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THE EFFECTS OF SEX AND PUBERTY ON FOOD CRAVINGS AND LOSS OF CONTROL EATING AMONG YOUTH IN THE NATURAL ENVIRONMENT AND LABORATORY

by

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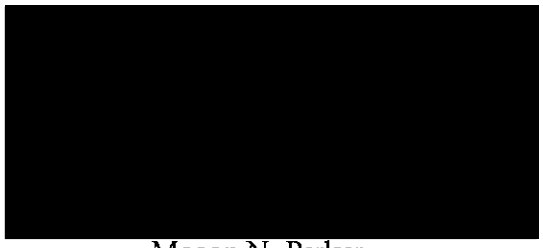

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ABSTRACT

The Effects of Sex and Puberty on Food Cravings and Loss of Control Eating Among Youth in the Natural Environment and Laboratory

Megan N. Parker, M.S., 2020

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Food cravings are cross-sectionally and prospectively associated with increased food consumption and weight gain, irrespective of body mass index, among children and adults. Preliminary research suggests food cravings may also be linked to loss of control (LOC)-eating in adults, but research among youth is nascent. Biological and psychological changes during puberty may strengthen the link between food cravings and LOC-eating. As such, the current study utilized ecological momentary assessment (EMA) and laboratory test meal methodologies to compare the relationships between food cravings and LOC-eating in male and female youths and in youth at different pubertal stages. In the natural environment, momentary craving, hunger, and degree of LOC-eating were rated multiple times a day during a two-week EMA protocol. In the laboratory, youth rated food cravings prior to a test meal designed to simulate a LOC-eating episode. Immediately after, youth rated the degree to which they experienced LOC-eating during the meal. Participant's sex and pubertal stage were determined during

a physical exam (girls: breast Tanner staging, boys: testicular volume). EMA data were analyzed by generalized linear mixed models and test meal data were analyzed by multiple linear regressions. All analyses adjusted for hunger. Participants were 87 healthy males and females between the ages of 8 and 18 years (12.98 ± 2.68 years, 58.6% female, 48.3% non-Hispanic White, 0.57 ± 1.11 BMIz). Twelve subjects were in the pre-pubertal, 19 mid-pubertal, and 56 late-pubertal stage. Higher two-week average and momentary food cravings were related to greater LOC-eating severity in the natural environment (*ps* < .01), but these relationships did not differ by sex (*ps* = .10-.97). Puberty moderated the relationship between two-week average cravings and LOC-eating such that two-week average cravings were more strongly associated with greater LOC-eating for pre- compared to mid- (p = .01) and late-pubertal youth (p = .01) and mid-pubertal youth did not differ from late-pubertal youth (p = .48). During the test meal, pre-meal cravings were positively related to greater LOC-eating during the meal (p <.01), but there were no differences by sex (p = .24) or pubertal group (p =.13). Together, results from the current study suggest that food cravings are related to LOC-eating in youth, but this relationship does not appear to differ by sex. Further, among pre-pubertal youth, higher general levels of cravings were more strongly positively associated with LOC-eating severity in their natural environment, but the relationship between momentary cravings and LOC-eating did not differ by pubertal status in either the natural environment or the laboratory. Additional studies are needed to clarify the mechanisms through which food cravings promote LOC-eating in individuals throughout the lifespan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

LOSS OF CONTROL EATING IN CHILDREN AND ADOLESCENTS

Binge-eating is defined by consuming an objectively large amount of food in a relatively short period of time while experiencing a sense of loss of control while eating (1) and is the key diagnostic feature for numerous eating disorders including binge-eating disorder, bulimia nervosa, anorexia-binge/purge subtype, and some otherwise specified feeding and eating disorder diagnoses (1). Loss-of-control eating (LOC-eating) is defined as feeling unable to control what or how much one eats and is often characterized by one or more of the following: feeling unable to stop eating after starting, feeling unable to keep oneself from beginning to eat, feeling driven or compelled to keep eating (1). Although it is a diagnostic criterion for binge-eating, LOC-eating is a distinct phenomenon that can occur separate from other diagnostic features. For example, over time overeating episodes tend to remit naturally (38) whereas LOC-eating tends to persist or worsen for approximately 50% of youth (19; 38; 105; 116). Youth who report objectively large overeating episodes (i.e., eating an amount of food in one sitting that is unambiguously large) tend to be more similar to youth who deny LOC-eating and overeating episodes, on measures of adiposity, mood symptoms and eating pathology (118). Similarly, youth who report LOC-eating while consuming smaller amounts of food tend to be more similar to youth who experience LOC-eating while consuming objectively large amounts of food than youth who deny LOC-eating (112; 118). These findings suggest that, among youth, the presence of LOC-eating is a more important indicator of disordered eating than the size of the LOC-eating episodes (32; 35; 72; 98; 111; 118). As such, detecting factors associated with feeling out of control while eating,

regardless of the amount consumed, may be paramount for identifying which youth are most at risk for developing binge-eating in adulthood.

Children as young as eight years of age have reported LOC-eating (96; 118), and approximately 12-48% of children and adolescents of all weight strata experience LOC-eating (19; 35; 37; 110-112; 115). In addition to its high prevalence among children and adolescents, it is associated with numerous health consequences. Cross sectional studies indicate that youth who report LOC-eating have poorer physiological and metabolic health (78; 90; 117), higher fat mass and body mass index (32; 35; 80; 96; 98; 112; 118) and worse cardiovascular health (32) compared to peers who do not experience LOC-eating. Among youth, LOC-eating is also associated with poorer psychological health including higher depression (35; 39; 98), anxiety (80; 98), and eating disorder cognitions (35; 39; 80; 96; 98; 118). Prospective studies show that youth who report LOC-eating tend to experience poorer psychosocial outcomes (32; 103; 105; 116) and are likely to develop a partial- or full-syndrome binge-eating disorder 5-10 years later (46; 47; 105; 116). Importantly, onset of these full syndrome eating disorders does not typically occur until 18-20 years of age (52; 57; 105), and is rare prior to pubertal onset (58) rendering childhood and adolescence critical periods for identifying individuals who experience LOC-eating and are therefore at increased risk for developing a binge-eating disorder in adulthood.

Sex Differences in Loss of Control Eating Prevalence

Certain subsets of youth may be at heightened risk for LOC-eating, simply because of their sex. There are well established sex differences in the prevalence of eating disorders, with adult females being two to ten times more likely than adult males

to have an eating disorder (1; 52; 59). However, prior to adulthood the impact of sex on LOC-eating may be more complex. Some studies that examined self-reported LOC-eating found higher prevalence rates of LOC-eating among females than males throughout development (27; 103). However, sex differences in prevalence of LOC-eating are less pronounced prior to adulthood (59) and studies utilizing more rigorous diagnostic methods (i.e., clinician rated interviews) have observed similar prevalence rates among males and females in early to middle childhood (77; 111; 112) and early adolescence (39; 112) with sex disparities emerging in middle to late adolescence (11; 27). This pattern suggests that when examining risk factors for LOC-eating in male and female youth, one must also consider developmental stage. Indeed, prospective studies have identified puberty as a significant contributor to LOC-eating development in both boys and girls (18; 86). However, the sex differentiated prevalence of eating disorders in adults suggests puberty may be an especially critical developmental period for females.

LOSS OF CONTROL EATING AND PUBERTY

One sex differentiated factor that varies across pubertal development is gonadal hormones (e.g., estrogen, progesterone, and testosterone). Combined estrogen and progesterone drive pubertal development in girls, whereas testosterone drives development in males. Emerging research supports the notion that these hormonal differences may, in part, underlie sex differentiated risk for LOC-eating during puberty. For instance, during puberty estrogen and progesterone have been linked to increased sensitivity to psychological and social risk factors (58; 71; 100; 123) and increased genetic influences on LOC-eating in girls (58; 71; 100; 123), whereas testosterone appears to lower risk for LOC-eating (22; 59-61). Although studies testing why this

occurs are scarce, some have hypothesized that gonadal hormones may promote LOC-eating during puberty by increasing one's neurobiological sensitivity to the rewarding and pleasurable aspects of palatable foods (71). However, no study to date has examined if increases in desire to consume palatable food are disproportionately linked to LOC-eating during later pubertal development.

FOOD CRAVINGS AND LOSS OF CONTROL EATING

Food cravings (130), or an intense desire to consume specific palatable foods, are conceptualized as a motivational state driven by a desire to obtain pleasure or reward from food (49). Food cravings are more intense and specific in nature than hunger (49) and have been reported by a wide range of individuals including: children and adolescents, adults, individuals with overweight, individuals with healthy weight, males, females, individuals of different races, and individuals with and without eating disorders. Given their cross sectional (8; 14; 50; 67; 74; 76; 99; 126) and prospective (8) relationships with increased weight and food intake and adults and youth, food cravings are theorized to be key factors in etiological models of obesity (8).

Food cravings have also been implicated in developmental and maintenance models of binge-eating (63; 87). Indeed, food cravings are associated with binge-eating in adults without eating disorders (12; 14; 55) and in adults with bulimia nervosa and binge-eating disorder (41; 54; 79; 82; 102; 124). Preliminary studies have also reported a positive relationship between food cravings and LOC-eating in youth with overweight (9; 36), signifying cravings as a potentially important intervention target for treatments that aim to reduce excess weight. However, studies have not yet tested cross sectional relationships among craving and LOC-eating in youth with healthy weight. To establish

if food cravings are a relevant target for the prevention of obesity and binge-eating disorders, examinations in youth across the weight spectrum are needed.

FOOD CRAVINGS BY SEX AND PUBERTY

The consistent relationships between food cravings, food intake and binge-eating in adults across weight strata, suggest similar relationships should be observed in youth, regardless of weight status, but similar to LOC-eating prevalence, food cravings may differ by sex and pubertal status. In adults, food cravings differ in nature, frequency, and intensity in males and females (12; 43; 67; 84; 126). In general, females tend to crave sweet, fat, and carbohydrate rich foods (which are often consumed during LOC-eating episodes), whereas males crave savory, protein rich foods (13; 40; 43; 56; 94; 130; 134). Females also report more frequent and intense food cravings (43; 67; 126; 130), and negative emotions when indulging in cravings (67). Studies have also reported stronger associations among food cravings and overall eating disorder pathology (13; 51; 53). There has been inconsistent findings on sex's impact on the relationship between food cravings and binge-eating with one study reporting a stronger relationship among females (102) and another reporting no differences by sex (13). Nevertheless, all studies to date that have directly tested the impact of sex on food cravings and LOC-eating have been conducted among adults. Thus, the extent to which these relationships may differ between boys and girls is unknown.

Food cravings may also become more strongly linked to LOC-eating during later pubertal development. Changes in gonadal hormones are associated with increases in the rewarding and appetizing value of food (4; 71). Specifically, estrogen and progesterone appear to underlie susceptibility to food cravings (10; 16; 28; 43; 65; 94; 122) and LOC-

eating in post-menstrual women (23; 62). Following menstrual onset, progesterone and estrogen fluctuate on a monthly cycle. During different phases of the cycle, LOC-eating frequency changes (62), as does preference for and consumption of sweet, fat, and carbohydrate rich foods (10; 16; 40; 56; 65; 94; 122). Menstrual onset occurs as part of normal pubertal development, typically around the age of 12-13 (15; 85), therefore, it is possible that girls in the later stages of puberty, who are more likely to have started menstruating, may experience stronger food cravings compared to younger peers.

Relatively little is known about how testosterone impacts food cravings among males in adulthood or youth. Testosterone stimulates food intake (30) and increases dramatically in boys from pre-puberty to adulthood (5; 108). As such, males in later stages of pubertal development may experience increased drives to consume food compared to their younger counterparts, although this has yet to be tested.

Notably, all healthy youth undergo pubertal development, but not all healthy youth experience LOC-eating or develop a binge-eating disorder. However, youth who experience overall stronger food cravings compared to their peers, both within and across pubertal stages, may be more likely to feel out of control while eating. Similarly, youth who experience larger momentary spikes in food cravings may experience greater LOC-eating. Therefore, examining the impact of sex and pubertal stage on both general levels of food cravings and momentary levels of food cravings may provide a more comprehensive understanding of which youth may be most at risk for LOC-eating.

METHODOLOGIES FOR ASSESSING LOSS OF CONTROL EATING

Early identification of risk among youth is key for preventing the development of eating disorders. Therefore, it is imperative to utilize assessments of LOC-eating that are

most sensitive to detecting experiences of feeling a sense of loss of control while eating in youth. Previous research suggests that clinician administered interviews are a superior assessment modality compared to self-reported measures (119). However, even the most empirically supported interview, the Eating Disorder Examination (20), has limitations; primarily it requires youth to retrospectively recall experiences that occurred over the previous one to three months. Youth are particularly poor at reporting on eating behaviors (131) thus, modalities that reduce the amount of time between the eating event and reporting it may be particularly useful for capturing psychological experiences in girls and boys.

Two commonly used methodologies that reduce time between eating and an individual's report of experiences during the meal are ecological momentary assessment (EMA) and laboratory test meals. EMA uses intensive repeated measurements to capture psychological experiences (e.g., cravings for food, emotional states) and occurrence of behaviors (e.g., eating episodes, physical activity) as they happen in the moment in one's natural environment. EMA is a methodological approach that has less control over confounding influences on one's experiences or behaviors, but high ecological validity (i.e., generalizable to real life settings) (101). EMA has been used extensively to examine binge-eating in adults with eating disorders (26; 42) and general eating behaviors in youth (75). Few studies have specifically assessed LOC-eating in children and adolescents using EMA, but preliminary studies have demonstrated excellent acceptability and feasibility (36; 48; 91).

Alternatively, laboratory based test meals have been used to measure eating behaviors in children and adolescents (113). Test meals are often used to measure energy

intake but are less frequently used to examine the cognitive correlates of eating episodes. However, similar to EMA, laboratory-based assessments of eating can be used to assess both behaviors (e.g., food choices, consumption of snack foods) and psychological experiences (e.g., affect, hunger, stress) prior to, during, and following an eating episode. In contrast to EMA, examining eating in a laboratory provides a standardized environment in which behaviors are measured, thus eliminating potential influences of contextual differences at the time of the meal. However, laboratory meals are limited because they only measure one instance of eating over a relatively short time period in an artificial environment. Given the complementary strengths and weaknesses of both methodologies, integration of EMA and in-laboratory data collection may provide a more comprehensive examination of the experiences that precede feeling out of control while eating.

RATINGS OF MOMENTARY LOSS OF CONTROL EATING IN YOUTH

Another consideration when examining LOC-eating in youth is the appropriateness of the scale on which individuals report LOC-eating. Multi-dimensional measurements of LOC-eating have been proposed (6; 68), but despite demonstrating adequate psychometric properties and convergent validity, dichotomous classifications of LOC-eating are generally sufficient for detecting youth with clinically significant LOC-eating (111; 116). As such, diagnoses of LOC-eating and binge-eating (1) require a clinician to make a yes/no decision about whether an individual experienced a sense of loss of control during reported eating episodes.

Contrary to diagnostic interviews, studies utilizing EMA have typically required participants to rate experiences of LOC-eating on a dimensional scale. In studies among

adults with eating disorders, dimensional ratings are typically dichotomized for analyses with a rating of three or higher, on a one to five Likert scale, usually indicating a LOC-eating episode occurred (3; 33; 133). In adults diagnosed with eating disorders, this method has demonstrated adequate concordance with frequency of binge-eating, as measured by clinical interviews (133). However, dimensional ratings of LOC-eating have been examined in EMA studies among non-clinical samples of college students (45), youth with overweight or obesity (36; 91) and youth with LOC-eating (91). Although, one study did examine absence or presence of any amount of LOC-eating (34), a clinically sufficient threshold has not yet been determined or validated in non-clinical youth samples. Thus, the appropriateness of applying clinical cutoffs for categorizing the clinical significance of LOC-eating that were established in adult eating disorder samples to generally healthy youth remains unknown.

Additionally, assessing LOC-eating dichotomously in clinical interviews may be sufficient for identifying youth experiencing clinically significant LOC-eating, however, it may not be fully sensitive to detecting youth who do not currently meet clinical threshold, but are at risk for developing clinically significant LOC-eating in the future. When examined continuously, ratings of LOC-eating reported during an EMA protocol did not differ between youth who did and did not report LOC-eating during a clinical interview (36). It is possible that a subset of individuals do not understand what is being assessed and therefore mistakenly endorse LOC-eating. Alternatively, dimensional measurements of LOC-eating during an EMA protocol may be a more sensitive measure for identifying individuals with a stronger proclivity to feel out of control while eating, even if it does not meet a clinically significant threshold. Given the importance of

identifying etiological factors of LOC-eating among youth, assessment of LOC-eating severity, rather than presence or absence of LOC-eating may help elucidate which youth are most at risk.

Similarly, studies that have utilized laboratory-based test meals have tended to examine LOC-eating as dichotomous construct (113; 114; 121). Typically, these studies have compared the energy intake of youth who report LOC-eating and youth who deny LOC-eating in a separate interview. Similar to EMA, although not tested, some youth who deny LOC-eating in an interview may report LOC-during a test-meal. Thus, examining differences in predetermined groups of youth may obscure detection of youth who feel some degree of loss of control while eating. Given the importance of LOC-eating rather than overeating, for the development of binge-eating disorders, the current study sought to examine severity of LOC-eating during EMA and a laboratory-based test meal, rather than group differences in energy intake among youth who reported and denied LOC-eating during an interview.

THE CURRENT STUDY

Given the salience of food cravings on eating behaviors and the potential impacts of sex and puberty on these relationships, the current study aimed to utilize a combination of EMA and laboratory methodologies to investigate the associations between food cravings and LOC-eating among youth by sex and across pubertal stages.

AIMS AND HYPOTHESES

Aim 1. Investigate the relationships between food cravings and LOC-eating in male and female youths in the natural and laboratory environment. *Hypothesis 1a:* In the natural environment, youth with higher general food cravings (i.e., a person who has a

higher average level of craving compared to the sample's average level of craving) will report greater LOC-eating severity during a two-week EMA period. *Hypothesis 1b:* In the natural environment, greater within-subject food cravings (i.e., increases in a person's momentary level of cravings compared to their average level of cravings) will be associated with greater LOC-eating severity during the next eating episode. *Hypothesis 1c:* Youth experiencing greater food cravings immediately prior to a test meal will report greater LOC-eating severity during the meal.

Aim 2. Determine if sex moderates the relationships between food cravings and LOC-eating severity both in the natural environment and during a laboratory-based test meal. *Hypothesis 2a:* In the natural environment, associations between general food cravings and LOC-eating severity will be stronger for females than males. *Hypothesis 2b:* In the natural environment, associations between momentary food cravings and LOC-eating at the next eating episode will be stronger for females than males. *Hypothesis 2c:* Associations between pre-test meal food cravings and LOC-eating severity during the test meal will be stronger for females than males.

Aim 3. Determine if pubertal status moderates the relationships between food cravings and LOC-eating severity both in the natural environment and during a laboratory-based test meal. *Hypothesis 3a:* Associations between general food cravings and LOC-eating severity will be stronger among youth in later stages of pubertal development compared to youth in previous stages (i.e., the relationship will be stronger among post pubertal youth compared to mid- and pre-pubertal youth and stronger among mid-pubertal youth compared to pre-pubertal youth). *Hypothesis 3b:* Associations between momentary food cravings and LOC-eating at the next eating episode will be

stronger among youth in later stages of pubertal development compared to youth in previous stages. *Hypothesis 3c:* Associations between pre-test meal food cravings and LOC-eating severity during the test meal will be stronger among youth in later stages of pubertal development compared to youth in previous stages.

CHAPTER 2: METHODS

PARTICIPANTS

A convenience sample of non-treatment-seeking youth was recruited via flyers and mailings for the Children's Growth and Behavior Study (Clinical Trials Identifier: NCT02390765), which aims to understand how eating behaviors longitudinally impact weight gain in children and adolescents. Boys and girls were eligible at baseline if they were between the ages of 8 and 17 years. Exclusionary criteria included 1) current or past major or mental illness, brain injury, or pregnancy, 2) current use of medication known to affect body weight and food intake, 3) recent weight loss (>5% body weight) or body mass index <5th percentile for age and sex, 4) current or past use of illicit substances, and 5) a full scale intelligence quotient score <70. No additional inclusion or exclusion criteria were assigned for the current study's sample.

STUDY PROCEDURES

The study procedures were approved by the Institutional Review Board at the National Institutes of Health (15CH0096). All study appointments were conducted at the outpatient Pediatric Clinic at the National Institutes of Health Hatfield Clinical Research Center. At the first study visit, consent and assent were obtained from the parent/guardian and child, respectively. Participants then underwent a physical exam and completed a

semi-structured interview. Participants were also given the option to complete a two-week EMA protocol. When interested, youth were trained on completing the EMA protocol and were given an iPhone for the duration of the real-time, real-world data collection. Approximately two-weeks later participants returned to the laboratory, had their body composition measured, and partook in a test meal.

Ecological Momentary Assessment Procedures

To report craving and LOC-eating in the natural environment, participants completed EMA surveys for approximately 14 days. Consistent with prior research on children and adolescents with LOC-eating (36; 48; 91), the EMA protocol contained interval-contingent surveys (i.e., participants were instructed to complete a survey immediately after the end of school and before bed), signal-contingent surveys (i.e., participants received a notification instructing them to complete a survey), and event-contingent surveys (i.e., participants were told to complete a survey any time they ate or drank something they considered to be a meal or snack). Signal-contingent surveys were randomly delivered around stratified daily intervals, approximately 11:10am, 1:50pm, 3:30pm, 5:40pm, and 8:20pm. On weekends, participants were asked to complete one interval-contingent survey before bed and received five signal-prompted surveys between the hours of 11am and 9pm. On weekdays, the survey schedule was designed to minimize interference with school; participants were instructed to complete two interval-contingent surveys, one after school and one before bed, and received three signal-prompted surveys between the hours of 3pm and 9pm. Completion of event-contingent surveys were optional, but encouraged.

The day following the baseline visit participants practiced completing EMA surveys at home. If compliance on the practice day was poor (completed ≤ 80% of signal and interval contingent surveys) study personnel contacted the participant. A cut-off of 80% was chosen in accordance with previous guidelines for reporting EMA data (107). During this check in, study personnel discussed how to overcome barriers to compliance and participants were asked to complete an additional practice day. If compliance on practice days was >80% of signal and interval surveys, participants began the 14-day protocol. All EMA data were collected using the Real Time Assessment In the Natural Environment (ReTAINE) system (81). Compliance and compensation were based on number of completed signal-contingent and interval-contingent surveys. Participants were compensated up to $100 ($25/week and $50 bonus if compliance ≥ 80%) for completing the EMA protocol.

Laboratory Test Meal Procedures

Youths were instructed to fast overnight prior to the study visit. At approximately 10:00am, participants were given a breakfast shake. The amount was standardized by weight and the past week's average activity level. Between 11:00am and 12:00pm, participants were then presented with a buffet style test meal (~9,835 kcal) varying in food types (e.g., sliced bread, cheese slices, apple slices, sandwich cookies, jelly beans etc.), and macronutrient content (e.g., 54% carbohydrate, 12% protein, 33% fat). Youths were instructed to "let yourself go and eat as much as you want" then were left alone to eat. Before the test meal, participants reported on current levels of food cravings and hunger. After eating, participants indicated the degree to which they felt a sense of loss of control during the meal.

MEASURES

EMA and Test Meal Measures

Cravings, hunger, and LOC-eating were assessed using the same items during the EMA protocol and test meal, however, the rating scales varied slightly (described in detail below).

Food Craving

Current food cravings were measured by items adapted from the state version of the Food Cravings Questionnaire (79). Four items from the Intense Desire to Eat subscale were used to assess current cravings: "How strong is your desire to eat one or more specific foods?", "How much do you crave one or more specific foods?", "How strongly do you want to eat one or more specific foods?", and "How much does your desire or craving to eat have power over you?". Items were averaged to compute a composite score of food cravings. Internal reliability for EMA and pre-meal craving was excellent (Cronbach's alpha .95 and .92, respectively).

Loss of Control Eating Severity

To measure LOC-eating severity, items were adapted from the Eating Disorder Examination (EDE; 20) a widely used semi-structured interview used to assess presence of LOC-eating episodes. LOC-eating was assessed by the following questions: "How much did you lose control during this eating episode?", "Did you feel that you could not keep yourself from eating?", "Did you feel that you could not stop eating once you started?", and "During the eating episode you just finished, how much did you feel a sense of loss of control?", "How upset or distressed are you about how much you just ate?" and "How much did you feel driven to eat?". Previous EMA studies have deemed

these EMA items acceptable for children and adolescents (36; 91). The EDE and child version of the EDE have both demonstrated excellent test-retest and interrater reliability, internal consistency, and discriminant validity in adults, children and adolescents (31; 93; 118; 129). Items were averaged to compute a composite score of LOC-eating severity. Internal reliability for EMA and post-meal LOC-eating were excellent (Cronbach's alpha .89 and .85, respectively).

Hunger Item

A single item, "How hungry are you?" was used to assess current level of hunger.

Ecological Momentary Assessment Measurement Scale

When an eating episode was reported in the EMA protocol, participants were asked to rate the degree to which they experienced LOC-eating during that episode. Current food cravings and hunger were reported in signal-contingent and interval-contingent surveys. All questions utilized a 1 = 'not at all' to 5 = 'extremely' Likert-type scale.

Test Meal Measurement Scale

During the test meal, participants used paper and pencil to draw a vertical line indicating where they currently fell on 9.5 cm long Visual Analogue Scales for each craving, hunger, and LOC-eating item. A ruler was used to measure the distance between the left-most end of the scale and where participants drew a line bisecting the scale. The distance was then divided by the total length of the scale and multiplied by 100. Therefore, possible ratings ranged from 0 to100.

Measurement of Moderators

Sex

Participants self-reported their biological sex as either male or female. Biological sex was confirmed during the physical exam.

Pubertal Development

A medical physician or nurse practitioner confirmed biological sex and determined pubertal stage during the physical exam (7). For females, pubertal development was determined by breast development as measured by observation and palpation (73). Tanner stage one indicated pre-puberty, stages two and three indicated early to mid-puberty, and stages four and five indicated late-puberty. For males, pubertal development was determined by testicular volume (pre-puberty = ≤ 3 mL, early to mid-puberty = 4–12 mL, late-puberty = >12 mL) as measured by orchidometer beads and standards were according to Prader (109). When stages were discordant between the right and left breasts (or testes), the higher stage was assigned.

Measurement of Covariates

Parents self-reported the child's race, and ethnicity. Height was measured in triplicate to the nearest millimeter using a calibrated stadiometer. Fasting weight was measured in triplicate on a scale calibrated to the nearest hundredth of a kilogram (0.1kg). Standardized deviation body mass index scores (BMIz; kg/m^2) were calculated following Center of Disease Control and Prevention growth standards for age and sex (66). Total body fat mass (kg) was measured by dual-energy x-ray absorptiometry (DXA) using an iDXA system (GE Healthcare, Madison WI).

STATISTICAL ANALYSES

Analyses were conducted in SPSS version 25 and RStudio version 1.3.959 (89; 95).

Ecological Momentary Assessment Analyses

Surveys completed during practice days were removed and only protocol days were included in analyses. To test for differences in EMA measures of craving, hunger, and LOC-eating by sex and pubertal status EMA ratings were aggregated within-persons then averaged across the entire sample. Differences in LOC-eating severity, cravings, and hunger among sex and pubertal groups were tested with t-tests (Sex coded 1= males, 2 = females) and ANOVAS (puberty coded 1= pre, 2=mid, 3=late). Effect sizes for sex and puberty comparisons were determined by Cohen's d and partial eta-squared, respectively.

To examine if cravings were associated with LOC-eating in the natural environment generalized linear mixed models (GLMMs) were conducted. Ratings of cravings and hunger was lagged within person and within days. To examine the effects of cravings on LOC-eating severity at both a group and individual level, changes in between subject cravings (i.e., an individual's general level of craving compared to the entire sample's general level of craving) and within-subject cravings (i.e., momentary deviations from one's general level of craving) were calculated. Cravings decreased linearly across the EMA protocol; thus, expected levels of general and momentary cravings were calculated by individually regressing each subject's cravings on the number of the day in the study, centered on the first day (128). Participants' general levels and momentary levels of cravings were then centered on their personal intercept and regression slope, respectively. Thus, general levels of cravings represent an individual's level of craving on day one, compared to the full sample's level of craving

on day one. A participant's momentary level of cravings represented the difference between their reported level of craving and the level of craving they were expected to report given the number of the day in the study. LOC-eating was positively skewed (i.e., a large majority of reports indicated no LOC-eating was experienced), therefore, GLMMs assumed a gamma distribution and a logit function. Random intercepts and slopes were included. To nest surveys within persons, individual identification number was included as a random effect. Random slopes of momentary food cravings were also modeled. Models assumed an AR1 covariance structure which accounts for the correlation among the reports provided by a single individual.

To test whether cravings were associated with LOC-eating, both general and momentary cravings were included in the same model as predictors of LOC-eating severity. To test whether sex and puberty each moderated the relationships between craving and LOC-eating severity, sex and pubertal status were added into separate GLMMs as main and interactive (with general and momentary cravings) independent variables. In moderation analyses, females were set as the reference sex. To examine differences between pre- and mid-pubertal groups, and pre- and late-pubertal groups, analyses were conducted first with pre-puberty set as the reference. Then, to examine differences between mid- and late-pubertal groups, a separate analysis was conducted with late-puberty set as the reference. To examine the effect sizes, conditional R-square approximations for each GLMM were obtained in R-Studio using the lme4 (2) and sjstats (70) packages. Conditional R-square was interpreted because it accounts for the variance explained by both the fixed and random effects.

Test Meal Analyses

T-tests and ANOVAS tested for differences in cravings, hunger, and LOC-eating severity by sex and pubertal status, respectively. Effect sizes for sex and pubertal status comparisons were determined by Cohen's d and partial eta-squared.

To test whether pre-meal craving predicted LOC-eating severity during the test meal a linear regression was conducted. R-square was used to interpret the size of the effect. To determine if sex and pubertal status impacted the relationship between pre-meal cravings and LOC-eating severity, separate moderation analyses were run using the PROCESS macro (44) for SPSS. Puberty was a multicategorical moderator (i.e., 3 stages), therefore, indicator coding was used to examine moderation effects. Pre-puberty was set as the reference group. Conditional effects of each level of the moderator (e.g., pre-, mid-, late-puberty) on the focal predictor (i.e., food cravings) were examined to determine if craving was more strongly related to LOC-eating severity for mid- and late-pubertal groups compared to the pre-pubertal group. To test if the relationship between craving and LOC-eating was different among mid- and late-pubertal groups moderation analyses were re-run with late-puberty set as the reference group. Changes in R-square when moderators and interaction variables were included were obtained from the PROCESS macro (44) and interpreted as a measure of effect size for the moderation analyses.

Covariates

Initially, age, race/ethnicity, sex, height, LOC-eating status, fat mass (kg), lean mass, and hunger were included as covariates in all analyses. Continuous covariates were examined for skewness (>1.5 or < -1.5 on skewness or kurtosis). Age and fat mass were log transformed to improve normality. Race/Ethnicity was categorized as either "non-

Hispanic white" or other. Given prior evidence that peaks in food cravings correspond with peaks in hunger and mealtimes (92), analyses adjusted for levels of hunger at the time that food cravings were rated. Fat mass is a more robust and accurate predictor of weight status than BMI (29; 88), therefore fat mass was included in all analyses to adjust for differences in weight status. However, only hunger significantly contributed to models and thus all other covariates were removed for parsimony.

CHAPTER 3: RESULTS

DESCRIPTIVE STATISTICS

Sample Characteristics

One-hundred and twenty participants completed the EMA protocol. EMA compliance was plotted using a histogram and the distribution was inspected visually. There was a break between those above and below 30% compliance, therefore, the six individuals with compliance below 30% were excluded from analyses. Of the 114 youth who completed the EMA protocol, 26 individuals were excluded because they reported either one or zero eating episodes. A final sample of 87 participants, ages 8 to 18, were included in EMA analyses. There were no significant differences among those who were and were not included in analyses on BMIz, age, height, fat mass (*ts* = .02-1.35, *ps* =.18 - .99) or sex or race (x^2s = 0.94-8.72, *ps* = .07-.63), but there were differences in ethnicity (x^2=10.13, *p* = .01) Fifty-one individuals (58.6%) were female. A majority of the participants identified as white (*n* = 47, 54.0%) and non-Hispanic (*n* = 78, 89.7%). Nine individuals had overweight (10.3%) and 19 (21.8%) had obesity. Ten participants (11.5%) endorsed LOC-eating during the EDE interview. Participant characteristics for the entire sample, by sex, and by pubertal stage are shown in Table 1.

Ecological Momentary Assessment

On average, compliance with EMA surveys (M = 75.52% SD = 17.81) was consistent with previous studies among youth (69) and did not differ by sex ($t(85) = 0.33$, $p = .74$) or pubertal stage ($F(2,84) = 0.05$, $p = .95$). On average, craving ratings were reported 2.87 hours (SD = 2.03, range .01 - 9.86) prior to LOC-eating ratings. Cravings for food were reported in 24.6% (n = 359) of the analyzed surveys. Some degree of LOC-eating (i.e. a composite score greater than 1) was endorsed during 34.5% (n = 505) of the reported eating episodes and by 66.7% of participants (n = 58). One individual who reported LOC-eating during the EDE did not endorse LOC-eating during EMA. Forty-nine individuals who did not report LOC-eating during the EDE interview reported LOC-eating on at least one EMA survey. Average ratings of cravings, hunger, and LOC-eating severity by sex and pubertal status can be found in Table 2. Cravings, hunger, and LOC-eating severity did not differ by sex (ts = 0.28-0.51, ps = .61-.78), or pubertal status (Fs = 0.22-1.61, ps = .21-.80). Severity of hunger was associated with severity of cravings at the same timepoint (ß = 0.24, $p < .01$).

Craving and Loss of Control Eating

In the natural environment, higher general cravings were related to greater LOC-eating severity (ß = 0.17, $p < .001$) and increases in momentary cravings were associated with higher LOC-eating severity at the next eating episode (ß = 0.06, $p = .001$). Specifically, for every one unit increase in general food cravings, LOC-eating severity increased by 19% and for every one unit increase in momentary food cravings LOC-eating severity increased by 6%. Further, general and momentary cravings explained an additional 14% of the variance in LOC-severity ($\Delta R^2 = .14$). Sex did not significantly

moderate the relationship between general cravings and LOC-eating severity (ß = -0.10, p = .10), nor did it moderate momentary cravings and LOC-eating severity (ß = -0.001, p = .97) or explain any additional variance in LOC-severity (ΔR^2 = .14). However, general cravings were more robustly associated with LOC-eating severity for those in pre-puberty compared to mid-puberty (ß = -0.25, p = .01) and late-puberty (ß = -0.19, p = .005). The strength of the relationship was not significantly different between mid- and late-pubertal youth (ß = -0.06 p = .48). Figure 1 displays the relationships between general cravings and LOC-eating severity by pubertal status. Puberty did not significantly moderate the relationships between momentary cravings and LOC-eating severity (mid vs pre ß = 0.01, p = .90; late vs pre ß = 0.04, p = .59; mid vs late ß = -0.03, p = .51). Puberty explained an additional 21% of the variance in LOC-eating severity (ΔR^2 = .21). See Table 3 for full GLMM statistics.

Test Meal

Of the 87 individuals who completed EMA, 13 did not participate in the test meal. There were no significant differences between participants who did and did not complete the test meal: age (t(85) = -0.15, p = .89), height (t(85) = 0.34, p = .74), fat mass (t(85) = -0.10, p = .92), pubertal stage (x^2(2) = 1.80, p = .41), sex (x^2(1) = 2.11, p = .15), race (x^2(1) = 1.88, p = .17), baseline LOC-eating status (x^2(1) = 0.22, p = .64). Three youths reported no pre-meal cravings and three reported no LOC-eating (i.e., 0/100 on all LOC-eating items) during the test meal. Ratings of pre-meal cravings, pre-meal hunger, and LOC-eating severity did not differ by sex (ts = -0.10-0.36, ps = .72-.92), or puberty (Fs = 0.58-2.77, ps = .07-.56). Pre-meal hunger and cravings, and test meal LOC-eating severity ratings can be found in Table 4. Pre-meal hunger and cravings were strongly

related ($r(72) = .63, p < .01$). Correlations among laboratory measurements and EMA measurements were moderate: LOC-eating severity ($r(72) = .42, p < .01$), craving ($r(72) = .51, p < .01$) and hunger ($r(72) = .34, p < .01$).

Craving and Loss of Control Eating

Pre-meal craving was a significant predictor of LOC-eating severity (ß = 0.31, $p < .01$). Neither sex nor puberty moderated this relationship (sex: ß = -0.17, $p = .21$, $\Delta R^2 = .02$; puberty: ßs = -0.08 and 0.20, *ps* =.23 and .68, $\Delta R^2 = .04$). See Table 5 for full regression statistics.

CHAPTER 4: DISCUSSION

SUMMARY OF FINDINGS

The current study provides insights into the relationship between food cravings and LOC-eating in male and female youth. Consistent with our hypotheses, general level of food cravings and momentary levels of food cravings were positively associated with higher LOC-eating and higher LOC-eating severity at the next meal, respectively. Pre-meal cravings were also positively associated with LOC-eating severity during a test meal. Contrary to hypotheses, these relationships did not differ by sex in the natural environment or laboratory settings. Further, in the natural environment a stronger relationship between general two-week cravings and average two-week LOC-eating was observed in pre-pubertal youth compared to mid- and late-pubertal youth. Differences by pubertal statuses were not observed between momentary cravings and LOC-eating severity at the next meal in the natural environment nor pre-meal cravings and LOC-eating during the test meal. Taken together, food cravings appear to be a relevant factor preceding LOC-eating for male and female youth of broad age and weight ranges.

Craving and Loss of Control Eating

This study extends prior work by demonstrating that similar to adults, the relationship between food cravings and LOC-eating is salient in youth with healthy weight and with overweight or obesity. Among our sample, youth with higher general and momentary levels of food cravings also reported more severe LOC-eating. A previous study remaining this relationship in youth with overweight or obesity only observed a relationship between general, but not momentary, food cravings and LOC-eating. The discrepancies among findings may be the result of differences in the measurement of craving. Specifically, the previous study utilized a single item, which are less stable than a composite score, which was used in the current study.

Studies in adults typically report that higher general, but not momentary, cravings are associated with eating disorder status and severity (12; 13; 24; 53; 120; 124), although some studies have also found a relationship between momentary cravings and binge-eating (132). It is possible that over time, as momentary increases in cravings promote more frequent LOC-eating, cravings become more stable. Thereby greater levels of trait food cravings may limit one's ability to report increases in momentary food cravings among adults who engage in more frequent LOC-eating. To test this possibility, future longitudinal studies are needed to examine changes in food cravings and disordered eating in samples of youth and young adults who report LOC-eating episodes.

The Impact of Sex on Cravings and Loss of Control Eating

In the current study, females did not report stronger food cravings than males, which is inconsistent with studies in adults (43; 51; 67; 126; 130). It is possible that sex differences in cravings do not emerge until adulthood. Alternatively, biological sex alone

may not be a nuanced enough measurement to capture differences among males and females prior to adulthood, rather sex by developmental stage interactions may be more important. Increases in ovarian hormones during different phases of the menstrual cycle appear to underlie the adult female's greater preference for and consumption of sweet, fat, and carbohydrate rich foods (10; 16; 40; 56; 65; 94; 122). The effects of ovarian hormone cycles (in females) and testosterone (in males) on increased susceptibility to food cravings may be tempered when examining youths of all pubertal stages, given younger youth have not yet experienced hormonal changes. To elucidate when and why cravings become exacerbated in females, as compared to males, longitudinal studies should examine intra-sex differences and interaction among sex and other biological factors (e.g., puberty, menstrual status, overall hormonal levels, daily fluctuations in hormones, menstrual cycle phases).

Findings from the current study are consistent with one study in adults that found no sex differences in the relationship between self-reported craving and binge-eating frequency (13). Alternatively, Chao et al (13) found sex differences in the relationship between cravings and trait levels of eating disorder psychopathology (e.g., shape and weight concerns). This might suggest that food cravings are equally impactful on LOC-eating in boys and girls, but disproportionately impact girl's perceived increase in shape and weight following LOC-eating episodes. Future studies might examine the relationships between momentary food cravings and other indices of eating disorder pathology (e.g., momentary shape and weight concerns, secretive eating, guilt about eating) to test for possible sex differences in alternative pathways through which cravings may increase risk for developing an eating disorder.

The Impact of Puberty on Cravings and Loss of Control Eating

Differential patterns emerged regarding the effect of puberty on general and momentary cravings and LOC-eating. These findings were in contrast to our hypotheses. Although the relationship was present among youth of all pubertal stages, among pre-pubertal youth, greater general food cravings were even more robustly associated with greater LOC-eating in the natural environment. Prior to puberty, motivational drives to eat may exacerbate feeling out of control while eating, however, after pubertal onset, these drives may become less salient than when other environmental factors are present. For example, following pubertal onset social and affective processing develops (21; 127). When these processing capabilities change, other psychological factors (e.g., focus on body shape and weight, or interpersonal relationship stress) may become more prominent drivers of disordered eating (64; 83; 91; 104; 106; 125) than general cravings for food. Future studies with larger samples of pre- and mid-pubertal youth prone to LOC-eating, should identify how specific biological (e.g., overall hormonal levels, daily fluctuations in hormones, hourly fluctuations in hormones), psychological (e.g., dissatisfaction with shape and weight, emotion regulation, eating styles), and social factors (e.g., interpersonal distress, eating environment, autonomy over food choices) impact the link between food cravings and LOC-eating in males and females during this transition period. Longitudinal studies testing these relationships within individuals prior to and following pubertal onset are necessary for determining the mechanisms directly underlying these changes.

Importantly, results regarding the effects of puberty on momentary cravings on LOC-eating did not differ in natural and environmental contexts. There was also moderate concordance among reports of craving, hunger, and LOC-eating severity

experienced in EMA and during the test meal. This suggests the laboratory test meal used in the current study may be a valid paradigm for measuring LOC-eating severity in healthy children and adolescents. Previous research has reported discordant relationships between negative affect and LOC-eating in EMA and laboratory environments among different samples of youth. It is possible that examining experiences reported over multiple eating episodes is more robust to identifying salient predictors of LOC-eating in youth, or that experiences of LOC-eating in the laboratory do not approximate LOC-eating in the natural environment; yet, that did not appear to be the case in the present study. Factors associated with LOC-eating in a controlled laboratory environment may also become less relevant when also coping with stressors in one's everyday life. However, results from the current study demonstrated concordant evidence for an association between craving on LOC-eating in the natural and controlled environments. Differences in study samples or methodology may also contribute to contradictory findings. To identify if sources of discrepancies in extant laboratory and naturalistic settings reflect true differences in predictors of LOC-eating or are a result of error introduced by research, studies utilizing identical measurements across multiple methodologies in different environmental contexts are essential.

STRENGTHS AND LIMITATIONS

There are a number of notable study strengths. First, we utilized EMA to capture ecologically valid and repeated measures of food cravings and LOC-eating in a natural environment. Given the nature of EMA, the current study was able to examine a large number of eating episodes and LOC-eating ratings in youth. EMA also allowed for the examination of youth who may experience LOC-eating but would have been excluded

due to not reporting LOC-eating in a clinical interview. Second, the study utilized a multimethod approach, using the same items to examine the relationship between craving and LOC-eating in both controlled laboratory and naturalistic settings. This allowed for a more nuanced understanding of how food cravings may impact LOC-eating across developmental periods and environmental contexts. Third, a trained medical professional conducted pubertal staging. This method is considered the gold standard measurement of pubertal development (17; 25; 97). The use of DXA to measure fat mass, instead of BMIz, was an additional strength. Finally, all analyses adjusted for levels of hunger at the same time ratings of cravings were provided. As such, results of the current study are more likely to reflect the effects of intense and potentially maladaptive drives to eat, rather than normative desires for food driven by time of day or physiological hunger.

Limitations include the relatively small sample sizes of the pre-puberty and mid-puberty groups, which may have reduced generalizability to larger samples and suggest the pubertal moderation findings should be interpreted cautiously. Additionally, there are likely important sex by pubertal status interactive effects on craving and disordered eating that we were unable to test given the small number of participants in the pre- and mid-pubertal groups. Future studies should aim to recruit equal numbers of pre-, mid- and late-pubertal youth to examine potential sex by pubertal status interactions. Second, pubertal staging is determined by development of external sex organs which is driven by, but not identical to, gonadal hormone concentrations (97). Thus, pubertal staging may not be sensitive enough to approximate the exact biological mechanisms that may be driving the observed differences between youth at different pubertal stages. Additionally, the items used to assess LOC-eating severity have demonstrated excellent internal

consistency in in the present study, and in previous studies, however, the psychometric properties of these items have not yet been determined. Therefore, future studies should determine whether these items appropriate for assessing LOC-eating among youth in their natural environment. Finally, compliance in the overall sample was adequate, however, a subset of youth was excluded from analyses due to poor compliance and infrequent reporting of meals and snacks during the EMA protocol. Future studies may benefit from implementing more intensive training and check-in procedures to improve youth's compliance with EMA surveys.

CONCLUSIONS

In the current study, both boys and girls reported feeling more out of control when experiencing increased cravings. Increased motivation for obtaining pleasure from food appears to be one factor linked to excess weight gain and disordered eating. This substantiates a need for more direct examinations of the mechanism underlying increased motivations to consume food in male and female youths. Testing the interactions between biological and psychological changes during puberty may be a pertinent avenue for future research. For example, gonadal hormones function through the same neurobiological pathways associated with attention biases and reward processing, which may alter one's sensitivity to food cravings, especially during the later stages of pubertal development. Elucidation of mechanism linking cravings to disordered eating could inform the development and refinement of treatments targeting food cravings, LOC-eating and excess weight gain in youth.

Table 1. Participant Characteristics

	Total (n = 87)	Males (n = 36)	Females (n = 51)	Sex *p, ES*		Pre-pubertal (n = 12)	Mid-pubertal (n = 19)	Late-pubertal (n = 56)	Puberty *p, ES*	
Age	12.98±2.68	12.53±2.84	13.29±2.54	0.19	0.28	9.0±0.74	11.58±1.77	14.30±2.04	<.01	0.53
BMIz	0.57±1.11	0.45±1.19	0.66±1.06	0.39	0.19	0.13±.94	0.28±1.04	0.76±1.13	0.09	0.06
Fat Mass (kg)	17.55±11.90	15.61±12.76	18.92±11.18	0.20	0.28	8.32±5.75	13.57±7.19	20.88±12.75	<.01	0.29
Height (cm)	157.53±14.83	158.63±18.58	156.76±11.63	0.57	0.12	133.95±8.15	151.27±9.83	164.71±10.57	<.01	0.55
NonHispanic White (*n,%*)	42, 48.28	19, 37.25	23, 63.89	0.48	0.08	7, 58.33	10, 52.63	25, 44.64	0.63	0.1

Note*:* Abbreviations: ES, effect size; M, mean; SD, Standard Deviation; BMIz, standardized body mass index; kg, kilograms; cm, centimeters. Data are presented as M±SD, unless otherwise specified. Group differences were tested using chi-square, independent samples t-tests, and ANOVAs, as appropriate. T-test effect sizes determined by Cohen's d. ANOVA effect sizes determined by partial eta-square. Chi-square effect sizes determine by Cramer's V.

Table 2. EMA Descriptive Statistics

	Total (*N*=87)	Males (*n*=36)	Females (*n*=51)	Sexes *p* , *ES*		Pre-Pubertal (*n*=12)	Mid-Pubertal (*n*=19)	Late-Pubertal (*n*=56)	Puberty *p* , *ES*	
Eating Episodes reported (*n*)	1462	418	1044	<.01	0.71	182	296	984	0.79	0.01
Eating Episodes with LOC[a] (*n*)	505	150	355	0.08	0.38	39	98	368	0.36	0.02
Cravings reported[b] (*n*)	359	107	252	<.01	0.71	55	69	235	0.79	0.01
LOC severity[c] (M±SD)	1.23±0.41	1.25±0.51	1.21±0.33	0.66	0.09	1.28±0.76	1.18±0.27	1.24±0.34	0.80	0.01
Cravings[c] (M±SD)	1.30±0.50	1.32±0.66	1.29±0.36	0.78	0.06	1.54±1.06	1.28±0.37	1.26±0.33	0.21	0.04
Hunger[c] (M±SD)	1.51±0.56	1.54±0.67	1.48±0.46	0.61	0.11	1.73±0.98	1.47±0.41	1.47±0.47	0.33	0.03

Note: Abbreviations: LOC, loss of control eating; unless otherwise specified mean and standard deviations are presented. [a]Eating episodes with LOC-eating indicates the number of EMA surveys where any degree of feeling out of control while eating was endorsed. [b]Cravings reported indicates the number of EMA surveys where any degree of food craving was endorsed. [c]Unweighted averages, aggregated within-persons, are presented. T-test effect sizes determined by Cohen's d. ANOVA effect sizes determined by partial eta square.

Table 3. Ecological Momentary Assessment Generalized Linear Mixed Models

Model	Variable	ß	SE	*t*	*p*	95% CI	*Conditional* ΔR^2
Craving	Intercept	0.13	0.03	5.18	<.001	0.08 - 0.18	.14
	Hunger	0.02	0.01	2.69	.01	0.01 - 0.03	
	General Cravings	0.17	0.03	5.76	<.001	0.11 - 0.22	
	Momentary Cravings	0.06	0.02	3.19	.001	0.02 - 0.10	
Sex Moderation	Intercept	0.15	0.04	3.99	<.001	0.08 - 0.23	.14
	Hunger	0.02	0.01	2.64	.01	0.004 - 0.03	
	General Cravings	0.23	0.05	4.85	<.001	0.14 - 0.32	
	Momentary Cravings	0.06	0.03	1.85	.07	-0.004 - 0.13	
	Sex						
	Female vs Male	-0.03	0.05	-0.55	.58	-0.12 - 0.07	
	Sex x General Cravings						
	Female vs Male	-0.10	0.06	-1.66	.10	-0.21 - 0.02	
	Sex x Momentary Cravings						
	Female vs Male	-0.001	0.04	-0.04	.97	-0.08 - 0.08	
Puberty Moderation	Intercept	0.13	0.06	2.10	0.04	0.01 - 0.24	.21
	Hunger	0.02	0.01	2.59	0.01	0.004 - 0.03	
	General Cravings	0.32	0.06	5.56	<.001	0.21 - 0.43	
	Momentary Cravings	0.03	0.06	0.52	0.60	-0.09 - 0.16	
	Puberty						
	Mid vs pre	0.02	0.06	0.33	0.74	-0.11 - 0.15	
	Late vs pre	-0.02	0.08	-0.20	0.84	-0.16 - 0.13	
	Mid vs Late[a]	-0.04	0.05	-0.67	.50	-0.14 - 0.07	
	Puberty x General Cravings						
	Mid vs pre	-0.19	0.07	-2.85	.01	-0.32 - -0.06	
	Late vs pre	-0.25	0.09	-2.64	.01	-0.43 - -0.06	
	Mid vs Late[a]	-0.06	0.08	-0.70	.48	-0.22 - 0.10	
	Puberty x Momentary Cravings						
	Mid vs pre	0.04	0.07	0.54	.59	-0.10 - 0.17	

Late vs pre	0.01	0.07	0.12	.90	-0.13 - 0.15
Mid vs Late[a]	-0.03	0.042	-0.66	.51	-0.11 – 0.06

Note: Abbreviations: ß, coefficient, SE, standard error, CI, confidence interval. Mid vs Late[a] coefficients are from separate analyses run with late-puberty as the reference stage. The conditional R^2 =.31 when only hunger was included in the model. Conditional ΔR^2 was calculated by subtracting R^2 of each model from .31.

Table 4. Test Meal Descriptive Statistics

	Total (*n*=74)	Males (*n*=33)	Females (*n*=41)	Sexes *p* , *ES*		Pre- Pubertal (*n*=10)	Mid- Pubertal (*n*=18)	Late-Pubertal (*n*=46)	Puberty *p* , *ES*	
Pre-meal craving	33.36±25.72	33.89±28.92	32.94±23.18	0.88	0.04	43.76±33.18	32.70±27.66	31.36±23.13	0.39	0.03
Pre-meal hunger	64.36±21.05	64.09±24.26	64.58±18.37	0.92	0.02	78.11±23.81	64.71±20.07	61.24±20.03	0.07	0.07
Post-meal LOC severity	18.00±15.40	18.72±17.01	17.42±14.16	0.72	0.08	20.71±19.24	14.78±10.74	18.67±16.15	0.56	0.02

Note: Abbreviations: ES, effect size; LOC, loss of control eating. All numbers presented as mean, standard deviation. Data presented as mean ± standard deviation. Group differences were tested using chi-square, independent samples t-tests, and ANOVAs, as appropriate. T-test effect sizes determined by Cohen's d. ANOVA effect sizes determined by partial eta square.

Table 5. Test Meal Regression and Moderation Models

Model	Variable	ß	SE	*t*	*p*	95% CI	ΔR^2
Craving	Constant	17.279	5.485	3.150	.002		.179
	Hungry	-0.150	0.101	-1.487	.141		
	Craving	0.311	0.083	3.768	<.001		
Sex Moderation	Constant	11.253	9.499	1.185	.240	-7.697, 30.204	.019
	Hungry	-0.162	0.102	-1.591	.116	-0.365, 0.041	
	Craving	0.556	0.211	2.640	.010	0.136, 0.976	
	Sex	4.598	5.481	0.839	.404	-6.335, 15.532	
	Sex x Cravings	-0.165	0.131	-1.267	.209	-0.426, 0.949	
Puberty Moderation	Constant	22.491	9.415	2.389	.020	3.699, 41.283	.044
	Hungry	-0.150	0.103	-1.454	.151	-0.355, 0.056	
	Craving	0.227	0.152	1.486	.142	-0.077, 0.5307	
	Puberty 1	-2.832	9.239	-0.307	.760	-21.272, 15.609	
	Puberty 2	-8.124	8.422	-0.965	.338	-24.935, 8.686	
	Puberty 1 x Cravings	-0.079	0.188	-0.422	.674	-0.454, 0.295	
	Puberty 2 x Cravings	0.203	0.168	1.210	.231	-0.132, 0.538	

Note: Abbreviations: ß, coefficient, SE, standard error, CI, confidence interval. Indicator coding used for the multicategorical moderator (puberty). Coding is as follows: pre-puberty = 1, mid-puberty =2, late-puberty =3. Puberty 1 represents combined effect for pre- and late-puberty groups. Puberty 2 represents combined effect for pre- and mid-puberty groups.

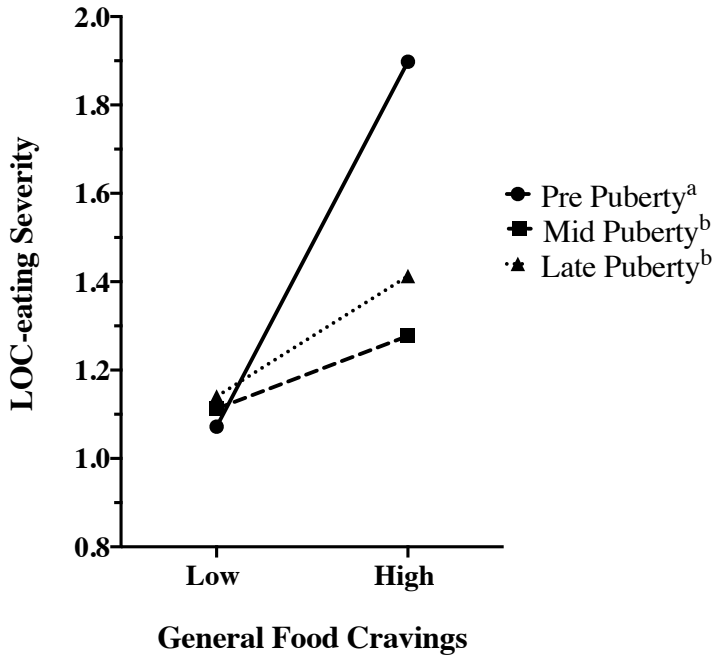


Figure 1. EMA Craving and Loss of Control Eating by Pubertal Status

Note: Abbreviations: LOC-eating, loss of control eating; Low, low food cravings, High, high food cravings. Superscripts (a and b) denote which pubertal stages were statistically different. Low cravings represent participants whose mean centered levels of craving were < 0 and high cravings represent participants whose mean centered levels of craving were > 0. Predicted scores of LOC-eating severity were saved from the generalized linear mixed model and graphed for each pubertal group.

Appendix A

Analysis Code

Variable Key:
LOC_All = LOC-eating severity
FatMass_log = Transformed total body fat mass (kg)
LagHungry = Hunger at the time of craving ratings
CravingWSC = Momentary food cravings
CravingBSC = General food cravings
Height = Height

SPSS Code for conducting generalized linear mixed models

```
*Aim 1, Craving predict LOC.
*Generalized Linear Mixed Models.
GENLINMIXED
  /DATA_STRUCTURE SUBJECTS=ParticipantId
REPEATED_MEASURES=Survey_Number COVARIANCE_TYPE=AR1
  /FIELDS TARGET=LOC_ALL TRIALS=NONE OFFSET=NONE
  /TARGET_OPTIONS DISTRIBUTION=GAMMA LINK=LOG
  /FIXED  EFFECTS=Laghungry CravingBSC CravingWSC USE_INTERCEPT=TRUE
  /RANDOM EFFECTS=CravingWSC USE_INTERCEPT=TRUE
SUBJECTS=ParticipantId COVARIANCE_TYPE=UNSTRUCTURED
    SOLUTION=FALSE
  /BUILD_OPTIONS TARGET_CATEGORY_ORDER=ASCENDING
INPUTS_CATEGORY_ORDER=ASCENDING MAX_ITERATIONS=100
    CONFIDENCE_LEVEL=95 DF_METHOD=RESIDUAL COVB=MODEL
PCONVERGE=0.000001(ABSOLUTE) SCORING=0
    SINGULAR=0.000000000001
  /EMMEANS_OPTIONS SCALE=ORIGINAL PADJUST=LSD
  /SAVE PREDICTED_VALUES(PredictedValueCraveWSC).

*Aim 2, Craving predict LOC.moderated by sex
*Generalized Linear Mixed Models.
GENLINMIXED
  /DATA_STRUCTURE SUBJECTS=ParticipantId
REPEATED_MEASURES=Survey_Number COVARIANCE_TYPE=AR1
  /FIELDS TARGET=LOC_ALL TRIALS=NONE OFFSET=NONE
  /TARGET_OPTIONS DISTRIBUTION=GAMMA LINK=LOG
  /FIXED  EFFECTS=Laghungry CravingBSC CravingWSC Sex_F1_M2
CravingBSC*Sex_F1_M2
    CravingWSC*Sex_F1_M2 USE_INTERCEPT=TRUE
  /RANDOM EFFECTS=CravingWSC USE_INTERCEPT=TRUE
SUBJECTS=ParticipantId COVARIANCE_TYPE=UNSTRUCTURED
    SOLUTION=FALSE
  /BUILD_OPTIONS TARGET_CATEGORY_ORDER=ASCENDING
INPUTS_CATEGORY_ORDER=ASCENDING MAX_ITERATIONS=100
```

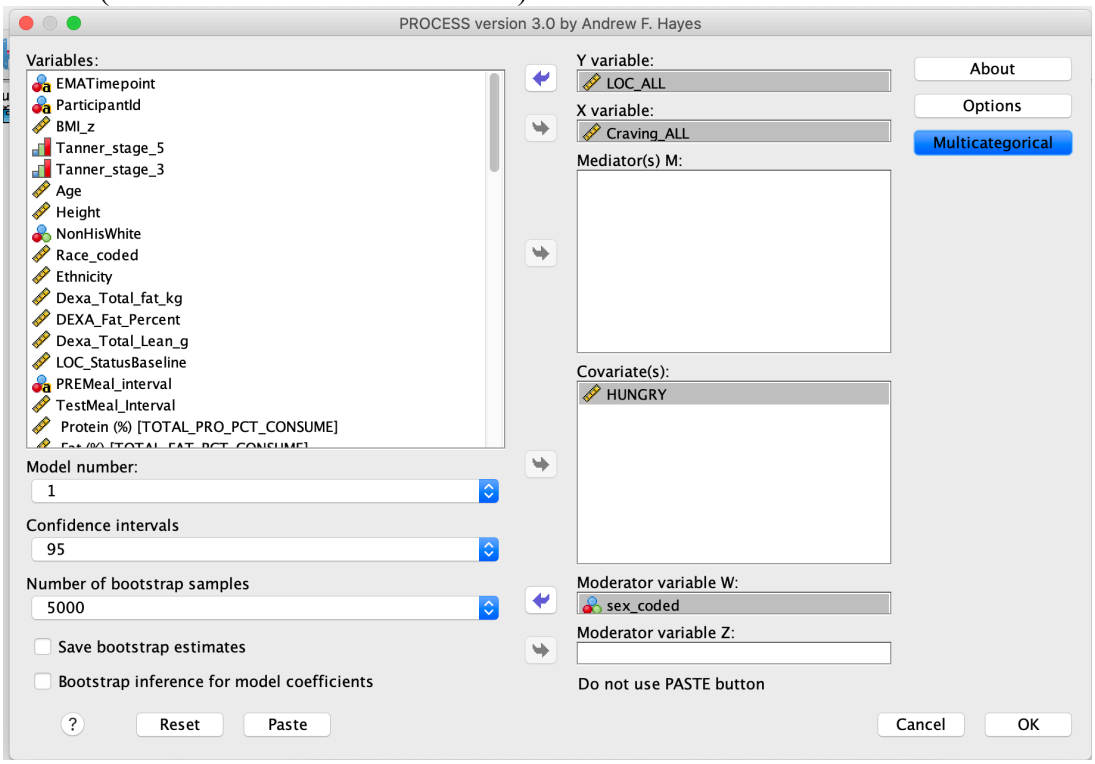
```
   CONFIDENCE_LEVEL=95 DF_METHOD=RESIDUAL COVB=MODEL
PCONVERGE=0.000001(ABSOLUTE) SCORING=0
   SINGULAR=0.000000000001
  /EMMEANS_OPTIONS SCALE=ORIGINAL PADJUST=LSD
  /SAVE PREDICTED_VALUES(PredictedValueCraveWSC_sex).

*Aim 3. Craving predict LOC moderated by Pubertal status.
*Generalized Linear Mixed Models.
GENLINMIXED
  /DATA_STRUCTURE SUBJECTS=ParticipantId
REPEATED_MEASURES=Survey_Number COVARIANCE_TYPE=AR1
  /FIELDS TARGET=LOC_ALL TRIALS=NONE OFFSET=NONE
  /TARGET_OPTIONS DISTRIBUTION=GAMMA LINK=LOG
  /FIXED  EFFECTS=Laghungry CravingBSC CravingWSC Tanner3_recoded
CravingBSC*Tanner3_recoded
   CravingWSC*Tanner3_recoded USE_INTERCEPT=TRUE
  /RANDOM EFFECTS=CravingWSC USE_INTERCEPT=TRUE
SUBJECTS=ParticipantId COVARIANCE_TYPE=UNSTRUCTURED
   SOLUTION=FALSE
  /BUILD_OPTIONS TARGET_CATEGORY_ORDER=ASCENDING
INPUTS_CATEGORY_ORDER=ASCENDING MAX_ITERATIONS=100
   CONFIDENCE_LEVEL=95 DF_METHOD=RESIDUAL COVB=MODEL
PCONVERGE=0.000001(ABSOLUTE) SCORING=0
   SINGULAR=0.000000000001
  /EMMEANS_OPTIONS SCALE=ORIGINAL PADJUST=LSD
  /SAVE PREDICTED_VALUES(PredictedValueCraveWSC_puberty).
```

SPSS code for test meal regression and moderation models

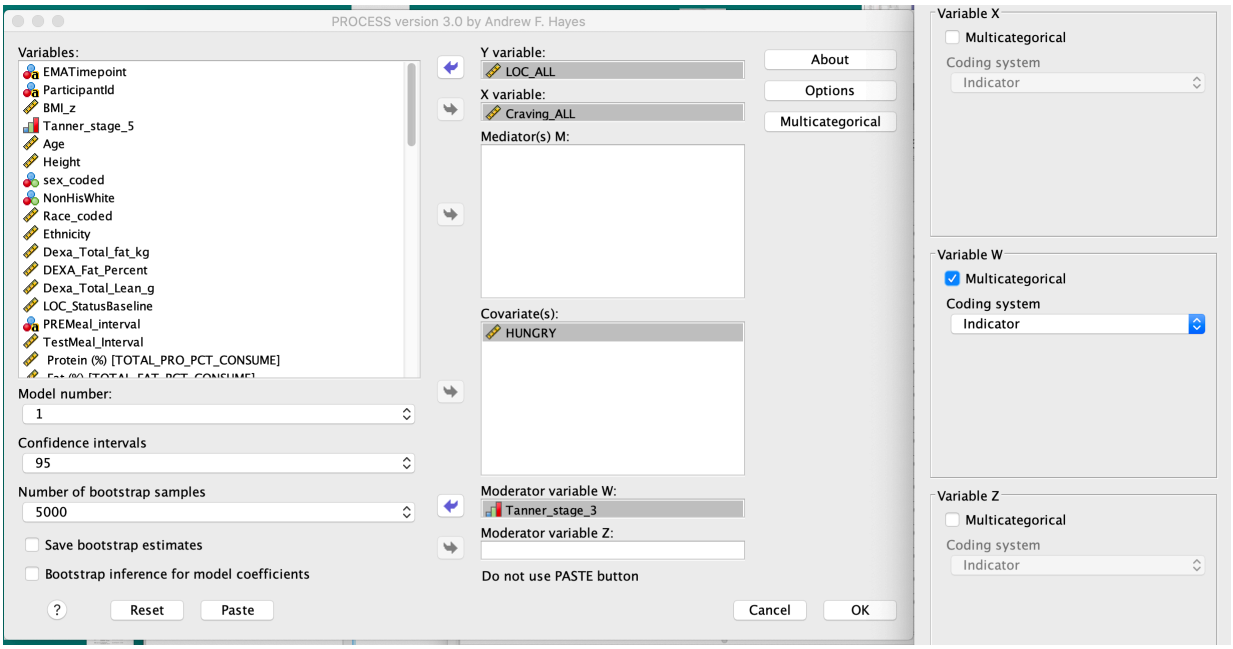
**Craving

```
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA CHANGE
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT LOC_ALL
  /METHOD=ENTER HUNGRY Craving_ALL.
```

** Sex (screenshot of PROCESS Macro)



*Puberty (screen shot of PROCESS Macro)



RStudio code for obtaining R^2

```[r]
library(lme4)
library(lmerTest)
library(sjstats)

#get empty (or null) model
base <- glmer (LOC_ALL ~ 1  + Laghungry  + (1 | ParticipantId), data=thesisEMA,
family =Gamma(link=log))
summary(base)

#craving
cravings <- glmer (LOC_ALL ~ 1+ Laghungry +CravingBSC+CravingWSC + (1
+CravingWSC | ParticipantId), data=thesisEMA,family =Gamma(link=log))
summary(cravings)

#sex
sex <- glmer (LOC_ALL ~ 1+  Laghungry +CravingBSC+
CravingWSC + as.factor(sex_coded)+ as.factor(sex_coded)*CravingBSC
+as.factor(sex_coded)*CravingWSC + (1 +CravingWSC | ParticipantId),
data=thesisEMA,family =Gamma(link=log))
summary(sex)

#puberty
puberty <- glmer (LOC_ALL ~ 1+ Laghungry+CravingBSC+
```

```
CravingWSC + as.factor(Tanner_stage_3)+ as.factor(Tanner_stage_3)*CravingBSC
+as.factor(Tanner_stage_3)*CravingWSC + (1 +CravingWSC | ParticipantId),
data=thesisEMA,family =Gamma(link=log))
summary(puberty)

anova(base, cravings, sex, puberty)

 #get R-square approximations
performance::r2(base)
performance::r2(cravings)
performance::r2(sex)
performance::r2(puberty)
```

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