p < 0.001$, 95% CI [0.24, 0.59]. Both DoG tasks were significantly positively correlated with performance on the Flanker, Fish GNG, Day/Night Stroop, Tower, and HTKS Tasks (r-values: 0.25–0.54, p-values < 0.05, see **Table 3** for 95% CIs). For the Zoo GNG and Balance Beam Tasks, only the Tongue Task was significantly correlated (r-values: 0.29–0.36, p-values < 0.05, see **Table 3** for 95% CIs). With regard to the mother-report surveys, only the DECA SR subscale and Snack Delay Task were significantly correlated, $r_{(87)} = 0.26$, $p = 0.03$, 95% CI [0.05, 0.44]. Direct comparisons of the associations between each of the cognitive variables and the food DoG tasks revealed that the associations were stronger between the Tongue Task and the Zoo GNG, Balance Beam, HTKS, and CBQ-VSF EC compared to the Snack Delay Task and each of those measures (p-values < 0.05).

TABLE 2 | Descriptive data of self-regulation and family environment variables.

Variable	*N*	*M*	*SD*	Observed Range
Snack delay task	88	2.01	1.66	0–4.00
Tongue task	85	15.65	5.66	0.63–18.75
Flanker task	81	2.52	1.91	0–7.06
Fish Go/NoGo task*	66	0.66	0.17	0.01–1.00
Zoo Go/NoGo task*	83	51.68	14.39	8.22–68.24
Day/Night stroop task	83	65.29	34.72	0–100.00
Balance beam task*	88	3.04	4.91	–5–21.57
Tower task	86	6.57	3.60	0–10.00
HTKS task	82	19.43	18.67	0–52.00
CBQ-VSF EC subscale	87	5.36	0.64	4–6.58
DECA SR subscale*	87	33.56	4.57	18–45.00
Gross family income (US$)	86	69,329.00	48,754.00	0–260,000.00
Maternal years of education	88	15.15	2.47	8–22.00
Maternal depression symptoms (CES-D)	88	9.67	8.80	0–38.00
Child negative events–past year (CLEQ)	87	2.31	2.24	0–10.00

*HTKS, Head-Toes-Knees-Shoulders Task; CBQ-VSF EC, Child Behavior Questionnaire (Very Short Form) Effortful Control subscale; DECA SR, Devereux Early Childhood Assessment Self-Regulation subscale; CES-D, Center for Epidemiological Studies–Depression scale; CLEQ, Coddington Life Events Questionnaire. *indicates variable Winsorized at 3 standard deviations from the mean for analyses; uncorrected values are presented here.*

After disattenuating the correlations to account for measure reliability, the correlation between the Snack Delay and Tongue Tasks increased from 0.43 to 0.80, 95% CI [0.70, 0.86]. All correlations between laboratory measures were significant at $p < 0.05$. The pattern of significant correlations between the laboratory and mother-report surveys remained the same. Lastly, direct comparisons of the associations between each cognitive variable and the two food DoG tasks showed that the correlations between the cognitive measures and the Tongue Task were all significantly stronger than those between the cognitive measures and the Snack Delay Task.

Associations Between DoG Tasks and Family Environment

After adjusting for multiple comparisons, family income was significantly positively associated with performance on the Tongue Task, $r_{(83)} = 0.40$, $p = 0.001$, 95% CI [0.20, 0.56] (**Table 4**). Children from families with higher yearly gross incomes performed better on the Tongue Task. The positive association between family income and Snack Delay Task performance was not statistically significant ($p = 0.0501$). Maternal years of education was not significantly associated with performance on either food DoG task (Snack Delay Task: $p = 0.27$; Tongue Task: $p = 0.0501$). The associations between SES measures and Tongue Task performance were significantly stronger than those between SES measures and Snack Delay Task performance (p-values < 0.05).

Child negative life events in the past year was significantly negatively associated with performance on the Snack Delay Task, $r_{(87)} = -0.29$, $p = 0.019$, 95% CI [-0.47,−0.09], such that children who experienced more recent negative life events did not wait as long for the second snack as compared to children who had experienced fewer negative life events. There was not a significant association between child negative life events and Tongue Task performance ($p > 0.05$), nor were there significant associations between mother-reported depressive symptoms and performance on either task (p-values > 0.05). The association between child negative life events and Snack Delay performance were significantly stronger than the association with Tongue Task performance (p-values < 0.001).

DISCUSSION

The purpose of the present study was to present associations among two commonly-used measures of food DoG and an array of cognitive measures in a community sample of preschool-aged children, and explore the degree to which food DoG was associated with four measures family environment thought to play a role in DoG development.

Food DoG and Cognitive Measures

Performance on both food DoG tasks was significantly positively associated with performance on the cognitive tasks in this data set. Like most tasks used to assess EC and EF, tasks used in the current study suffer from task impurity, in that successful performance is dependent on multiple cognitive processes (63, 64). However, while EF is broadly implicated in eating behavior in young children [e.g., (9)], previous analyses on the present sample directly compared the degree to which food DoG (Snack Delay), attentional control (Flanker) and inhibitory control (GNG) predicted later EAH. Here, we found that only food DoG significantly predicted later EAH (41), indicating that this hot EF measure may better capture the food-related regulatory processes recruited when making food choices in the absence of hunger.

Compared to the laboratory assessments, the two mother-report measures showed a different pattern. Even after

TABLE 3 | Correlations among self-regulation variables.

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Snack Delay		0.80 [0.70, 0.86]	0.41 [0.21, 0.58]	0.48 [0.27, 0.65]	0.37 [0.16, 0.54]	0.49 [0.31, 0.64]	0.37 [0.17, 0.54]	0.58 [0.41, 0.70]	0.45 [0.26, 0.61]	0.14 [-0.07, 0.34]	0.39 [0.19, 0.55]
2. Tongue	0.43** [0.24, 0.59]		0.67 [0.53, 0.78]	0.77 [0.65, 0.86]	0.50 [0.32, 0.65]	0.72 [0.60, 0.81]	0.73 [0.61, 0.81]	0.69 [0.56, 0.79]	0.91 [0.86, 0.94]	0.31 [0.10, 0.49]	0.18 [-0.04, 0.38]
3. Flanker	0.27* [0.06, 0.46]	0.48** [0.29, 0.64]		0.66 [0.49, 0.78]	0.84 [0.76, 0.89]	0.56 [0.39, 0.70]	0.92 [0.88, 0.95]	0.52 [0.34, 0.67]	0.83 [0.74, 0.89]	0.12 [-0.10, 0.33]	0.00 [-0.22, 0.22]
4. Fish Go/NoGo	0.31* [0.08, 0.52]	0.54** [0.34, 0.69]	0.57** [0.37, 0.72]		0.75 [0.62, 0.84]	0.60 [0.42, 0.74]	0.69 [0.53, 0.80]	0.53 [0.32, 0.68]	0.67 [0.50, 0.78]	−0.24 [-0.46, 0.00]	0.05 [-0.20, 0.29]
5. Zoo Go/NoGo	0.20 [-0.02, 0.40]	0.29* [0.08, 0.48]	0.60** [0.44, 0.73]	0.52** [0.32, 0.68]		0.63 [0.48, 0.75]	0.69 [0.55, 0.78]	0.52 [0.34, 0.66]	0.95 [0.92, 0.97]	0.03 [-0.19, 0.25]	0.09 [-0.13, 0.30]
6. Day/Night	0.32* [0.11, 0.50]	0.51** [0.32, 0.65]	0.48** [0.29, 0.64]	0.51** [0.30, 0.67]	0.44** [0.24, 0.60]		0.95 [0.92, 0.96]	0.53 [0.36, 0.67]	0.79 [0.70, 0.86]	0.05 [-0.17, 0.27]	0.16 [-0.06, 0.36]
7. Balance Beam	0.17 [-0.04, 0.37]	0.36** [0.16, 0.53]	0.56** [0.39, 0.70]	0.41** [0.18, 0.59]	0.34** [0.13, 0.52]	0.56** [0.39, 0.69]		0.69 [0.56, 0.79]	0.85 [0.77, 0.90]	−0.05 [-0.26, 0.16]	0.11 [-0.11, 0.31]
8. Tower	0.37** [0.18, 0.54]	0.48** [0.30, 0.63]	0.46** [0.26, 0.61]	0.44** [0.22, 0.62]	0.37** [0.16, 0.54]	0.45** [0.26, 0.61]	0.41** [0.22, 0.57]		0.76 [0.64, 0.84]	0.05 [-0.16, 0.26]	0.24 [0.03, 0.43]
9. HTKS	0.25* [0.03, 0.44]	0.53** [0.35, 0.67]	0.60** [0.44, 0.73]	0.47** [0.26, 0.64]	0.56** [0.38, 0.69]	0.56** [0.39, 0.69]	0.43** [0.23, 0.59]	0.54** [0.37, 0.68]		0.05 [-0.17, 0.27]	-0.03 [-0.25, 0.19]
10. CBQ-VSF EC	0.08 [-0.13, 0.29]	0.19 [-0.03, 0.39]	0.09 [-0.12, 0.31]	−0.18 [-0.40, 0.07]	0.02 [-0.20, 0.24]	0.04 [-0.18, 0.25]	-0.03 [-0.24, 0.18]	0.04 [-0.18, 0.25]	0.03 [-0.19, 0.25]		0.51 [0.33, 0.65]
11. DECA SR	0.26* [0.05, 0.44]	0.13 [-0.09, 0.33]	0.00 [-0.22, 0.22]	0.04 [-0.2, 0.28]	0.06 [-0.16, 0.28]	0.14 [-0.08, 0.34]	0.06 [-0.15, 0.27]	0.21 [-0.01, 0.40]	-0.02 [-0.24, 0.20]	0.38** [0.18, 0.54]	

Statistics below the diagonal are Spearman correlations with 95% confidence intervals shown in brackets. Significance tests are corrected for multiple comparisons using the Benjamini-Hochberg (53) method. Statistics above the diagonal show disattenuated correlations with 95% confidence intervals in brackets. Correlations were disattenuated using the following reliability estimates: Snack Delay, 0.55 (42); Tongue Task, 0.58 (54); Flanker Task, 0.89 (44); Fish Go/NoGo, 0.84 (47); Zoo Go/NoGo, 0.58 (46); Day/Night Task, 0.84 (48); Balance Beam Task, 0.42 (43); Tower Task, 0.85 (42); HTKS Task, 0.6 (52); CBQ-VSF EC, 0.64 (present sample); and DECA SR, 0.87 (present sample). HTKS, Head-Toes-Knees-Shoulders Task. CBQ-VSF EC, Child Behavior Questionnaire (Very Short Form) Effortful Control subscale. DECA SR, Devereaux Early Childhood Assessment Self-Regulation subscale. ** $p < 0.001$. * $p < 0.05$.

TABLE 4 | Correlations between measures of delay of gratification and family environment.

Variable	1	2	3	4	5
1. Snack delay task					
2. Tongue task	0.43** [0.24, 0.59]				
3. Family income ($)	0.23 [0.02, 0.42]	0.40**[0.20, 0.56]			
4. Maternal education (years)	0.12 [-0.09, 0.33]	0.24[0.03, 0.43]	0.58** [0.42, 0.70]		
5. Maternal depression (CES-D total)	-0.15 [-0.35, 0.05]	−0.19[-0.39, 0.02]	-0.29* [-0.47,−0.08]	−0.16[-0.36, 0.06]	
6. Child negative life events in past year (CLEQ)	-0.29* [-0.48,−0.09]	0.00[-0.21, 0.21]	-0.28* [-0.47,−0.08]	−0.23[-0.42,−0.02]	0.28* [0.07, 0.47]

*Statistics are Spearman correlations with 95% confidence intervals shown in brackets. CES-D, Center for Epidemiological Studies–Depression; CLEQ, Coddington Life Events Questionnaire. All p-values corrected for multiple comparisons using the procedure of Benjamini-Hochberg (53). **$p < 0.001$. *$p < 0.05$.*

disattenuating the correlations to account for measure reliability, we found that the CBQ-VSF EC subscale positively correlated with performance on the Tongue Task only, whereas the DECA SR subscale was positively correlated with the Snack Delay Task and the Tower Task. The two mother-report measures were positively correlated with each other, a pattern that suggests some common method variance. This may be due to known low levels of convergence between survey and behavioral measures of EF, which could indicate that the types of assessments reflect different underlying mechanisms, or could be simply due to the differing method of measurement [e.g., (29, 65)]. Regardless, the finding that mother-reported EC was positively correlated with Tongue Task performance and mother-reported SR [which includes EF; see (66)], suggests that the two food DoG tasks may vary slightly in their underlying cognitive bases—with the Tongue Task relying more on EC and the Snack Delay relying more on EF. However, this remains to be tested empirically.

Food DoG and Family Environment

Our investigations into how the food DoG tasks were associated with measures of family environment were mostly consistent with the extant literature. First, the overall qualitative pattern showed positive associations between measures of family SES (i.e., income, maternal education) and food DoG. This is in line with research showing that individuals who have more resource certainty perform better on DoG tasks (28, 67). Of the four correlations, the only one that rose to the level of significance was the association between family income and performance on the Tongue Task. This may be due to the increased temptation of holding a desired treat on one's tongue in the Tongue Task, as opposed to simply looking at it as is done in the Snack Delay.

Second, with regard to measures of environmental stress, negative associations between maternal depression and food DoG were not significant. While in the same direction as the empirical and theoretical literature stating that maternal depression predicts poorer child food DoG [e.g., (37, 68)], the non-significant association seen in the present data may be due to the fact that we used a low-risk, community sample. Specifically, the CES-D ranges from 0 to 60, with a clinical cutoff of 16 (69). Our sample ranged from 0 to 38, with a mean of 9.67. Indeed, only 19 of the 87 mothers scored 16 or above on the CES-D. We did see, however, a significant negative correlation between recent child negative life events and performance on the Snack Delay Task, such that more negative life events were associated with shorter delay time. This is consistent with Life History Theory, where a lower sense of control is associated with a decreased willingness to delay gratification (67). While a sense of control can vary by person and situation, it may be that a large number of recent negative life events imparts a general sense of uncontrollability for a young child, thus motivating them to choose the sooner, more certain reward.

Limitations, Conclusions, and Future Directions

In addition to the ones listed above, this study had several limitations. First, this data set did not include measures of working memory or non-food DoG, which would help us better understand the extent to which these results capture EF and DoG more generally. Second, recent work has shown that the use of reaction time differences as measures of Flanker Task performance can be unreliable (70), and as such these results should be interpreted with caution. Third, this was a relatively racially-homogeneous, low-risk, community sample of families; as such, these data may not be generalizable to other samples. While we did have reasonable variance in our measures of family environment, children raised in higher-risk environments may show different associations between those measures and food DoG. Fourth, we observed differences in the pattern of significant findings for the two GNG Tasks, which may be because the Zoo version employs a greater variety of stimuli than the Fish version and thus requires more working memory (71). Lastly, we did not include any measures of observed parenting behavior in these analyses, which would be useful with regard to better understanding how food DoG relates to environmental context.

These findings are meaningful to the literature in two ways. First, the patterns of associations between food DoG and the cognitive measures in this study inform the ongoing discussion on how to situate DoG in the family of related constructs. Our results suggest that, compared to the more popular Snack Delay Task, the Tongue Task may be a better way to measure hot EF in the context of food DoG, as it is more consistently correlated with performance on non-food cognitive tasks. However, future work using tasks that more clearly recruit separate cognitive processes [e.g., working memory, cognitive flexibility, behavioral inhibition; (64)] is needed to determine the degree to which different food DoG tasks rely on separate underlying cognitive constructs. Second, the present findings support and add to the literature on environmental influences on DoG development. Specifically, we found that family income and child negative life events are meaningfully associated with food DoG, in directions that are consistent with the literature. These results stress the role that childhood resource certainty and controllability may have on the development of DoG. Taken together, these results demonstrate the degree to which an array of common cognitive measures are associated with food DoG, the development of which may be meaningfully affected by specific aspects of family environment.

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: https://osf.io/dfmhe/.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board of the University of Oregon. 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. Both authors contributed to the article and approved the submitted version.

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