Hedonic Appetite, Inhibitory Control Training, and Food Consumption in Adolescents

By

Carolina M. Bejarano, MA

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Chairperson: Christopher C. Cushing, Ph.D.

Ric G. Steele, Ph.D., ABPP

Jordan A. Carlson, Ph.D.

Kelsie T. Forbush, Ph.D.

Nancy J. Kepple, Ph.D.

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The dissertation committee for Carolina Bejarano certifies that this is the approved version of the following dissertation:

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Chairperson: Christopher C. Cushing, Ph.D.

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Abstract

Hedonic appetite is a psychological and motivational process that refers to the drive to consume palatable foods for pleasure, rather than for physiological sustenance. Hedonic appetite can be associated with excess energy intake and dysregulated eating, which contribute to a variety of psychosocial and physical health challenges. Previous work indicates that hedonic appetite may fluctuate in adolescents. The present study piloted novel methodology designed to test whether hedonic appetite can be intentionally manipulated, and if changes relate to food consumption behavior. Adolescent participants (n=40; M age=15.1; 70% female) completed daily-diary surveys of hedonic appetite for six evenings prior to a lab visit. At the lab visit, participants were randomized to a Go/No Go (GNG) Intervention or Control Group, completed a measure of hedonic appetite, and participated in a lab "taste test" as an objective measure of palatable food consumption. A multilevel model was run to determine whether the GNG Intervention task resulted in decreased within-person (WP) hedonic appetite. Effect size estimates were calculated to evaluate whether changes in hedonic appetite were associated with palatable food intake, and power calculations were conducted. Results indicated that the GNG intervention did not result in significant changes in WP hedonic appetite in this sample. Findings included small-medium effect sizes for the relationship between Group and WP hedonic appetite; Group and *Fatty, Fast Food,* and *Total* consumption; as well as for WP hedonic appetite and *Sweet, Fatty,* and *Total* consumption. There were medium-large effect sizes for the relationship between Group and *Sweet,* and between WP hedonic appetite and *Fast Food.* The effect sizes for the total indirect effect of the mediation models were small-medium. Results of the power analysis estimated that some specific direct effects of the mediation models could yield .80 power with 200-2,000 participants. Though the GNG task did not change hedonic appetite in the present study, it may have effects on palatable food consumption in fully powered studies. Relationships among WP hedonic appetite and types of palatable food consumption merit further research. Proposed explanations for mechanisms of GNG training in the context of dietary behavior and ideas for future research are discussed.

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Hedonic Appetite and Dietary Behavior

Dietary behavior is driven by biological, cognitive, environmental, and psychological factors that determine food consumption (Sleddens et al., 2015). Biological drives to obtain energy to sustain survival and activity are the foundation for physiological hunger and appetite. Cognitive processes that influence dietary behavior include decision-making for healthful food choices and attention toward food cues (Hofmann, Friese, & Wiers, 2008). Exposure to the modern food environment, where palatable food is widely available both in terms of convenience and economic cost, has a substantial influence on food intake (Gorin & Crane, 2008). The psychology of eating lies partly in the subjective experience of individual preference (Lowe & Butryn, 2007), and systems of reward that motivate consumption of particular foods (Avena, 2015). However, many dynamic psychological processes drive food consumption and have yet to be fully understood. Specifically, hedonic appetite is a psychological and motivational process that refers to the drive to consume palatable foods for pleasure, rather than for physiological sustenance (Lowe & Butryn, 2007). There is some evidence that hedonic appetite fluctuates (Bejarano & Cushing, 2018), but further investigation is necessary to understand the nature of this variable. Overall, there is a need for the field to create novel methodologies that combine attention toward dynamic psychological experiences, biological processes, cognitive components, and environmental influences in order to work towards a more comprehensive and nuanced understanding of individual dietary behavior.

Neurobehavioral Inhibitory Control Model of Feeding

A theoretical model that provides a basis for research questions pertaining to drivers of individual dietary behavior is the neurobehavioral inhibitory control model of feeding

(Appelhans, 2009). As an overview, this model connects social and environmental input with respective brain regions that affect three *motivational processes*: 1.) inhibitory control (*i.e.*, the capacity to inhibit a prepotent or automatic response to a stimuli), 2.) hedonic appetite, and 3.) homeostatic hunger. These brain regions and processes then influence feeding behavior and the associated factors of selective attention and delay discounting (*i.e.*, preference for smaller, immediate rewards over larger, delayed rewards). According to Appelhans' model, one of the three motivational processes, inhibitory control, is regulated by the prefrontal cortex, which manages input from social surroundings and the food environment. The second motivational process of hedonic appetite is regulated by the mesolimbic dopamine system, which is implicated in responses to palatable food cues. The model refers to homeostatic hunger as the third motivational process, which is regulated by the hypothalamus and the inputs of gastrointestinal and adipocyte peptides and insulin. An important distinction in the motivational processes of hedonic appetite and homeostatic hunger is that eating may often be initiated by homeostatic hunger, and continue due to hedonic appetite. Although eating episodes may often begin in response to homeostatic hunger, hedonic appetite is thought to override physiological feedback signals that energy balance has been reached (Berthoud, 2011), sustaining eating behavior beyond physiological need. While a basic understanding of the whole model provides important perspective, the role of hedonic appetite and inhibitory control are the focus of the present study.

The neurobehavioral inhibitory control model of feeding indicates that palatable food consumption is the product of interactions between hedonic appetite and inhibitory control (Appelhans, 2009; Lowe & Butryn, 2007). The model posits that hedonic eating occurs when an individual consumes palatable food outside of physiological need and that this behavior developed from evolutionary value, to store energy as fat to protect against times of food shortages. At the same time, the model acknowledges that occasionally inhibiting hedonic eating was functional for ancestral humans; as it allowed them to store food to be consumed later, rather than consume it when it was acquired. Therefore, this interaction of hedonic eating and inhibitory control has an evolutionary basis that raises questions about individual eating tendencies present in modern times.

The neurobehavioral inhibitory control model includes background on the neuroscience of feeding (Appelhans, 2009). Hedonic feeding involves an interplay of “liking” and “wanting” processes that create appetitive motivation, or hedonic appetite, mediated by the mesolimbic system (Berridge, 2007). “Liking” refers to the sensory enjoyment of tasting and consuming palatable foods, while “wanting” refers more to the rewarding nature of a palatable food. While the two processes indeed interact, they have unique neurophysiological underpinnings. “Wanting” is linked to the mesolimbic system, and is associated more with the addictive tendencies that drive food consumption and contribute to obesity (Mela, 2006). “Liking” of palatable foods is thought to be mediated by opioid neurotransmission in the nucleus accumbens (Kelley & Berridge, 2002) and is related to the pleasantness one experiences while eating. The processes of liking and wanting can converge when an individual consumes palatable food: dopamine is released in the nucleus accumbens in response to both anticipating and experiencing the palatability and pleasantness of the food (“liking”), while the mesolimbic system influences motivation to continue to consume more of the palatable food (“wanting”) without changing the individual’s perceived pleasantness of the food (Aberman & Salamone, 1999; Appelhans, 2009).

Hedonic Appetite in Adolescents

Typical human dietary behavior is characterized by the pursuit of caloric energy as well as pleasurable reward. As mentioned, hedonic appetite is a drive to consume palatable foods for pleasure, rather than a need for physiological sustenance (Lowe & Butryn, 2007). Palatable food items are those that quickly replenish energy stores, may be calorie-dense, and/or have an effect of reward or pleasure on the consumer. The modern food environment provides consistently convenient and affordable access to palatable food, which puts people at risk for acting on hedonic appetite and increases risk for subsequent weight gain. Notably, the motivational process of hedonic appetite and the behavior of consuming palatable food are separate processes, with the potential to be linked. In other words, just as an individual may consume palatable food without experiencing hedonic appetite, experiencing hedonic appetite may or may not result in palatable food consumption, and this variation is partially due to the influence of inhibitory control, as explained in the neurobehavioral inhibitory control model. When studying appetite and food consumption behavior, it is also important to consider other individual factors that influence these mechanisms. For example, those with higher body weight may tend to have a higher caloric intake due to energy expenditure needs, frequency of food cravings (Chao, Grilo, White, & Sinha, 2014), and neural reward response to visual food cues (Pursey et al., 2014). Additionally, a variety of medications affect appetite and certainly influence consumption behavior in youth (Correll & Carlson, 2006).

Adolescents are a key population in which to examine the mechanisms of hedonic appetite, as this group is in a developmental period marked by increasing independence and autonomy in dietary choice (Stok, De Ridder, Adriaanse, & De Wit, 2010). Moreover, this age group is generally known to be high in reward-seeking, tends to consume a diet high in palatable foods (Reedy & Krebs-Smith, 2010), is vulnerable to developing disordered or maladaptive eating patterns (Rohde, Stice, & Marti, 2015) and is at the peak developmental period of risk for obesity (Ferreira, Twisk, van Mechelen, Kemper, & Stehouwer, 2005; Ogden et al., 2016).

Therefore, understanding the drivers of consumption of palatable foods has potential application for prevention and intervention efforts targeting obesity and disordered eating behavior, as well as promotion of healthful lifestyles.

Our previous findings indicated that hedonic appetite has the potential to fluctuate in adolescents, and conceptualization of hedonic appetite as both trait (between-person) and state (within-person) may be most appropriate (Bejarano & Cushing, 2018). The construct encompasses both trait and state elements in that some individuals may generally have higher levels of hedonic appetite than other individuals (*i.e.*, between-person, trait) and, for all individuals, levels of hedonic appetite may increase or decrease daily, in deviation from their usual level (*i.e.*, within-person, state). In our work, findings indicated that 33% of the variability in hedonic appetite was accounted for by within-person fluctuation, and 67% was between-person. This indicates that hedonic appetite mostly varies across adolescents, but it also has the potential to fluctuate within an individual adolescent from day-to-day. Moreover, the between-person and within-person elements exhibited different associations with food consumption when examining the effects on consumption of foods in *sweet, starchy, fatty,* and *fast food* categories. In particular, between-person hedonic appetite was positively associated with consumption of *fatty* foods, while within-person hedonic appetite was positively associated with consumption of *starchy* foods. The findings from this study pointed towards the state and trait elements of interest in hedonic appetite, but experimental work is warranted to support their existence. The current study builds from these findings by testing whether it is possible to manipulate the state component of hedonic appetite, and by calculating effect size estimates of how changes in hedonic appetite influence adolescents' eating behavior. Additionally, continuing to examine overall palatable food consumption and consumption on of the respective categories of palatable food (*sweet, starchy, fatty,* and *fast food)* may add clarity to the differential relationships that were found previously.

Inhibitory Control, Hedonic Appetite, and Food Consumption

Inhibitory control, a key dimension of executive function, has emerged as a mechanism by which hedonic appetite may vary, with some recent research conducted in youth. In the context of palatable food consumption, inhibitory control refers to inhibiting attention or a response towards a food cue or stimulus. For example, fMRI data indicated that adolescents with higher hedonic appetite had lower neural activation in the prefrontal cortex, suggesting that those who scored higher in hedonic appetite may have had difficulty inhibiting their impulses to consume energy-dense palatable food (Jensen, Duraccio, Carbine, Barnett, & Kirwan, 2017). The existing research has connected inhibitory control to hedonic appetite, palatable food consumption (Appelhans et al., 2011; Manasse et al., 2015), dysregulated eating, excess body weight, and poor psychosocial outcomes in adults (Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016; Lowe et al., 2016) and youth (Gowey et al., 2017).

Hedonic eating appears to occur as a result of the motivational process of hedonic appetite overpowering inhibitory control, while dietary restraint appears to be a product of inhibitory control over hedonic appetite. In other words, inhibitory control is often the mechanism by which individuals abstain from palatable food consumption (DelParigi et al., 2007; Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001). In the context of the neurobehavioral inhibitory control model, attention allocation plays a role in the dynamics between inhibitory control and hedonic appetite. Humans generally tend to allocate attention toward the potentially rewarding stimuli of palatable food, and this attention can promote the goal-directed behavior of consuming the food (Appelhans, 2009). Therefore, attention is considered in the conceptualization of how inhibitory control functions. Generally, there are two pathways to consider when targeting inhibition as a mechanism for disrupting the association between hedonic appetite and palatable food consumption. A person might either attempt to avoid consumption once a food stimulus has already entered conscious awareness (*i.e.,* top-down control) or might never be consciously aware of the food stimulus in the first place (*i.e.,* bottom-up control). Active top-down inhibitory control, which requires the intentional inhibition of a response once one *has attended to* palatable food stimuli, has been shown to fail in dieting plans and especially under stressful conditions (Lattimore & Maxwell, 2004). If top-down inhibition is likely to fail, there is value in determining whether training more automatic (bottom-up) inhibitory control would create a tendency towards *not attending* to palatable food. If palatable food is less likely to come into conscious awareness, then the drive to eat should be reduced without relying on top-down control.

It seems that top-down inhibition requires intentional cognitive effort to inhibit attention toward palatable foods, which often fails when cognition is taxed by attention toward other stimuli or when one is fatigued, both contexts that are common in human experience. In contrast, bottom-up inhibition is more automated; rather than intentionally redirecting attention from food stimuli, an individual attends less to palatable food cues, making the need to consciously inhibit palatable food consumption less frequent and less cognitively effortful (Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017). Therefore, because top-down impulse inhibition processes are likely to fail, it is important to investigate cognitive training protocols that act on earlier preconscious brain mechanisms that signal the availability of reward.

The distinction between top-down and bottom-up inhibitory control is of additional importance when considering mechanisms that inhibit food consumption in the developmental phase of adolescence. Adolescence is a transitional period of cognitive and neurobiological development during which development of the prefrontal cortex lends to increasingly improved cognitive control (Casey & Jones, 2010). As top-down processes are not fully developed typically until the transition from adolescence to adulthood, it may be even less beneficial to target top-down inhibition in adolescents as compared to adults. However, striatal regions that underlie bottom-up associations and learned relations function effectively at a very young age (Casey & Jones, 2010). Therefore, targeting bottom-up associations, such as through a Go/No Go (GNG) task, may be appropriate in the adolescent age group.

Go/No Go Inhibitory Control Training

A Go/No Go Inhibitory Control task is a procedure in which two categories of visual stimuli are randomly presented and a respondent is required to respond to images from one stimuli category (*Go)* while withholding a response to an alternative stimuli category (*No Go)* (Donders, 1969). The majority of evidence suggests that GNG training creates automatic (bottom-up) stop associations that influence outcomes of food choice, portion size, and body weight (Stice, Lawrence, Kemps, & Veling, 2016) when the *No Go* category comprises food stimuli. GNG tasks are thought to have these effects as a result of direct food item stop associations that lead to automatic bottom-up inhibition, meaning that in this task, the requirement to inhibit a response is consistently and simultaneously paired with a *No Go* cue so that an individual is trained to more automatically inhibit their response. This process is in contrast to the top-down associations thought to be trained by other inhibitory control training tasks (*e.g.,* stop-signal training, SST), in which a “Go” cue is presented prior to a “Stop” signal and the stimuli of interest is intermittently (rather than consistently) paired with the “Stop” signal. In other words, the GNG task trains a more automatic restraint of a response, while a

Stop-signal task trains a cancellation of a response (Stice et al., 2016). Moreover, GNG training has shown to have stronger effects pertaining to food consumption when compared to stop-signal training (Jones et al., 2016). The suggested advantage of bottom-up training (GNG) as compared to top-down training (stop-signal) parallels findings from intervention studies that top-down inhibition for food consumption is often not sustainable, while bottom-up inhibition may be more consistently effective in targeting hedonic eating (Forman et al., 2016, Lattimore & Maxwell, 2004).

Go/No go (GNG) inhibitory control training has been shown to improve target behaviors by inhibiting prepotent responses toward opposite undesired behaviors (Allom, Mullan, & Hager, 2016). Recent reviews have convincingly argued that GNG inhibitory control training works by targeting lower-order preconscious cognition by repeatedly training brain systems to ignore stimuli automatically (Veling et al., 2017). Because stimuli are ignored at the preconscious level, an individual is less likely to have to rely on ineffective top-down impulse control to avoid engaging in the unhealthy behavior. Overall, there is some evidence that GNG training can modify food choices and food intake, and is associated with subsequent weight loss in adults (Veling et al., 2017). Few studies have examined the influence of GNG training in youth, but a recent study in children 7-10 years old found GNG training to significantly reduce consumption of energy-dense candy, as compared to a control group (Folkvord, Veling, & Hoeken, 2016). Another recent study found some evidence for GNG training to be related to adolescents' inhibitory control for intake of sugar sweetened beverages (Ames et al., 2014).

Present Study

The current study was based on the following **scientific premises**: 1) hedonic appetite is a construct with both state and trait properties that hold unique associations with palatable food consumption, 2) inhibitory control influences dietary behavior, and there is some evidence of its association with hedonic appetite in predicting food consumption, and 3) GNG inhibitory control training may decrease consumption of palatable food, with preliminary evidence in youth. However, no studies have examined mechanisms by which hedonic appetite may change. It is unclear whether state hedonic hunger can be manipulated by training bottom-up inhibitory control. Finally, there is a need to further understand the effects of GNG training on food consumption in youth, both in controlled laboratory settings and in naturalistic, free living contexts (Folkvord, Veling, & Hoeken, 2016).

The present study continued our investigation of hedonic appetite as both a state and trait variable. If state (within-person) hedonic appetite could be experimentally manipulated, it would increase confidence about the existence of this phenomenon. The present study aimed to test the effect of a GNG task on changes in state hedonic appetite. In addition, the current project provided effect size estimates of hedonic appetite as a mechanism by which GNG inhibitory control training conferred an effect on dietary behavior. The combined methodology of an experimental laboratory task and daily diary assessment (*i.e.,* assessing constructs of interest in close temporal proximity to the individual's experience each day, as compared to a sole measurement of a construct at one time point) allowed for detection of such effects, and may address limitations of previous studies that have focused on only one of these methods. Still, it was important to pilot this novel combined methodology for feasibility to inform a fully powered study. This study combined experimental and daily diary methods to: 1) explore the existence of a state hedonic appetite process, and 2) estimate whether changes in hedonic appetite influence consumption of palatable food.

Study Hypothesis (Aim 1). One goal of the present project was to test whether hedonic appetite could be experimentally manipulated. We hypothesized that participants assigned to the food GNG Intervention condition would experience a significant decrease in WP hedonic appetite compared to those in the Control GNG condition.

Exploratory Analyses (Aim 2). In addition, the design explored the preliminary effect of a food GNG task compared to a control GNG on total palatable food intake, and *sweet*, *starchy*, *fatty,* and *fast food* consumption, respectively. Exploratory mediation analyses were conducted to calculate effect sizes for the relationships between GNG inhibitory control training and post-GNG within-person (WP) hedonic appetite, and post-GNG WP hedonic appetite and the categories of palatable food consumption. The goal of these analyses was to generate effect size data to inform future fully powered trials. Specifically, we identified effect sizes for: a) the association between post-GNG within person (WP) hedonic appetite and experimental grouping; b) post-GNG WP hedonic appetite and total palatable food consumption and the categories of *Sweet*, *Starchy, Fatty,* and *Fast food;* and c) experimental grouping and consumption of total palatable food and in each of the four categories. We used the exploratory results and the observed effect sizes to conduct a post hoc power analysis to inform future fully powered work. The conceptual model is depicted in *Figure 1.*

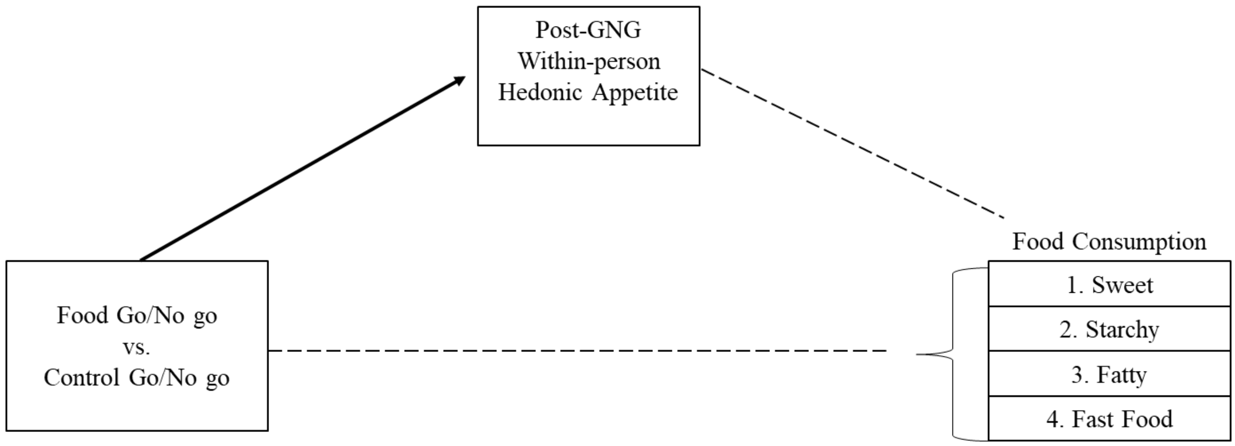

Figure 1. Conceptual model reflecting hypothesized and exploratory effects.

Note: Food consumption was measured in total caloric intake and caloric intake of *Sweet, Starchy, Fatty,* and *Fast Food*, respectively. The bolded line indicates a fully powered statistical test with a directional hypothesis. The dashed lines indicate exploratory analyses intended to generate effect sizes.

Method

Participants

The targeted population for this study was adolescents, ages 13-18 years. In order to best control for the food environment across participants, adolescents that lived in a home setting with their parent(s) or caregiver(s) were eligible to participate, while those living in a college dormitory or other non-traditional setting were not eligible. Eligibility criteria included the ability to read at their grade level and in English, and absence of any significant visual impairment. As the study aimed to understand eating behavior in typically functioning adolescents, those with developmental delays, past or current self-reported eating disorder diagnoses, and any health conditions that significantly affect activity or eating habits were excluded. Adolescents with food allergies or dietary restrictions were also excluded so that the drivers of food consumption could be examined without this influence. The process of determining eligibility also had participants provide information pertaining to mental health history, and current medications so that any potential additional effects on weight or appetite could be accounted for (*e.g.*, stimulant medication for ADHD, prednisone).

Procedure

The study procedures and measurement sequence are summarized in *Figure 2.* All procedures, including parental consent and adolescent assent processes, were approved by the Human Research Protection Program (IRB) at the University of Kansas (study # STUDY00141427) institutional review board (IRB).

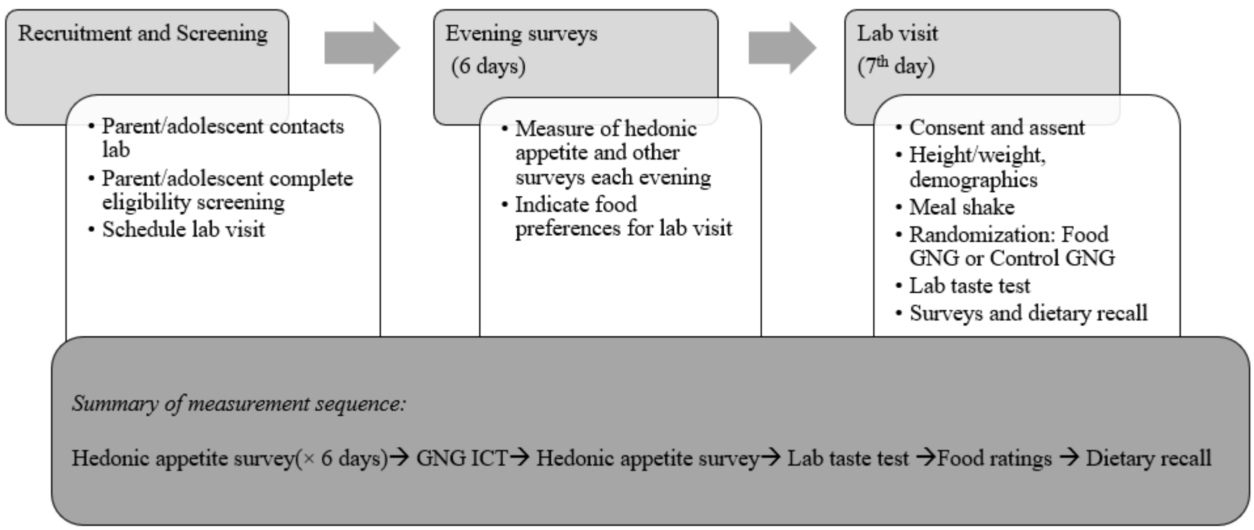

Figure 2. Description of study procedures and measurement sequence.

Recruitment and Screening. Recruitment efforts consisted primarily of posting flyers at local institutions, businesses, schools, and community events. The flyers advertised a study about adolescent health that required participation in daily surveys and a lab visit at the local university, offered \$20 to \$40 compensation, and provided complimentary snack food. The flyers instructed parents of adolescents ages 13-18 to contact the lab to complete a brief telephone screening for eligibility for study participation. Those who screened in were scheduled to come to the research lab for a 2-hour visit. Parents then provided their adolescent's e-mail address so that they could be sent an information statement and a link to a survey each evening for a week before the visit. By phone or email, research staff provided information about the scheduled visit and the study compensation ($40 available in 2 parts: $20 for completion of surveys during the week prior to lab visit, $20 for completion of lab visit and surveys 3 days after the lab visit). Each evening survey sent to the adolescent included a measure of hedonic appetite, as well as additional health behavior questionnaires so that the focus on eating behavior was covert. Prior to the lab visit, participants indicated their preference of specific foods in each of the four palatable food categories, *Sweet, Starchy, Fatty,* and *Fast food* (*i.e.,* choosing one out of two food options in each category: *Sweet:* Gummy bears or Chocolate M&Ms, *Starchy:* Dinner rolls or Cereal; *Fatty:* Fried Chicken or Hotdogs; *Fast food:* Potato chips or Cheese Pizza), so arrangements could be made to have these foods available during the lab visit and to ensure the foods offered were appropriate for individual food preferences. Adolescents were instructed to fast for 3 hours prior to coming to the lab visit.

Lab Visit. Parents and adolescents completed consent and assent processes, respectively, at the lab visit. Both were informed that, in the interest of understanding the research questions, they were not informed fully of the processes being examined in the study at the lab visit, but they would be informed of all the procedures before they occur and receive more detailed information about the study after participation was complete.

Meal Shake. Adolescents were provided a standard meal replacement shake at the beginning of the lab procedures in efforts to ensure that observed eating behavior was due to hedonic appetite rather than physiological hunger. The shake had 350 calories, and its composition was 15% protein, 57% carbohydrates, 29% fats, which is in line with acceptable micronutrient distribution ranges (Manore, 2005).

Randomization. Participants were then randomized to the Intervention (food) or Control GNG task designed on PsychoPy software (Peirce, 2009). The senior principal investigator on the team used a random number generator in SAS to create a randomization sequence prior to study enrollment and place each participant's randomization group into a sealed envelope. The research assistant administering the GNG task opened the envelope with the corresponding number for the participant, and administered the task that was indicated on the paper inside the envelope (Intervention or Control). The research assistant responsible for assessing the outcome by covertly weighing the food after the bogus taste test remained blind to the randomization condition.

Bogus Taste Test. After completing the GNG training, participants completed a hedonic appetite survey measure, then were brought to a separate room from their parent and the research staff, with a comfortable chair, an iPad playing a television show, and large amounts of the preferred palatable foods indicated prior to the visit. The bogus taste test included one food from each category, (*e.g.,* chocolate, cereal, fried chicken, potato chips). Adolescents were instructed to eat as much as they would like of all the foods offered. Water was provided and adolescents were left alone and allowed 20 minutes to complete the taste test. After 20 minutes, research staff brought participants back to the original room to complete ratings of the food they tasted, additional surveys on Qualtrics, and a dietary recall measure (ASA 24) on the computer. Once the participant left the room to complete the remaining procedures in another room, the amount of each type of food eaten by each participant was weighed covertly by a member of the research staff in order to record and calculate the amount of palatable food eaten from the amount that was offered.

Remaining Data Collection and Study Procedures. Adolescents' height and weight was recorded and each completed a demographic questionnaire. After completing computer tasks, participants were brought back to their parent, thanked for their participation, and given the opportunity to ask questions before leaving. Participants were reminded that their payment would be calculated (up to $40 in retail gift cards) and mailed to them. With the gift card, participants and parents were mailed a debriefing letter with information about the research questions of interest, as well as a brief list of mental health resources.

Constructs and Measures

Hedonic Appetite. The Power of Food Scale is a 15-item measure that assesses the construct of hedonic appetite (Cappelleri et al., 2009; Lowe et al., 2009). Items assessed participants' thoughts and feelings about eating, with particular attention to highly palatable foods. Response options were on a 5-point Likert scale, ranging from 1 (*don't agree at all)* to 5 *(strongly agree).* A mean of the total score was calculated, with higher scores indicating higher hedonic appetite (range 1-5). The PFS has shown evidence for adequate internal consistency reliability (α = .91) through confirmatory factor analyses supporting a three-factor solution and use of a total score in a sample of college students (Lowe et al. 2009). The PFS has also shown evidence for test-retest reliability with a re-administration at 4-months (r = .77, p < .001; Lowe et al., 2009). The measure has demonstrated good convergent validity through moderate significant correlations with several measures of eating attitude and behavior, as well as incremental validity with the PFS accounting for 22-39% additional variance in these measures (Lowe & Butryn, 2007; Lowe et al., 2009). Furthermore, the PFS had high internal consistency reliability in a previous sample of healthy adolescents (α = .94; Bejarano & Cushing, 2018). Recent data indicates that in a sample of children and adolescents, the PFS replicated the same factor structure, with one higher-order total score, as it has shown in adults (Cappelleri et al., 2009; Lowe et al.; 2009; Mitchell, Cushing, & Amaro, 2016). The PFS was used to measure hedonic appetite through each of the evening surveys, as well as at the lab visit.

Post-GNG Within-Person Hedonic Appetite. Adolescent participants completed the PFS at the lab visit, directly after completion of the Intervention or Control GNG task, respectively. Post-GNG hedonic appetite was therefore the seventh observation of hedonic appetite. Post-GNG within-person (WP) hedonic appetite was then the deviation of the measure of hedonic appetite after the GNG task from the WP hedonic appetite measured over the six days prior to the lab visit.

Food Preferences. The Food Preferences Questionnaire was administered once during the survey week to obtain information about participants' preferred foods so that arrangements could be made for the laboratory taste test. The measure was designed specifically for this study, based on factor loadings from the Food Craving Inventory (*i.e., Sweet, Starchy, Fatty, Fast food*; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002), and on studies examining consumption of palatable food in a lab setting (Appelhans et al., 2011). The Food Craving Inventory demonstrates good test-retest reliability (r = .86 for total; .87 for *sweet;* .79 for *starchy;* .91 for *fatty;* .87 for *fast food*) and internal consistency reliability (α = .93 for total; .86 for *sweet;* .84 for *starchy;* .86 for *fatty;* .76 for *fast food.* The FCI is significantly correlated with the Three Factor Eating Questionnaire and the Conceptual Craving Scale, which provides support for its convergent validity (White et al., 2002). The total FCI score and subscales are not significantly correlated with measures of dietary restraint, which provides support for the discriminant validity of the measure (White et al., 2002).

Demographics. The demographics questionnaire was used for collecting information about participant's sex, age, date of birth, address, phone number, race/ethnicity, place of birth, primary language, parent's education, parent's occupation, approximate family income, and parent's marital status. Participants completed the demographic questionnaire at the lab visit. Additional information regarding mental health history, eating disorder history, and medication usage during enrollment in the study was obtained either retroactively or during the initial telephone screening.

Height and Weight. Each participant's height and weight were measured at the end of the lab visit. Participants were asked to remove shoes and outerwear to obtain accurate measurements. Research staff measured height on a stadiometer to the nearest 0.1 cm and weight on a digital scale to the nearest 0.1 kg. Measurements were taken three consecutive times and averaged. Body mass index (BMI) percentile was calculated based on age and sex, as indicated by the Centers for Disease Control (CDC, 2007).

Inhibitory Control Training. A Go/No Go (GNG) Task was programmed using PsychoPy software which allows for tailoring to the stimuli of interest, for both a palatable food condition and a control condition. In the GNG task, participants were instructed to press a button when a *Go* cue was presented and to not press a button when a *No-Go* cue was presented. Adolescents in the food GNG condition were trained using pictures of palatable foods grouped as *Sweet, Starchy, Fatty,* and *Fast food* as *No-Go* cues, which are categories that have been validated in previous work. Four food stimuli pictures were used for each category (16 total; *e.g.*, French fries for fast food category) and a total of 16 non-food stimuli pictures were used (*e.g.*, animals). Those in the food intervention GNG condition were randomly presented palatable food and non-food stimuli and instructed to press a computer key in response to non-food stimuli while inhibiting responses to the palatable food stimuli. Those in the control group completed GNG tasks with all non-food stimuli (*e.g.,* animals, shapes). Previous work suggests that inhibiting responses to food items during a GNG task trains bottom-up inhibitory control over responses to food stimuli (Veling et al., 2017). Images used for the food and animal stimuli in the GNG tasks were used with approval from a food-pics image database designed to facilitate standardization and comparability across studies of eating behavior (Blechert, Meule, Busch, & Ohla, 2014; see Appendix A).

The GNG procedures were designed in accordance with past studies of this nature (Folkvord, Veling, & Hoeken, 2016; Veling, van Koningsbruggen, Aarts, & Stroebe, 2014). Participants in both groups completed a practice round of the GNG task to ensure they could perform the task correctly. If the participant made an incorrect response or did not respond within 1,000ms, a red cross appeared on the screen for 500ms. For both groups, each stimulus was presented for 1,000ms and the intertrial interval was 500ms. In the control group, there were 50% *Go* trials (*i.e.,* 16 images of animals presented 4 times each) and 50% *No-Go* trails (16 images of colored circles presented 4 times each). In the intervention group, there were also 50% *Go* trials (*i.e.,* 16 images of animals presented 4 times each) and 50% *No-Go* trials (16 images of palatable food presented 4 times each). *Figures 3 and 4* represent the Intervention and Control GNG procedures, respectively.

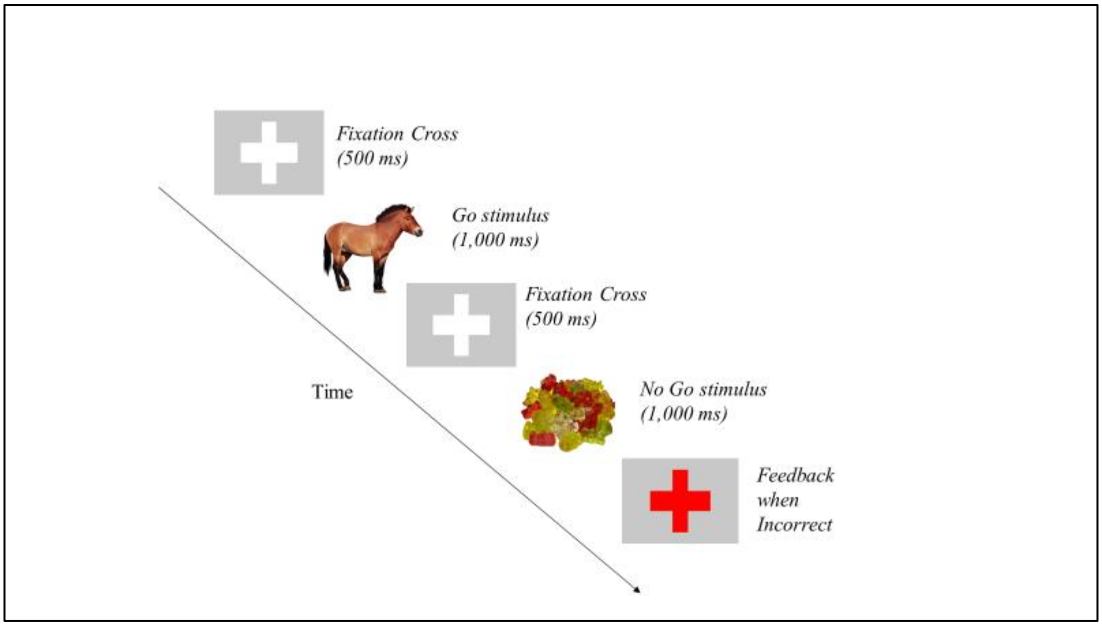

Figure 3. Example of stimuli in Food GNG task (Intervention group)

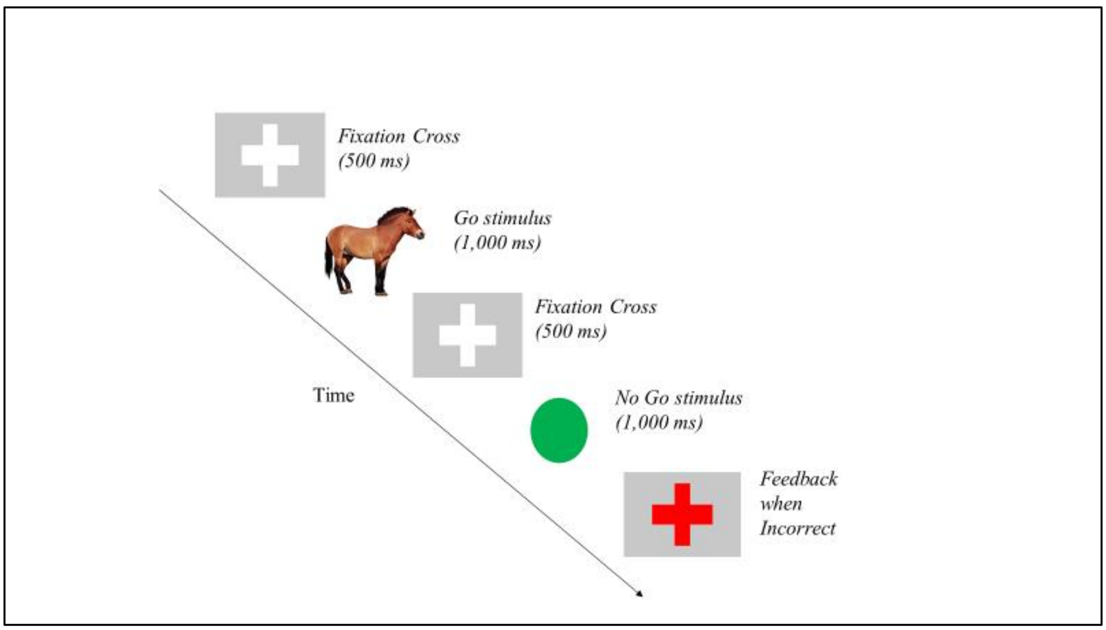

Figure 4. Example of stimuli in Control GNG task (Control group)

Eating Disorder Symptomology. The Eating Pathology Symptoms Inventory (EPSI) is a 45-item self-report measure that had respondents indicate how frequently each statement applied to them during the past four weeks, with response options ranging from 0 *(Never)* to 4 *(Very*

Often). Responses were summed in eight subscales of body dissatisfaction, binge eating, cognitive restraint, purging, restricting, excessive exercise, negative attitudes toward obesity, and muscle building (Forbush, Wildes, & Hunt, 2014). The EPSI is a well-validated measure that is used to assess psychopathology of eating disorders (Forbush et al., 2013). Specifically the EPSI scale scores show excellent internal consistency reliability (α = .84-.89); convergent validity through significant correlations of the body dissatisfaction subscale with eating pathology measures (e.g., EDE-Q Shape and Weight Concern Scales and EDI-3 Body Dissatisfaction Scale); and criterion validity as it distinguished patients with eating disorders from psychiatric outpatients (Forbush et al., 2013).

Palatable Food Consumption. The amounts of the four foods offered in the bogus taste test were standardized based on caloric content (*i.e.*, a predetermined amount of each food that contains 500-600 calories). Research staff were also trained to reliably measure each food offered in the study to serve food that contained the number of calories in the predetermined range. After the bogus taste test, the remaining portions of each food were weighed covertly on a food scale in grams and the participant's consumption of each food was calculated in calories. As mentioned, palatable food consumption was measured in four respective categories: *sweet, starchy, fatty,* and *fast food.* Although our past findings found significant positive relationships of hedonic appetite specifically with *starchy* and *fast food* consumption, further study was needed to differentiate effects on consumption across all four categories.

Typical Dietary Intake. The Automated Self-Administered 24-hour (ASA24) dietary assessment tool is a freely available web-based tool developed by the US National Cancer Institute to obtain high quality daily dietary data with minimal bias (Subar et al., 2012). The one-day dietary recall is considered acceptable as a valid assessment of typical dietary intake (Dietary

Assessment Primer, NIH, 2017). Participants completed the ASA24 at the lab visit, which was used as a potential covariate in the present study. Validation studies of the ASA24 indicate that there is close agreement between the ASA24 system and standardized interviewer-administered dietary recalls (Kirkpatrick et al., 2014). Though there is a youth version of the ASA24 available, this has been validated in youth 9-11 years old, and the adult version was considered to be a more appropriate choice for measuring dietary intake in the present study.

Liking of Foods Consumed. After the bogus taste test, participants rated the palatability of the foods they ate, on a scale ranging from 0 to 100. The ratings measure was adapted from other studies that have measured liking of foods in bogus laboratory taste tests (Appelhans et al., 2011).

Data Analytic Plan

A review of the relevant literature indicted that no existing studies have used randomization to two separate GNG Control and Intervention groups with the proposed relationships. However, one study used four different groups of children, two of which were in a GNG control condition, and the other two in a GNG intervention condition meant to decrease consumption of palatable foods. The number of participants in each of the four groups ranged from $n = 32$ to $n = 36$ and the researchers found significant effects on candy consumption and total energy intake (Folkvord, Veling, & Hoeken, 2016). The analyses for the present study included data from 40 participants (20 intervention, 20 control; after data screening) to determine feasibility of the methodology and to estimate the hypothesized effects to inform a future fully powered study.

Data Screening and Preliminary Analyses. A data screening process was completed using SPSS and dependent variables were examined for normality of distributions. Participants with fewer than five evening surveys completed were excluded from analyses, as this was insufficient data to calculate a within-person measurement of hedonic appetite. The evening survey data provided information for calculating state fluctuations in hedonic appetite. The observations of hedonic appetite were grand-mean centered. Trait (between-person, BP) hedonic appetite was then calculated by averaging each participant's daily grand mean centered score on the Power of Food Scale to obtain a person-mean. This created a variable that reflected each participant's deviation from the group's mean hedonic appetite. State (within-person, WP) hedonic appetite was calculated by subtracting the person-mean from each daily score on the Power of Food Scale, known as person-mean centering. This created a variable that represented daily deviation from one's typical level of hedonic appetite. The daily measurements of WP hedonic appetite prior to the lab visit (from study days 1-6) were coded as 0, and the measure of hedonic appetite at the lab visit following the GNG task was coded as 1 (from study day 7, post-GNG hedonic appetite). To determine how hedonic appetite performed over time, a multilevel model was fit with a fixed linear effect of time, as well as test alternate models (i.e., random linear, fixed quadratic, random quadratic) to determine how best to represent time in the final model. Model fit was assessed using nested model comparisons using the -2LL with significance testing using a chi-square distribution. The food consumption variables were measured in calories for *sweet, starchy*, *fatty,* and *fast food* categories respectively, and total calorie consumption.

Examining Potential Covariates. Bivariate correlations and independent samples t-tests were run to examine associations between potential covariates (*e.g.*, eating disorder symptomology, BMI percentile) and the dependent variables. Significant correlations and associations were then examined further using independent samples t-tests to examine potential differences between the participants randomized to the Food GNG Intervention group as compared to the Control group, with each potential covariate as a dependent variable. In particular, the dietary intake data obtained through the ASA24 was used as a randomization check to determine if the two groups ate significantly different amounts of total calories over the 24-hour period prior to the study visit. Information regarding participant's mental health and medication usage that could potentially affect appetite and eating behavior were also examined as potential covariates. Information was coded as having a potential influence on dietary behavior or not, and chi-square analyses were run to determine any differences between the randomization groups.

Primary Analysis (Aim 1). The main hypothesis of interest was tested by running a multilevel model in SAS v 9.4 using a random linear effect of time based on the results of models for time. As stated previously, observations of WP hedonic appetite obtained from study days 1-6 were coded as time=0, and the observation of WP hedonic appetite obtained after the GNG intervention on day 7 was coded as time=1 (i.e., post-GNG hedonic appetite) A time by group (GNG Intervention, GNG Control) interaction in SAS was then run to determine whether the GNG intervention caused a decrease in WP hedonic appetite for GNG Intervention participants.

Exploratory Analyses (Aim 2). Exploratory mediation models were run in MPlus (*i.e.*, one for each of food category dependent variable, one for total palatable food consumption in calories), comparing the GNG intervention group ($n = 20$) to the control group ($n = 20$). Group was included in the model as a dichotomous independent variable with the control group as the reference group, and post-GNG WP hedonic appetite (i.e., the value of WP hedonic appetite after the GNG intervention) was specified as the mediator. The models for each food consumption category dependent variable included the other respective groups as covariates (*e.g.,* model for *Sweet* food consumption controlled for *Starchy*, *Fatty*, and *Fast Food*). Models were run using bias-corrected bootstrapping (Preacher & Hayes, 2008). This set of analyses was conducted as exploratory hypothesis testing to estimate the direct and indirect associations of GNG training on palatable food consumption, through hedonic appetite. The results of the mediation analyses were used to calculate effect sizes for each path of the proposed mediation effect. The effect size for the relationship of GNG training with post-GNG WP hedonic appetite, the effect size for the relationship of GNG training with each of the food consumption dependent variables, and effect size for the relationship of WP hedonic appetite with food consumption were calculated to determine the proposed indirect effect of post-GNG WP hedonic appetite. For each model, the unstandardized regression coefficients and standard deviations of the respective dependent variable were used to calculate effect sizes for each path, then the product of the two effect sizes was calculated to represent the indirect effect, or the effect size of the full model (Kenny, 2018; Preacher & Kelly, 2011).

Post Hoc Power Analyses (Aim 2). Following the exploratory mediational analyses, post-hoc power analyses were conducted in MPlus to determine the necessary sample size for a future fully powered study. Using a Monte Carlo simulation for a bootstrap mediation in Mplus (Thoemmes, MacKinnon, & Reiser, 2010), we estimated the sample size for .8 power given the parameter estimates that came from the mediational models. Multiple iterations of the Monte Carlo simulation were run with increasing sample sizes up to 5,000 participants to attempt to reach .8 power. We tested the *a* path (association between WP hedonic appetite and experimental grouping), *b* path (association between WP hedonic appetite and total and four categories of palatable food consumption), and *c* path (association between experimental grouping and consumption of total and four categories of palatable food consumption) to determine how many participants it would take to detect a significant effect for each path should a significant effect exist.

Results

Preliminary Analyses

A total of 43 participants enrolled in the study. Data screening resulted in 3 participants excluded due to insufficient daily diary survey completion. The dependent variable *Starchy* food consumption violated assumptions of normality and was therefore not included in the subsequent analyses. The dependent variables of *Sweet*, *Fatty, Fast food*, and *Total* food consumption were normally distributed. After the data screening process, 40 participants (20 intervention, 20 control) with at least 6 observations of hedonic appetite were included in the analytic sample. The grand-mean of hedonic appetite was 1.75 (*SD*= .75, min=1.00, max=4.73). The mean between-person hedonic appetite of the sample was .01 (SD = .67, min=-.75, max=2.02) and the mean within-person hedonic appetite of the sample was .00 (*SD* = .35, min=-.84, max=1.95). Participants were mean age 15.1 (*SD* = 1.6), majority female (70%) and Caucasian (60%), and 45% reported an annual household income of > $61,000. Average BMI percentile was 50.2 (*SD* = 28.7) and average calories consumed the day prior to the study as measured by the ASA24 was 1726.3 (*SD* = 652.1). Additional data about adolescent mental health and medication history was obtained from 35 of the participant-parent dyads. Of these, 17.1% reported current or past history of anxiety, 11.4% for depression, 14.3% for ADHD, 5.7% for other concerns, and 0% for eating disorders. The same dyads reported current medications for the adolescent: 11.4% reported taking medication for anxiety or depression, 14.3% for acne medication, 8.5% for ADHD medication, and 2.9% for allergy medication, 2.9% for thyroid medication, and 8.5% other unspecified medication. The foods participants chose for the taste test were the following: M&Ms (*n*=21) and gummy bears (*n*=19) for *Sweet;* Cereal (*n*=18) and rolls (*n*=22) for *Starchy;* Fried chicken (*n*=33) and hotdogs (*n*=7) for *Fatty;* Potato chips (*n*= 12) and pizza (n=28) for *Fast food.* The average consumption in the lab taste test was 95.5 *Sweet* calories, 84.9 *Starchy* calories, 135.0 *Fatty* calories, 172.1 *Fast food* calories, and 487.5 *Total* calories. A summary of demographic information and descriptive statistics is presented in Table 1.

Table 1

Demographic Information and Descriptive Statistics

Demographic Variable	Total *n=40* (%)	Intervention *n=20* (%)	Control *n=20* (%)
Gender			
Female	28 (70%)	13 (65%)	15 (75%)
Male	12 (30%)	7 (35%)	5 (25%)
Race/Ethnicity			
Caucasian	24 (60%)	12 (60%)	12 (60%)
Asian	6 (15%)	4 (20%)	2 (10%)
Hispanic/Latino	4 (10%)	1 (5%)	3 (15%)
Biracial/Multiracial	3 (7.5%)	2 (10%)	1 (5%)
Other/Did not report	3 (5%)	1 (5%)	2 (10%)
Approximate Family Income			
< $10,000	1 (2.5%)	1 (5%)	0 (0%)
$10,000-$20,000	5 (12.5%)	2 (10%)	3 (15%)
$21,000-$30,000	7 (17.5%)	4 (20%)	3 (15%)
$31,000-$40,000	2 (5%)	0 (0%)	2 (10%)
$41,000-$50,000	2 (5%)	1 (5%)	1 (5%)
$51,000-$60,000	2 (5%)	1 (5%)	1 (5%)
> $60,000	18 (45%)	10 (50%)	8 (40%)
	Total *M (SD)*	Intervention *M (SD)*	Control *M (SD)*
Age (years)	15.1 (1.6)	15.1 (1.6)	15.2 (1.7)
BMI percentile	50.2 (28.7)	52.6 (30.8)	47.7 (27.0)
Calorie intake (diet recall)	1726.3 (652.1)	1708.67 (586.1)	1742.9 (724.2)
Sweet	95.5 (73.2)	83.7 (81.0)	107.4 (64.5)
Starchy	84.9 (97.3)	107.8 (110.9)	61.9 (77.8)
Fatty	135.0 (89.5)	140.3 (91.1)	129.7 (89.8)
Fast Food	172.1 (136.4)	168.7 (121.7)	175.5 (144.2)
Total	487.5 (240.8)	500.6 (246.9)	474.5 (240.3)

Note. *M* = mean; *SD* = standard deviation; *BMI* = body mass index. Three participants did not report approximate family income. Calorie intake represents the intake participants reported for the day prior to the lab visit via the ASA24.

Results of Covariate Screening

Independent samples t-tests were run to examine associations of gender and race/ethnicity, respectively. Gender was coded as female (1) and male (2). Race/ethnicity was grouped as white (0) and non-white (1) due to the majority of the sample identifying as white. Results of t-tests included significant associations of white race/ethnicity with *Fatty* consumption (t = -4.49, p < .001), *Total* calorie consumption (t = -2.27, p < .05), and income (t = -4.72, p < .001). Additionally, results of t-tests included significant associations of female gender with *Sweet* consumption (t = -3.77, p < .001), *Fatty* consumption (t = -7.99, p < .001), *Fast food* consumption (t = -3.57, p < .001), *Total* consumption (t = -8.39, p < .001), appetite (t = -2.17, p < .05), and BMI percentile (t = -2.39, p < .05),

Pearson correlations were run to examine associations of the remaining study variables (see Table 2). Results of bivariate correlations included significant associations of *Sweet* consumption with income and BMI percentile, *Fatty* consumption with income and reported appetite, and *Fast Food* consumption with age, income, BMI percentile, reported appetite and BP hedonic appetite. A correlation matrix is presented in Table 2. Significant correlations with the EPSI subscales were as follows: WP hedonic appetite with Body Dissatisfaction subscale (r=.54, p <.001) and Binge Eating subscale (r=.56 p <.001), *Fatty* consumption with the Negative Attitudes toward Obesity subscale (r=.39, p <.05), and *Total* consumption with Negative Attitudes toward Obesity subscale (r=.33, p <.05). Independent samples t-test did not result in any significant differences between the control and intervention group on any of the eight EPSI subscales, gender, income, race/ethnicity, or BMI percentile. Using the ASA24 total calorie consumption as a randomization check, the Control group consumed 1733.48 calories (*SD* = 702.84) and the Intervention group consumed 1703.11 (*SD* = 563.39; p = .69, non-significant difference). Results of chi-square analyses indicated that there were no significant differences between the randomized groups and mental health conditions, or medication usage that could influence dietary behavior, respectively. Results of covariate screening indicated the randomization process functioned effectively in controlling for any demographic variables associated with the dependent variables. Still, BP hedonic appetite, medication use, and body weight were determined to be necessary covariates based on existing literature, and were therefore included in the main analyses.

Table 2

Correlation Matrix of Study Variables

Variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1. Age	-	.19**	-.15*	-.23**	.12*	.00	-.05	-.07	-.17**	-.10
2. Household Income		--	-.28**	.07	.05	.00	-.17**	.13*	-.13*	.00
3. BMI percentile			--	.31**	-.29**	.00	-.12*	.03	.32**	.07
4. Reported Appetite				--	-.22**	.00	-.11	.19**	.12*	.02
5. BP Hedonic Appetite					--	.00	-.00	.09	-.30**	.03
6. WP Hedonic Appetite						--	.00	.00	.00	.00
7. Sweet Calories							--	.06	.00	.54**
8. Fatty Calories								--	.17**	.65**
9. Fast Food Calories									--	.71**
10. Total Calories										--

Note. Variable 4 refers to self-reported level of hunger at the lab visit prior to the taste test. Variables 5 and 6 are derived from centered variables. Variables 7-10 refer to calories consumed during the lab taste test. BP = Between-person; WP = Within-person.
$^*p < .05$, $^{**}p < .01$

Primary Analysis (Aim 1)

Aim 1 was to examine whether within-person hedonic appetite could be experimentally manipulated. After examining models for time, a multilevel interaction with a random linear effect of time was run. The results of the Time × Group interaction predicting WP hedonic appetite were non-significant. The association of the Time × Group interaction term with WP hedonic appetite was $\beta = .01$, *SE* = .12, *df* = 247, *p* = .96 (non-significant). The mean of hedonic appetite measured after the GNG intervention was the same for both groups (*M*=1.62). Full results of the multilevel model are presented in Table 3.

Table 3

Results of Multilevel Model (Aim 1)

	WP Hedonic Appetite	
	β (SE)	*p*
Fixed Effects		
Intercept	.19 (.07)	.01
Time	.02 (.19)	.93
Group	-.02 (.04)	.04
Time x Group	.01 (.12)	.96
Day	-.05 (.01)	<.0001
Residual Covariance	.12 (01)	<.0001
Random Effects		
Random Intercept Variance	.00 (00)	---

Note. WP = Within-Person. Time = 0 for observations of hedonic appetite prior to the intervention. Time = 1 for the observation of hedonic appetite after the intervention. Group = 0 for control; Group =1 for intervention. Day refers to the variable used to model time, accounting for observations over 7 days of study participation.

Exploratory Analyses (Aim 2)

Aim 2 was to explore the preliminary effect of a food GNG task compared to a control GNG on total palatable food intake, and *sweet, starchy, fatty,* and *fast food* consumption, respectively. Effect size estimates were calculated using recommended approaches for mediation models (Kenny, 2018; Lachowicz, Preacher, & Kelley, 2018). For each path, effect sizes were calculated based on unstandardized regression coefficients, standard deviations of the dependent variables, and group sample sizes. Effect sizes for each of the *a, b, c* paths were evaluated using standards of .1 for small, .39 for medium, and .59 for large, with associated explained variance of 2%, 15%, and 25% respectively (Cohen, 1988). The direction of effects to support the stated hypotheses are the following: negative association between Group and WP hedonic appetite (*a* path); positive association between WP hedonic appetite (*b* path); and negative association between Group and palatable food consumption (*c* path). As the effect size of the indirect effect was calculated by obtaining the product of the *a* and *b* paths for the respective dependent variable models, the effect size standards were squared and standards of .01 for small, .09 for medium, and .25 for large were used (Kenny, 2018). All effect sizes are reported; the direction of effect sizes in the medium to large range are interpreted. Effect sizes for the proposed mediational paths are presented in Table 4. Overall, the effect size for the *a* path (association of Group with WP hedonic appetite) was d = .36 (small-medium). The effect sizes for the *b* path (associations of WP hedonic appetite with respective food consumption dependent variables) ranged from small-medium. Specifically, Cohen's d for the *b* path for the *Sweet* model was .27 (small-medium). Cohen's d for the *b* path for the *Fatty* model was .33 (small-medium). Cohen's d for the *b* path for the *Fast Food* model was -.44 (medium-large), meaning that there was a negative association between WP hedonic appetite and *Fast Food* consumption. Finally, Cohen's d for the *b* path for the *Total* model was .20 (small-medium). The effect sizes for the *c* paths (associations of Group with food consumption dependent variables) also ranged from small-large. There was one large effect size for the association of Group with *sweet* food consumption (d=-1.37), meaning that there was a negative association as hypothesized. Effect sizes for the remaining respective *c* paths were d=.20 for *Fatty* (small-medium), d=-.27 for *Fast food* (small-medium), and d=.15 for *Total* (small).

The effect sizes for the total indirect effects of each model were > .1. Specifically, the calculated Cohen's d for the total indirect effect of group on *sweet* food consumption via WP hedonic appetite was .10 (medium). Cohen's d for the total indirect effect of group on *Fatty* food consumption via WP hedonic appetite was .11 (medium). Cohen's d for the total indirect effect of group on *Fast food* consumption via WP hedonic appetite was -.16 (medium based the squared standards for indirect effects). Lastly, Cohen's d for the total indirect effect of group on *Total* food consumption in the taste test was .07 (small).

Table 4

Effect Sizes for Exploratory Mediation Analyses (Aim 2)

	Cohen's d (95% CI)			
	a path	*b* path	*c'* path	Indirect effect *(ab)*
Model for dependent variable:				
Sweet	0.36 (-0.27, 0.98)	0.27 (-0.36, 0.89)	-1.37 (-2.06, -0.68))	0.10
Fatty	0.36 (-0.27, 0.98)	0.33 (-0.29, 0.95)	0.20 (-0.42, 0.82)	0.11
Fast Food	0.36 (-0.27, 0.98)	-0.44 (-1.07, 0.18)	-0.27 (-0.89, 0.36)	-0.16
Total	0.36 (-0.27, 0.98)	0.20 (-0.42, 0.82)	0.15 (-0.47, 0.77)	0.07

Note. CI = Confidence Interval. The *a* path refers to the association between Group (Intervention vs. Control) and WP hedonic appetite. The *b* path refers to the association between WP hedonic appetite and the food consumption dependent variable in the taste test, accounting for Group. The *c'* path refers to the association between Group and the food consumption dependent variable in the taste test. (See Figure 1).The indirect effect refers to the effect of Group on the food consumption dependent variable via the proposed mediator, hedonic appetite. Effect sizes are interpreted as absolute values. Cohen's d cutoffs *a, b, c:* .1 small, .39 medium, .59 large*;* Cohen's d cutoffs *ab*: .01 small, .09 medium, .25 large.

Results of the Monte Carlo post hoc power analyses for each path are presented in Table 5. For each mediation model predicting *Sweet*, *Fatty*, *Fast food*, and *Total* calorie consumption respectively to be fully powered it would take a sample size of over 5,000 participants. However, some of the model paths reached .80 power with predicted sample sizes smaller than 5,000 (see Table 5).

Table 5

Results of Monte Carlo Power Analyses

	Required sample size for .8 power			
	a path	*b* path	*c'* path	Indirect effect *(ab)*
Model for dependent variable:				
Sweet	**2,000**	>5,000[b]	**200**	>5,000[c]
Fatty	**2,000**	>5,000[a]	>5,000[b]	>5,000[b]
Fast Food	**2,000**	**1,000**	>5,000[b]	>5,000[a]
Total	**2,000**	>5,000[b]	>5,000[b]	>5,000[b]

Note. Power simulations were discontinued at 5,000 participants. Superscripts indicate power reached at 5,000 participants: a = .60 power, b = .20-.59 power, c = <.10 power. Bold numbers indicate the sample size resulted in .80 power for the specific model path.

Discussion

The present study piloted a novel combination of daily diary assessment and randomized experimental methodology to explore whether state hedonic appetite could be manipulated via a GNG inhibitory control training intervention in a sample of adolescents. This research question was part of a larger proposed mediation model for which effect sizes were calculated and post hoc power analyses were conducted. These exploratory analyses estimated whether changes in hedonic appetite influenced types of palatable food consumption, and the individual respective relationships between Group (Intervention vs. Control), WP hedonic appetite, and *Sweet, Fatty, Fast Food,* and *Total* calories consumed.

Discussion of Primary Findings

The participants randomized to the GNG Intervention group did not experience a significant decrease in WP hedonic appetite as compared to the Control group. Therefore, the main hypothesis was not supported. Although our previous work has found support for the fluctuating nature of hedonic appetite in adolescents (Bejarano & Cushing, 2018), it had not been determined whether the variable could be intentionally manipulated. A recent study used similar procedures using an internet-based GNG intervention in adults to target attention bias for highly palatable food and intention to eat unhealthy food. Interestingly, the researchers found that the Intervention GNG group did report lower intention to eat unhealthy food as an effect of the training, but the intervention also unexpectedly resulted in a heightened attention bias to highly palatable food (Love, Bhullar, & Schutte; 2020). It is possible that attentional processes also play a role in GNG hedonic appetite paradigms. If the GNG intervention were to heighten attention toward palatable food (rather than decrease it), consistent with Love, et al.'s findings, a decrease in WP hedonic appetite would not necessarily be expected. In other words, the GNG Intervention may potentially decrease palatable food consumption (Folkvord, Veling, & Hoeken, 2016; Veling et al., 2017), but the mechanism by which this occurs does not appear to be decreased hedonic appetite or less attention towards palatable food stimuli. Although the GNG task is intended to train attention away from these stimuli, it is still possible that mere exposure to food stimuli has an effect, such as is proposed to be the case in a Stop-signal inhibitory control training task (Veling et al., 2017). The Stop-signal task is thought to illicit an "action cancellation" response to food stimuli, meaning that the participant must stop the prepotent response to a food stimulus after has been initiated (Eagle, Bari, & Robbins, 2008). This process is sometimes thought to make Stop-signal training less effective than GNG training (Jones et al., 2016; Veling et al., 2017), and can also increase attention *towards* the no-go food cues, since participants must be aware of them in order to cancel their prepotent response. In contrast, the GNG task is thought to illicit an "action restraint" with bottom-up processing of the food stimuli. However, it is possible that some inadvertent increased attention towards food stimuli still occurs in *both* Stop-signal and GNG inhibitory control training tasks. This is a possible explanation for the GNG intervention's lack of expected decreased effect on attention towards palatable food and WP hedonic appetite.

Though the GNG inhibitory control training intervention did not show evidence of successfully manipulating WP hedonic appetite in this study, this appears to be related to the nature of the intervention itself, rather than the presence of the state/trait elements of hedonic appetite. Based on our past work, hedonic appetite is still considered to include both state and trait components. Continued work examining the fluctuating nature of the variable, and whether the state processes can be manipulated by another invention, is still warranted. For example, it is possible that increased "dose" of the intervention through longer duration or multiple sessions, alternate methods of capturing state change, and other conceptualizations of how to intervene on hedonic appetite are potential avenues for this research that could be considered.

Discussion of Exploratory Findings

Results of exploratory analyses in the present study yielded effect sizes and sample size estimates for fully-powered studies, for each respective path of the mediation models. The relationships between WP hedonic appetite and the categories of food consumption (*b* paths) yielded some small to medium effect sizes for *sweet*, *fatty*, and *total* food consumption, and one medium-large effect size for *fast food*. The largest effect size, for the relationship between WP hedonic appetite and *fast food* consumption, was negative, indicating that greater WP was related to less consumption. However, the results included very large confidence intervals which lead to non-significant effects. Still, the power analyses indicated that for the relationship between WP hedonic appetite and *fast food*, a sample size of 1,000 participants would yield .80 power to detect a significant effect. This exploratory result fits with our past research finding that WP hedonic appetite and autonomous dietary motivation were negatively associated with self-reported *fast food* consumption. It appears that the state component of hedonic appetite may have potential to influence this category of food consumption in particular. The previous findings suggest that it may be important to assess how WP hedonic appetite interacts with more stable traits to predict consumption. Further investigation of WP hedonic appetite and *fast food* consumption in a naturalistic setting using ecological momentary assessment while accounting for trait variables may help elucidate this process.

Regarding the relationships between GNG Group (Intervention vs. Control) and food consumption in the taste test (*c* path), the exploratory results for *sweet* food consumption stand out as potentially promising. There was a large effect size suggesting the GNG intervention could result in less *sweet* food consumption as compared to the control group. Additionally, the power analyses estimated that a sample size of 200 participants would provide sufficient power to detect a significant effect. This finding aligns with those of Houben & Jansen (2011) who found a GNG intervention significantly reduced chocolate consumption in adults a lab taste test, as compared to a control group. Additionally, a study in children found a GNG intervention to reduce candy consumption (Folkvord, Veling, & Hoeken, 2016). This pattern of evidence justifies further investigation of GNG interventions on *sweet* food consumption in particular.

Although there may be some research questions for further exploration within the respective associations of WP hedonic appetite and palatable food consumption, and GNG training and palatable food consumption, evaluation of the full mediational models suggests that hedonic appetite is likely not the mechanism by which GNG training confers an effect on consumption. As mentioned previously, the manner in which inhibitory control training functions (*e.g.*, top-down or bottom-up) is an important topic of discussion that will continue to inform future research. One difference in the conceptualization of the study described previously by Love et al. (2020) and the present study is that the former proposed that the GNG Intervention functioned through a top-down inhibitory control process. The researchers interpreted the significant effects on explicit intentions to eat less unhealthy food as evidence of the GNG training functioning as a top-down process. In contrast, the present study proposed that the GNG Intervention functioned via a bottom-up process trained to create more automatic ignoring of food stimuli. While this conceptualization remains consistent with Appelhans' neurobehavioral inhibitory control model of feeding (2009) in that inhibitory control and hedonic appetite are key interacting drivers of food consumption, they may not function in the manner hypothesized in the present study.

In addition to proposals that GNG training functions as bottom-up vs. top-down, it has also been considered to function as a devaluation process (Veling et al., 2017). Love et al. (2020) also comment on moving away from the top-down/bottom-up dichotomy and acknowledged that in experimental studies, attention bias on its own has had mixed associations with palatable food intake (Hardman, Rogers, Etchells, Houstoun, & Munafò, 2013; Kemps, Tiggemann, Orr, & Grear, 2014). Even studies that found some evidence for the top-down process acknowledge that it could be due to learning or devaluation of highly palatable foods, as changes in implicit learning can simply be reflected in explicit intentions about food consumption (Legget, Cornier, Rojas, Lawful, & Tregellas, 2015). It is possible that inhibitory control has components of both top-down intentional and bottom-up automatic processes (Howard, Johnson, & Pascual-Leone, 2014; Love et al., 2020). If this were the case, lack of hedonic response to a food stimulus might be a more automatic component, while effortful control during occasions of high hedonic appetite might be a more intentional component.

Finally, while inhibitory control is often the mechanism by which individuals abstain from palatable food consumption, it is not the *only* mechanism. Attention allocation plays a key role, and attention is often allocated towards rewarding palatable food stimuli. Therefore, decreasing the reward value of the stimuli, rather than training or re-allocating attention, may be at the core of these processes. In other words, rather than targeting top-down or bottom-up *attention,* interventions may need to focus on the *reward value* of palatable food. For example, exposure to food stimuli and habituation of response, as well as priming effects (Watson, Wiers, Hommel, Ridderinkhof, & de Wit, 2016) could lesson an overall reward response to certain palatable foods.

Study Strengths

The current project is innovative in terms of the hypothesized effects that were evaluated in an under-studied youth population, as well as the novel methodology by which they were evaluated. The design and methods attempted to address limitations of previous daily diary and ecological momentary assessment studies by combining daily assessment with a controlled experimental design in a lab setting (Manasse et al., 2015). The use of daily data capture through technology-based daily diary assessments was relatively novel, as many studies utilize a single assessment of the constructs of interest. The laboratory procedures are innovative as well, as they are tailored to resemble an adolescent's true experience of palatable food consumption, such as eating preferred foods of choice while comfortably watching a television show. The project methodology is an overall strength, as each component (*e.g.*, type of inhibitory control training, procedures of bogus taste test, construct measurement) was carefully chosen based on the most relevant and recent evidence available at the time of the study design. Moreover, the randomization and equal group distribution resulted in minimal concern about potential confounders of the hypothesized effects. Lastly, the formulation of *a priori* hypotheses of true sequential mediation are a strength of the study.

Study Limitations

A main limitation of the present study is the small sample size, which was an unanticipated change to the original proposed study that occurred as a result of the 2019-2020 coronavirus pandemic. Institutional policy required that the study close (University of Kansas, 2020); therefore, the study was necessarily underpowered. The analysis plans were adjusted so that effect sizes and power calculations were conducted for underpowered effects. Along with the sample size limitation, the participants in this study were predominantly Caucasian, female, and from higher income households. Recruiting more demographically diverse and underrepresented individuals is a necessary focus for future research in this area.

Additional limitations are related to the study variables. Hedonic appetite for the sample was relatively low (*M*=1.75). Though this average is consistent with our previous study in adolescents (Bejarano & Cushing, 2018), the overall low grand-mean may have limited the potential to detect significant effects pertaining to within-person hedonic appetite. Future work may target individuals reporting higher levels of hedonic appetite that relate to problematic eating behaviors. Additionally, the *Starchy* dependent variable violated assumptions of normal distribution and was not used in the main analyses. Similarly, it was not possible to account for all potential influences on individual food environments across home, school, and other contexts. However, the randomization process in the present study likely accounted for effects of this nature.

Lastly, the manner in which the meal shake was implemented is a potential limitation, as some protocols match standardized calorie intake prior to a bogus lab taste test on individual energy needs (Robinson et al., 2017). Procedures of this nature allow for more precision in ensuring each participant has comparable levels of homeostatic satiation prior to the task.

Conclusion and Future Direction

Results of exploratory analyses in the present study indicated that it may require 2,000-5,000 participants to be able to detect significant effects for pathways in the hypothesized mediational models. While a study of this magnitude is not necessarily feasible, we may consider a study of 2,000 *observations,* rather than *participants* as a future step to fully test these research questions. Such a study could be achieved through ecological momentary assessment (EMA). For example, an EMA study of 50 adolescents reporting hedonic appetite and dietary intake twice per day for 20 days would yield 2,000 total observations. Besides providing a feasible method for obtaining the number of data points for adequate power, it is possible that a complete EMA methodology may be necessary for to fully address research questions pertaining to WP hedonic appetite in future studies. The present study piloted an innovative hybrid methodology (daily diary and experimental laboratory study), but a study in which the data capture, intervention, and assessment occurs through EMA methodology may be more well-suited for continued investigations. In other words, both the manipulation and data collection need to occur in a longitudinal space. This is especially relevant as recent research still questions how long the effect of a GNG intervention can be expected to last. In terms of “dose” of an intervention, previous work has found that even a single-session attention modification training intervention for food cues resulted in decreased calorie intake and eating in the absence of hunger for children with obesity, as compared to a control attention intervention group (Boutelle, Kuckertz, Carlson, & Amir, 2014). However, examining this intervention’s effect at increased doses, particularly on within-person processes, is still warranted. Inhibitory control and its relationships of interest have been measured successfully via EMA (Jones, Tiplady, Houben, Nederkoorn, & Field, 2018). Knowing that individual differences (*e.g.*, motivation, weight status, intentions to restrict intake) affect both dietary behavior (Mason, Do, Wang, & Dunton, 2020) and the outcome of GNG interventions (Jones et al., 2016), capturing this more fully via EMA appears to be a promising avenue. In conjunction with this, some work has used internet platforms (Veling et al., 2014) and video games (Poppelaars et al., 2018) as methods of administering GNG interventions, which may be promising for future EMA protocols. Indeed, modern technology allows for high-level data capture that provides a more nuanced and accurate understanding of human behavior through mobile interventions and eHealth/mhealth approaches (Cushing, Monzon, Ortega, Bejarano, & Carlson, 2019; Riley et al., 2011). A consistent use of this approach could likely increase clarity of findings in this area of research, as interpretation of the results of the present study were based largely on existing group-level studies of related research questions.

Future clinical applications for continued research in this area include a focus on mindful decision making (Forman et al., 2016), state and trait improvements in mindfulness (Kiken, Garland, Bluth, Palsson, & Gaylord, 2015), or the role of affect regulation (Hoffman, Friese, & Roefs, 2009). Mindful decision-making training was found to be more effective for reducing hedonically-based eating particularly for individuals with high emotional eating, and may therefore be more appropriate for clinical populations than inhibitory control training (Forman et al., 2016). Mindfulness meditation interventions have shown improvements in state mindfulness leading to a trajectory of increased trait mindfulness, suggesting a promising application for ecological momentary assessment and interventions for mindful eating (Kiken et al., 2015). Similarly, inhibitory control training or similar interventions could be used to target affect regulation as a manner of minimizing automatic affection reactions that lead to increased hedonic palatable food consumption (Hoffman, Friese, & Roefs, 2009).

An improved approach for future research would be to measure individual differences and state processes in real time, design adaptive interventions based on these, and assess outcomes in the same intensive longitudinal framework. Research of this nature is valuable in understanding micro temporal processes of eating behavior that can further inform theoretical models (Mason et al., 2020). Current work in EMA protocols for eating and health behaviors (Dunton et al., 2014; Mason et al., 2020) and just-in-time-adaptive interventions that adapt to individual users over the study period (Spruijt-Metz & Nilsen, 2014) provide models that can be applied for future studies examining hedonic appetite, inhibitory control, and palatable food consumption in adolescents.

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Appendix A: *Food-pics* images

Images used for the food and animal stimuli in the GNG tasks were used with formal approval from a food-pics image database designed to facilitate standardization and comparability across studies of eating behavior:

Blechert, J., Meule, A., Busch, N. A., & Ohla, K. (2014). Food-pics: an image database for experimental research on eating and appetite. *Frontiers in Psychology, 5*, 617. https://doi.org/10.3389/fpsyg.2014.00617

The following specific *food-pics* image numbers were used in this study. Images of gummy bears (0157) and horse (1167) appear in Figures 3 and 4:

0026 potato chips
0046 fried
0053 hotdog
0061 pizza
0065 burger
0073 pasta
0157 gummy bears
0169 donut
0296 M&Ms
0298 cookie
0300 bread
0372 cereal
0488 waffle
0563 steak
1160 rhino
1161 fish1
1162 fish2
1167 horse
1171 elephant
1177 chick
1181 dog1
1179 dog2
1180 dog3
1183 fox
1184 polar bear
1185 cat
1186 dog4
1189 penguin
1192 frog
1193 bird