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# Empirical validation of a developmental model for binge-eating disorder in adolescents: a structural equation modeling approach

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**Abstract**

Loss of control (LOC) eating is characterized by a reported sense of being unable to control food intake, regardless of the amount of food consumed. It is the hallmark feature of binge-eating episodes, which involve consuming an unusually large amount of food within a discrete time frame, accompanied by a sense of LOC over eating. Some studies investigating the progression of LOC-eating symptoms in children and adolescents suggest that LOC-eating may be a precursor to binge-eating disorder (BED) in adults. To explain the progression from LOC-eating in childhood and adolescence to BED in adulthood, Tanofsky-Kraff and her colleagues developed a theoretical model highlighting three main constructs: negative affectivity, reward sensitivity, and executive functioning. However, a thorough empirical validation of this model has not yet been performed. The current study aims to empirically test Tanofsky-Kraff and her colleagues' model via structural equation modeling (SEM) and explore potential gender and age differences within this framework. We surveyed 969 adolescents aged 12 to 18 years from the Quebec City area who completed self-report questionnaires. Our findings revealed that both negative affectivity and reward sensitivity are significantly associated with binge-eating symptomatology, whereas self-reported executive functioning is not significantly associated with binge-eating symptomatology. These results support several key components of the proposed model and provide insights into the interactions between the variables when tested simultaneously. Additionally, our study underscores the importance of considering individual factors such as age and gender in understanding binge-eating symptomatology.

**Plain English Summary**

Some young people feel they can't control how much they eat, even if they aren't eating large amounts. This is called loss of control (LOC) eating. Some research suggests that LOC eating in children and adolescents could lead to binge-eating disorder (BED) later in life. To better understand why this might happen, experts have identified three key factors: struggling with negative emotions, being more sensitive to food rewards, and having difficulties with executive functioning. However, this idea hasn't been fully tested yet. We surveyed 969 teenagers, aged 12 to 18, from the Quebec City area to explore how these three factors might be linked to

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binge-eating symptomatology. Our results suggest that adolescents who struggle with negative emotions or feel strongly rewarded by food might be at higher risk to report binge-eating symptoms. These findings underscore the importance of teaching young people how to manage their emotions from an early age. The also highlight the differential role of these factors depending on age and gender, which is important for developing more personalized prevention and treatment strategies.

**Keywords** LOC-eating, Binge-eating, Adolescents, Risk factors, Prevention

Overeating is characterized by excessive consumption of food beyond the body's needs [1] and is often associated with excessive body weight [2]. This behavior can occur passively when individuals eat without experiencing true hunger, often selecting overly large portions or high-calorie foods [1, 3], or it can be accompanied by a loss of control (LOC) when individuals feel unable to stop eating or regulate their food intake [4, 5]. LOC eating is a key feature of binge-eating disorder (BED) [6].

BED is the most prevalent eating disorder, with a lifetime prevalence of 2.42% in adult women, 1.17% in adult men [7], and 1.32% in children and adolescents [8]. It is highly comorbid with psychiatric disorders, particularly mood, anxiety, and substance-related disorders, affecting approximately 94% of individuals with the condition [9]; it is also associated with overweight and obesity in more than half of cases [10–12], as well as with increased risk of metabolic issues (e.g., diabetes, hypertension) and chronic pain conditions [9, 10, 12]. Unfortunately, BED is often diagnosed late, by which time its consequences and comorbidities are already established, and its symptoms tend to be more entrenched and challenging to treat.

Binge-eating symptoms exist on a continuum of severity, starting with LOC-eating as the least severe form, progressing through binge-eating and subthreshold binge-eating disorder, and culminating in BED as the most severe subtype [6]. Accordingly, in this study, both binge eating and LOC-eating are conceptualized as varying degrees of severity within the broader construct of binge eating symptomatology. Three longitudinal studies examined the progression of LOC-eating symptoms in children and adolescents from the general population. These studies, which were conducted in Germany or the United States, included participants aged 6–13 years and spanned periods of one to five years [13–15]. Results of these studies revealed three trajectories among youth who initially exhibited LOC-eating behaviors: some experienced remission from these behaviors, others displayed recurrent LOC-eating behaviors (symptoms present at multiple timepoints), and a small percentage maintained persistent LOC-eating behaviors (symptoms present at all timepoints). The results also suggest that LOC-eating may be a precursor to BED in adults since it has been associated with the onset of subthreshold or full-syndrome BED over time. While these studies are very interesting in that they identify LOC-eating as a precursor to BED, much remains to be done to better identify which individuals with LOC-eating will progress to BED.

## Developmental model of BED

Tanofsky-Kraff et al. [6] proposed a theoretical and multifactorial model that aims to explain the transition from LOC-eating in childhood and adolescence to BED in adulthood, thereby helping to identify youth at risk of developing BED. This model highlights three key domains: negative affectivity, sensitivity to reward, and executive functioning. Research has linked these constructs to specific brain networks [16], indicating that they serve as proxies for the underlying neural mechanisms involved in emotion regulation, reward processing, and executive functions. More specifically, the model posits that youth exhibiting LOC-eating symptoms, particularly those with high levels of negative affectivity, heightened sensitivity to reward, and executive functioning difficulties—attributable to dysfunctions in their associated neural networks—are at greater risk of following a pathological trajectory, especially in the absence of adequate intervention. Studies have provided support for various aspects of this model.

### Negative affectivity

According to Krog and Duel (2003), negative affectivity reflects a disposition for having negative emotional reactions to one's surroundings and to oneself [17]. Negative affect includes several aversive mood states, including anger, guilt, fear, anxiety and depression [18]. In the field of eating behavior research, increased negative affectivity is considered a trigger for episodes of binge-eating symptomatology [19].

Preliminary findings in youths provide support for this hypothesis. To robustly establish the link between negative affect and binge-eating, longitudinal studies have been particularly valuable, as they allow for the examination of these associations over time. One study reported that initial levels of depression significantly predict LOC-eating and binge-eating [20]. Other studies focusing on children and adolescents from the general population have shown that anxiety symptoms also predict binge-eating [21–23]. These studies suggest that physical anxiety symptoms [21, 23] and possibly social anxiety [21] might be key factors in the development of BED. However, a significant limitation of these studies is that most

included both children and adolescents, despite the different developmental stages they represent. Owing to their ongoing brain development, adolescents may face unique challenges in effectively regulating their emotions, placing them at increased risk for anxiety and other stress-related disorders [24]. This developmental distinction could be crucial in understanding the association between negative affect, LOC-eating and BED. However, some studies have not established a clear connection between negative affect and binge-eating symptomatology [25, 26]. In these studies, negative affect was measured via indicators such as guilt, anger, loneliness, and sadness.

#### Executive functioning

Executive function encompasses a range of cognitive processes essential for goal-directed behavior, including planning, working memory, set-shifting, decision-making, error monitoring and correction, sequencing of complex actions, inhibition of habitual responses, and resistance to tempting stimuli [27–29]. These functions are crucial for the self-regulation of eating behaviors. Executive function continues to develop throughout adolescence, with some functions maturing more rapidly than others [30]. While this uneven development can be associated with unique challenges during this period, research on the relationship between executive functioning and binge-eating symptomatology in youth is limited and presents mixed findings.

Previous studies using objective measures of executive functions have found associations with binge-eating symptoms [31–33], others employing similar methods have not observed clear associations [34–35]. Similarly, studies using self-reported measures of executive functioning, including the Behavior Rating Inventory of Executive Function (BRIEF) used in the present study, have yielded mixed results, with some reporting significant associations [14, 36–42], while others did not [e.g., 43]. Among those that have found a connection, inhibitory control, which involves the ability to suppress inappropriate or impulsive responses in favor of more appropriate ones [44], has been associated with LOC-eating and binge-eating in some studies [39, 40], although this finding is not generalized [43]. Recently, working memory and set-shifting—components of executive function that involve retaining task-relevant information and flexibly adapting to changing goals [45]—have been linked to binge-eating in youth [40]. Although it remains challenging to definitively determine which aspects of executive function are most closely associated with the severity of binge-eating symptomatology, there is evidence suggesting that some executive function difficulties may play a significant role.

#### Reward sensitivity

Reward sensitivity is a motivational process that reflects an individual's tendency to detect and pursue rewarding and appetizing stimuli [46]. Individuals with binge-eating symptomatology show increased reward sensitivity, as evidenced by heightened activity in neural regions associated with reward processing (e.g., the ventral striatum and ventromedial prefrontal cortex) [47–49]. This heightened sensitivity has also been demonstrated in behavioral tasks [39, 50–52] and through self-reported measures [14, 39]. Two specific subcomponents of reward sensitivity—attentional biases [49–52] and positive reinforcement [14, 47, 48]—have been consistently associated with LOC-eating and binge-eating in previous studies. Attentional bias refers to the tendency to focus on specific stimuli, such as food cues [53], whereas positive reinforcement involves the expectation of positive outcomes from eating [6]. However, only one study has specifically examined adolescents, finding that heightened activity in neural regions associated with reward processing was linked to the severity of binge-eating [48]. Although it is well established that reward sensitivity peaks during adolescence [54], research on these associations in this age group remains limited. This study will therefore focus on the aspects of attentional biases and positive reinforcement that have been previously associated with binge-eating symptomatology.

#### Objectives and hypotheses

According to the model proposed by Tanofsky-Kraff and colleagues (2020), the interaction of negative affect, executive functioning and reward sensitivity could help identify young people most at risk of developing BED [6]. However, an empirical examination of all these components in a model has not yet been conducted. Therefore, the aim of the present study is to provide a preliminary empirical validation of the key components of the theoretical developmental model of BED via structural equation modeling (SEM). Based on the literature, we hypothesize that binge-eating symptomatology is associated with a pattern characterized by a greater presence of negative emotions (measured by depressive symptoms, physical symptoms of anxiety and social anxiety), reward sensitivity (measured by food reinforcement and attentional biases toward food cues), and difficulties in executive functioning. Since previous studies in adolescents have revealed differences in variables of interest between boys and girls (i.e [55–57]), as well as between different stages of adolescence (i.e [54, 58], a secondary aim of the present study is to assess the influence of gender and age on the configuration of the model and its relationships.

## Materials and methods

### Participants and procedure

A sample of 969 adolescents (571 girls, 397 boys, and one missing value) was recruited from seven schools (three private and four public) to participate in a larger study on the eating behaviors of adolescents. The only inclusion criterion was being aged between 12 and 18 years, with no exclusion criteria applied. Consent was obtained directly from participants aged 14 to 18[1], whereas parental consent was required for those younger than 14 [59]. Initial recruitment involved emailing the principals of public and private schools in Quebec city and the surrounding area to gauge their interest in the study. Principals who agreed to participate distributed the survey link to their students. The survey was administered via LimeSurvey [60], which is compatible with various electronic devices, including smartphones, tablets, and computers. To incentivize participation, a small financial incentive was offered in the form of a chance to win a $25 gift card. The study received approval from the Laval University Research Ethics Committee.

### Measures

#### *Binge-eating symptomatology severity*

The Binge-Eating Scale (BES) is a 16-item self-report questionnaire designed to assess behavioral, cognitive, and emotional symptoms associated with binge-eating episodes [61]. For each item, the participants select one of four statements that best describes their situation. Each item is assigned a weight on the overall scale on the basis of its severity, ranging from 0 to 3. The total score, which can range from 0 to 46, is calculated by summing the scores of all the items. A total score of 18 or more indicates more severe binge-eating symptomatology. The scale has been validated in an adolescent sample from a different cultural background [62] and was effectively used in previous research with adolescents from nonclinical populations [63–65]. Notably, Pasold et al. (2014) previously used this scale in a sample of adolescents (12–17 years) and showed similar prevalence of binge-eating symptoms than previous studies, as well as correlations between BES and related constructs [65].

The BES was selected in this study because it assesses binge-eating symptom severity along a continuum. As outlined by Tanofsky-Kraff et al. (2020), binge-eating behaviors range in severity, with LOC eating representing the less severe end, followed by binge-eating, subthreshold binge-eating disorder, and culminating in BED as the most severe form [6]. The BES captures this full range of symptom severity, making it a valuable tool for assessing both LOC-eating and more severe binge-eating behaviors. Supporting this conceptualization, Bodell et al. (2018) found strong correlations (ranging from 0.78 to 0.80) between the BES and LOC-eating measures in a nonclinical sample with a mean age of 19.6 years [66]. These findings suggest that the BES effectively captures core features of LOC-eating. Given that LOC-eating is considered a central feature of binge-eating pathology, using the BES allows for a more comprehensive assessment of binge-eating severity across different levels of symptom expression. In the present study, the questionnaire demonstrated excellent internal consistency (Cronbach's alpha = 0.89).

### Negative affectivity

#### *Depressive symptoms*

The Beck Depression Inventory (BDI), a 21-item self-report questionnaire, was used to assess depressive symptoms experienced over the past two weeks [67]. Each symptom is rated on a 4-point Likert scale from 0 (not associated with any suffering) to 3 (associated with intense suffering), and the total score ranges from 0 to 63. A score from 0 to 13 indicates normal to minimal depressive symptoms, a score from 14 to 19 indicates mild to moderate depressive symptoms, a score from 20 to 28 indicates moderate depressive symptoms, and a score from 29 to 63 indicates severe depressive symptoms. The BDI has demonstrated good psychometric properties for large-scale screening of depressive symptoms in high school adolescents [68–70]. In the current study, the BDI had a Cronbach's alpha of 0.90, indicating good internal consistency.

#### *Anxiety symptoms*

The Multidimensional Anxiety Scale for Children - Self Report (MASC) [71] is a 39-item self-report questionnaire utilized to evaluate emotional, cognitive, physical, and behavioral symptoms associated with anxiety in children and adolescents aged 8 to 19 years. The participants responded to each item on a 4-point Likert scale ranging from 0 (rarely true about me) to 3 (often true about me). These items can be categorized into four subscales: (1) physical symptoms, (2) social anxiety, (3) harm avoidance, and (4) separation anxiety. In this study, the Physical Symptoms and Social Anxiety subscales were employed, as research has shown their distinct contributions to the association with binge-eating symptomatology [21, 23]. The subscales consist of 12 and 9 items, respectively. The total scores for these subscales ranged from 0 to 36 and 0 to 27, respectively. Both subscales demonstrated good internal consistency, with Cronbach's alphas of 0.86 for the physical symptoms' subscale and 0.90 for the social anxiety subscale.

[1] In Canada, research ethics guidelines allow for minors aged 14 and older to provide their own consent in minimal-risk studies, depending on provincial regulations and ethics board approvals [56].

### Executive functioning

The Behavior Rating Inventory of Executive Function–Self-Report Version (BRIEF-SR) is an 80-item self-report questionnaire designed to assess adolescents' (ages 11–19) perceptions of their executive functions or self-regulatory strengths and weaknesses in everyday life [72]. The items are scored on a 3-point Likert scale ranging from 1 (never) to 3 (often), reflecting the frequency of certain behaviors over the past six months. Responses can be combined into two indices: the behavioral regulation index (BRI) and the metacognition index (MI). These indices have been independently associated with binge-eating symptomatology in previous studies [41, 73]. The BRI includes subscales for inhibition, shift, emotional control, and monitoring, whereas the MI includes subscales for working memory, planning/organizing, organization of materials, and task completion. The total scores for these subscales ranged from 34 to 102 and 42 to 126, respectively, with higher scores indicating greater difficulties. In this study, both indices demonstrated good internal consistency, with Cronbach's alphas of 0.83 for the BRI and 0.89 for the MI.

### Sensitivity to reward

The Food Craving Questionnaire–Trait (FCQ-T) [74] is a 37-item self-report questionnaire designed to assess various dimensions of food cravings. These dimensions include (1) having intentions and plans to consume food, (2) anticipation of positive reinforcement from eating, (3) anticipation of relief from negative states and feelings through eating, (4) lack of control over eating, (5) thoughts or preoccupation with food, (6) craving as a physiological state, (7) emotions experienced before or during food cravings or eating, (8) cues that trigger food cravings, and (9) guilt from cravings and/or yielding to them. In the present study, we used the subscales of anticipation of positive reinforcement from eating (comprising 5 items) and cues that trigger food cravings (comprising 4 items) to assess food reinforcement and attentional biases toward food cues. These components of sensitivity to reward have been consistently associated with binge-eating symptomatology [14, 49, 51]. The participants rated how often each statement applied to them generally via a five-point Likert scale ranging from 0 (never) to 4 (always). The total scores for the food reinforcement subscale ranged from 0 to 20, whereas the total scores for the attentional biases toward food cues subscale ranged from 0 to 16. Both subscales demonstrated good internal consistency, with Cronbach's alphas of 0.87 for the food reinforcement subscale and 0.80 for the attentional biases toward food cues subscale.

### Statistical analysis

In the first step, descriptive analyses were conducted via SPSS version 25.0. Statistical significance was set at an alpha level of 0.05, and effect sizes were interpreted following Cohen's guidelines (2013) [75].

Next, the assumptions for multivariate analyses were verified before proceeding to structural equation modeling (SEM) [76]. Specifically, multicollinearity among the study variables was assessed using the variance inflation factor (VIF), with a threshold value of 5 [77]. Since all assumptions except for normality were met, we used the maximum likelihood (MLR) estimator, which provides fit indices and standard errors robust to nonnormal distributions [78]. Missing data for the examined variables were minimal and were handled via full information maximum likelihood estimation (FIML). Moreover, the required sample size for the study was determined on the basis of Bentler and Chou's (1987) recommendation of 10 observations per parameter [79]. Consequently, 210 participants were necessary to adequately test the model.

Mplus 8 [78] was used to conduct SEM to test the proposed model, as presented in Figs. 1 and 2. Specifically, the model involved a multiple linear regression of negative affectivity, executive functioning, and sensitivity to reward on binge-eating symptomatology severity, with all three predictors modeled as latent variables. Indicators of these latent variables are presented in Figs. 1 and 2. While the model did not include explicit interaction terms, SEM accounts for shared variance among predictors, allowing for the assessment of their unique and combined contributions to the outcome variable. Given previous research showing differences between boys and girls in key variables in adolescence (e.g [55–57]), the model was tested separately for each gender. The validity and reliability of each latent factor were assessed by calculating the average variance extracted (AVE) and composite reliability (CR). According to the Fornell and Larcker criterion (1981), the AVE values should exceed 0.500, and the CR values should exceed 0.700 [80]. Commonly used goodness-of-fit indices were examined to assess the acceptability of the model. Specifically, the comparative fit index (CFI; ≥ 0.90 for acceptable; ≥ 0.95 for excellent), the Tucker–Lewis index (TLI; ≥ 0.90 for acceptable; ≥ 0.95 for excellent), and the root-mean-square error of approximation (RMSEA; ≤ 0.08 for acceptable; ≤ 0.06 for excellent) with 90% CI were used [81–84]. Finally, multigroup invariance analyses were performed to determine if the structural models were equivalent across age groups. The participants were divided into two brackets on the basis of the Centers for Disease Control and Prevention (CDC) chart (2022) [85]: young teens (12–14 years; $n = 349$) and teenagers (15–18 years; $n = 612$). To test invariance, constrained and unconstrained models were compared by examining changes in chi-square,

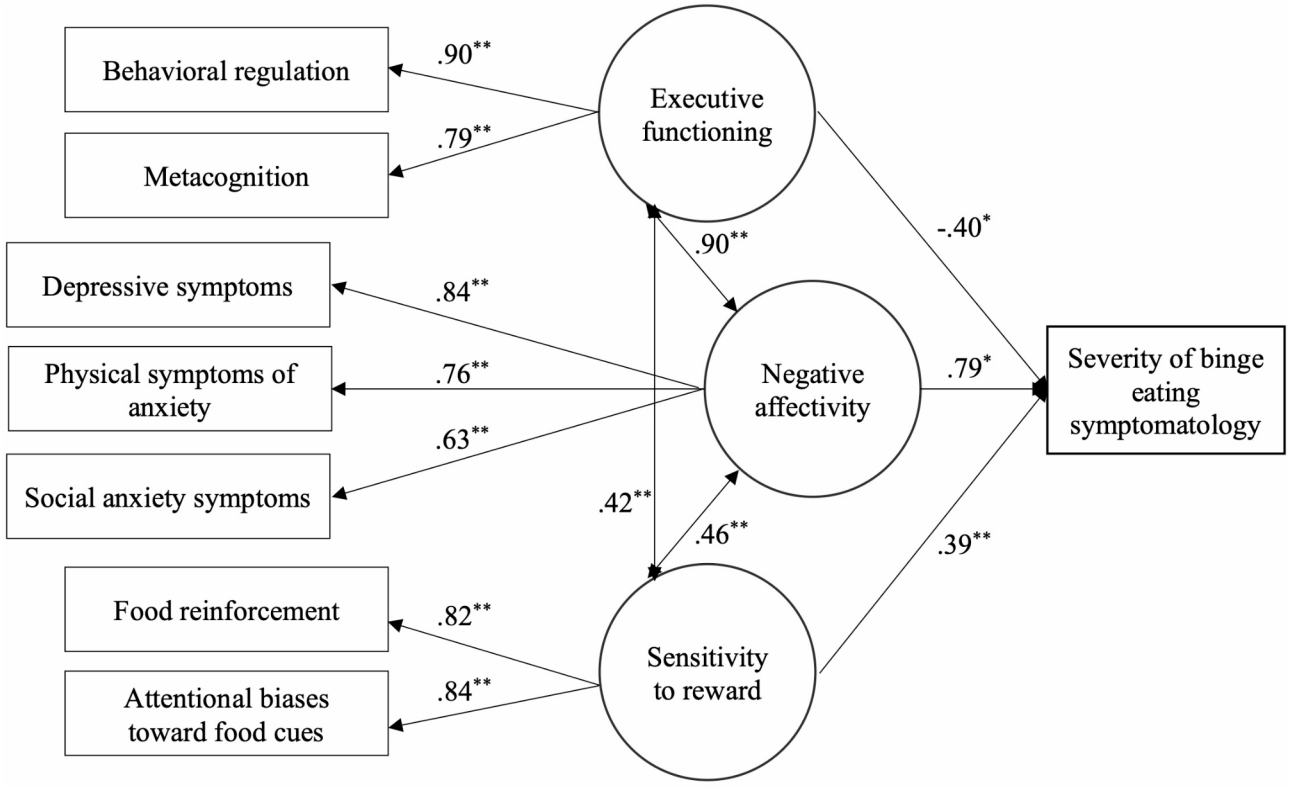


**Fig. 1** Structural equation model of the severity of binge-eating symptomatology in adolescent girls (A1). *Note.* The one-headed arrows represent standardized regression weights, and the double-headed arrows represent correlations

CFI, TLI, and RMSEA. Invariance was indicated when the constrained and unconstrained estimated models did not differ significantly, as evidenced by a nonsignificant chi-square difference test, minimal changes in CFI and TLI ($\Delta$CFI ≤ 0.01; $\Delta$TLI ≤ 0.01), and minimal increases in RMSEA ($\Delta$RMSEA ≤ 0.015) [86, 87]. In such cases, model fit was improved by removing one or more equality constraints on model parameters across age groups, resulting in subsequent test evaluations of partial invariance [88].

## Results

The final sample consisted of 59.0% girls and 41.0% boys, with a mean age of 14.91 years (*SD* = 1.31). According to ethnic identity, 93.0% of the sample identified as Caucasian, 1.5% Asian, 1.4% Hispanic, 1.4% Indigenous/Aboriginal, 1.1% African American, and 0.5% with other ethnic identities. According to the World Health Organization body mass index-for-age percentile growth charts for Canada [89], among the 886 participants whose height and weight were reported, 31 participants (3.5%) were at risk for underweight, 670 participants (75.6%) had a healthy weight, 128 participants (14.4%) were overweight, 48 participants (5.4%) were obese, and nine participants (1%) had severe obesity. The distribution of this sample (14.4% overweight and 6.4% obesity) closely mirrored the rates of overweight (16.0%) and obesity (8.3%) reported in a Quebec survey on adolescent health and lifestyle conducted in 2020 and 2021 [90]. The results indicated that 5.8% of the participants ($n$ = 51) scored 18 or higher on the BES, suggesting more severe binge-eating symptomatology. Additionally, binge-eating symptomatology was positively associated with all the variables, with small to medium effect sizes. Descriptive statistics and correlations between the variables are presented in Table 1.

### Structural equation model (SEM)

Model fit indices of the examined models are presented in Table 2. Figures 1 and 2 illustrate the SEM results for girls and boys, respectively. The model for boys (B1) was saturated, resulting in perfect fit indices: CFI = 1.00, TLI = 1.00, and RMSEA = 0.00. The model for girls (A1) demonstrated an excellent fit to the data, as reflected by the following fit indices: CFI = 0.98, TLI = 0.96, and RMSEA = 0.06. Additionally, the validity and reliability of each latent factor were confirmed, with CR values ranging from 0.76 to 0.84 for boys and 0.80 to 0.83 for girls and AVE values ranging from 0.71 to 0.94 for boys and 0.69 to 0.95 for girls. The absence of multicollinearity was also verified, with VIF values ranging from 1.60 to 3.19.

A comparison of the models for adolescent boys and girls revealed several similarities. The item loadings onto their respective latent factors were consistently strong

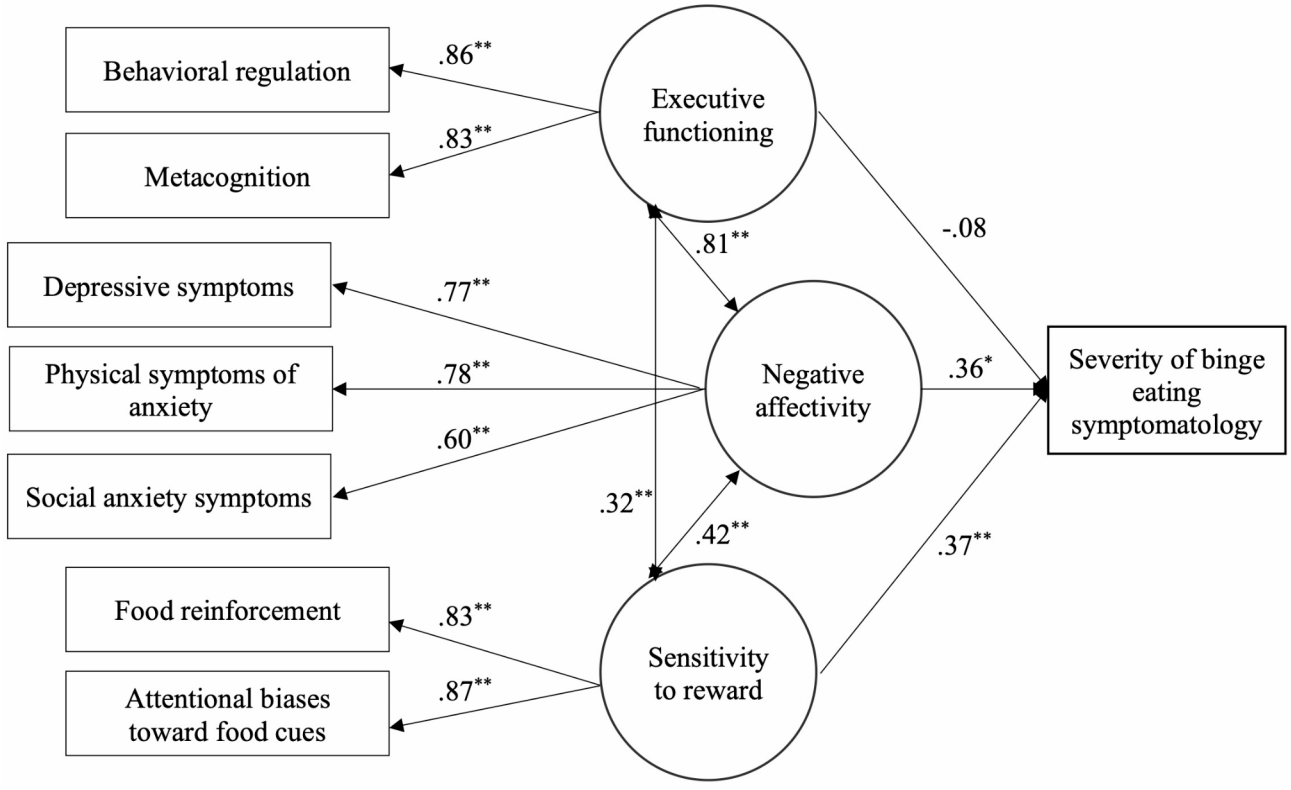


**Fig. 2** Structural equation model of the severity of binge-eating symptomatology in adolescent boys (B1). *Note.* The one-headed arrows represent standardized regression weights, and the double-headed arrows represent correlations

**Table 1** Descriptive statistics and bivariate correlations

| Variable | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Binge-eating symptomatology | 5.9 | 6.19 | - | | | | | | | |
| 2. Depressive symptoms | 9.1 | 8.72 | 0.51** | - | | | | | | |
| 3. Physical symptoms of anxiety | 10.1 | 6.87 | 0.44** | 0.63** | - | | | | | |
| 4. Social anxiety symptoms | 11.0 | 7.30 | 0.36** | 0.50** | 0.58** | - | | | | |
| 5. Behavioral regulation | 49.8 | 11.00 | 0.39** | 0.63** | 0.59** | 0.46** | - | | | |
| 6. Metacognition | 65.3 | 15.09 | 0.31** | 0.56** | 0.48** | 0.36** | 0.70** | - | | |
| 7. Food reinforcement | 7.0 | 4.86 | 0.45** | 0.29** | 0.29** | 0.27** | 0.30** | 0.24** | - | |
| 8. Attentional biases to food cues | 6.8 | 4.00 | 0.49** | 0.30** | 0.29** | 0.29** | 0.26** | 0.24** | 0.71** | - |

**Table 2** Model fit indices of the examined models

| Models | χ2(df) | CFI | TLI | RMSEA |
|---|---|---|---|---|
| A1. SEM of binge-eating symptomatology in girls | 45.35(15) | 0.980 | 0.963 | 0.060 |
| A2. Same as A1, grouping by age (i.e., young teens and adolescents) | 75.89(34) | 0.972 | 0.955 | 0.066 |
| A3. Same as A2, with parameters constrained to be equal between age groups | 139.45(48) | 0.940 | 0.930 | 0.083 |
| A4. Same as A3, with some parameters allowed to vary between age groups[1] | 94.21(44) | 0.9767 | 0.958 | 0.064 |
| B1. SEM of binge-eating symptomatology in boys | 13.03(15) | 1.000 | 1.000 | 0.000 |
| B2. Same as B1, grouping by age (i.e., young teens and adolescents) | 45.72(36) | 0.988 | 0.981 | 0.037 |
| B3. Same as B2, with parameters constrained to be equal between age groups | 77.33(50) | 0.966 | 0.962 | 0.053 |
| B4. Same as B3, with some parameters allowed to vary between age groups[2] | 49.14(45) | 0.995 | 0.994 | 0.022 |

[1] The parameters allowed to vary were the associations between (1) executive functioning and binge-eating symptomatology severity, and (2) reward sensitivity and binge-eating symptomatology severity

[2] The parameters allowed to vary were the associations between (1) executive functioning and binge-eating symptomatology severity, (2) reward sensitivity and binge-eating symptomatology severity, and (3) negative affectivity and binge-eating symptomatology severity

and statistically significant ($p$ <.001) for both genders. Small to large correlations were also found among the three latent factors in both groups ($p$ <.001). Sensitivity to reward was positively and significantly associated with binge-eating symptomatology in both boys ($\beta$ = 0.37, $p$ <.001) and girls ($\beta$ = 0.39, $p$ <.001), with a small effect size. However, key differences emerged between boys and girls. Negative affectivity was positively related to binge-eating symptomatology in both groups, but with a small effect size for boys ($\beta$ = 0.36, $p$ =.036) and a medium effect size for girls ($\beta$ = 0.79, $p$ <.001). Furthermore, executive functioning was not significantly linked to binge-eating symptomatology in boys ($\beta$ = −0.08, $p$ =.579), whereas it was significantly negatively related to binge-eating symptomatology in girls ($\beta$ = −0.40, $p$ =.043). The model accounted for 31.7% of the variance in binge-eating symptomatology in boys and 52.3% in girls.

#### Age group invariance analyses

Finally, multigroup invariance analyses were performed to determine if the structural models (A1 and B1) were equivalent across age groups. The participants were divided into two brackets [85]: young teens (12–14 years; $n$ = 349) and teenagers (15–18 years; $n$ = 612). To test invariance, constrained (A3 and B3) and unconstrained models (A2 and B2) were compared. Changes in fit indices exceeded the acceptable thresholds ($\Delta$CFI ≤ 0.010; $\Delta$TLI ≤ 0.010; $\Delta$RMSEA ≤ 0.015), and the corrected chi-square difference tests were significant (girls: $\chi$2 = 58.55; $p$ ≤.001; and boys: $\chi$2 = 28.98; $p$ =.011), indicating that full invariance was not supported. Nevertheless, partial invariance was achieved when the associations between executive functioning and reward sensitivity with binge-eating symptomatology were allowed to vary between age groups for girls (A4). Similarly, partial invariance was supported when associations between executive functioning, reward sensitivity, and negative affectivity with binge-eating symptomatology were allowed to differ between age groups for boys (B4).

Key differences emerged between young teens and teenagers in the associations that were allowed to vary (A4 and B4). In girls, executive functioning was not significantly related to binge-eating symptomatology in younger adolescents ($\beta$ = −0.35, $p$ =.069) but were significantly and negatively associated with these symptoms in older adolescents ($\beta$ = −0.49, $p$ =.011). In boys, executive functioning was not a significant factor for binge-eating symptomatology in either younger adolescents ($\beta$ = 0.15, $p$ =.225) or older adolescents ($\beta$ = −0.49, $p$ =.011). In both genders, reward sensitivity was unrelated to binge-eating symptomatology in younger adolescents (girls: $\beta$ = 0.20, $p$ =.136; boys: $\beta$ = −0.07, $p$ =.704) but was significantly associated with these symptoms in older adolescents (girls: $\beta$ = 0.41, $p$ <.001; boys: $\beta$ = 0.42, $p$ <.001). Finally, for boys, negative affect was strongly and positively linked to binge-eating symptomatology in younger adolescents ($\beta$ = 1.08 $p$ =.003), but this association was not significant in older adolescents ($\beta$ = 0.08, $p$ =.562).

## Discussion

The developmental model of BED proposed by Tanofsky-Kraff et al. (2020) aims to explain and predict the transition from LOC-eating in childhood and adolescence to BED in adulthood [6]. In this cross-sectional study, we simultaneously tested the factors proposed in this model using data from a large sample of adolescents. Our findings support key components of this model, offering valuable insights into the combined association of these variables while underscoring the importance of considering individual factors such as age and gender, as highlighted by Tanofsky-Kraff et al. (2020) [6].

Results show that negative affect was significantly associated with the severity of binge-eating symptomatology in both boys and girls. These results align with prior research showing links between binge-eating symptomatology and symptoms of depression [20] and anxiety [21–23]. Our results can be contextualized within the framework of affect theory, which suggests that adolescents may engage in binge-eating as a means of escaping or alleviating negative emotions [91]. For example, adolescents with depressive symptoms might resort to binge-eating symptomatology to improve their mood or counteract feelings of hopelessness, irritability, guilt, and worthlessness [92]. Similarly, those experiencing physical symptoms of anxiety might engage in binge-eating to reduce fears related to bodily sensations and their perceived consequences [93], whereas adolescents with social anxiety might do so to ease fears of negative judgment, embarrassment, and social interactions [94]. To examine the relationship between negative affect and LOC eating many researchers have used ecological momentary assessment capturing negative emotions immediately preceding binge-eating episodes (e.g., [95–96]). Our study, which assessed general symptoms of depression and anxiety rather than momentary fluctuations in affect, suggests that an overall heightened level of negative affectivity is associated with greater binge-eating severity, even when these symptoms are not captured at the exact moment that precedes binge episodes. This highlights the importance of considering both stable affective traits and transient emotional states in understanding the role of negative affect in binge-eating.

The association between negative affect and binge-eating symptomatology was stronger in girls than in boys, a finding that has been well-documented in the literature, including meta-analyses and reviews [e.g., 97–98]. This pattern is also supported by a recent Canadian study of 67 248 adolescents from the general population, which

reported higher levels of anxiety and depressive symptoms in cisgender girls compared to cisgender boys [56]. Additionally, our results revealed a strong and positive association between negative affect and binge-eating symptomatology in younger adolescents, whereas this relationship was weaker or not significant in older adolescents. Adolescence is a developmental period marked by significant social, psychological, and biological changes, along with considerable brain reorganization in both structure and function [99, 100]. Furthermore, this period is recognized as a sensitive window for the development of cognitive functions, including affect regulation [101]. As emotion regulation capacities typically improve throughout adolescence, this may explain the weaker association between negative affect and binge-eating symptomatology observed in older adolescents within our sample.

In addition, our findings revealed significant associations between both attentional biases toward food cues and positive reinforcement with the severity of binge-eating symptomatology in both boys and girls. Previous studies have shown that some individuals assign greater incentive salience (i.e., motivational value) to food cues [14, 34, 44–49]. In environments with access to highly palatable foods, heightened reward sensitivity may increase the likelihood of more severe binge-eating symptomatology. While previous research has linked attentional biases to food cues and positive reinforcement with LOC-eating in children and binge-eating in adults [14, 39, 47–52], our findings contribute to the literature by confirming that these associations are also relevant in adolescents, even when accounting for other factors, such as negative affectivity and executive functioning.

The relation between heightened sensitivity to reward and binge-eating symptomatology was similar for both boys and girls. These results are supported by those reported by Altikulaç and colleagues (2019) in their study of 271 adolescents and young adults, which found that most aspects of sensitivity to reward—such as admiration (enjoyment of being flattered, liked, and gaining positive attention), passivity (enjoyment of giving others control over decisions), and sociability (enjoyment of engaging in group interactions)—were similar between girls and boys [55]. Additionally, we found that reward sensitivity was unrelated to binge-eating symptomatology in younger adolescents but was significantly associated with these symptoms in older adolescents. These evolving relationships, where negative affect is more strongly associated with binge-eating symptomatology in younger adolescents but weakens with age, while reward sensitivity is not linked in younger adolescents but becomes strongly associated in older adolescents, suggest developmental shifts in how these factors interact.

Finally, although univariate analyses revealed a significant positive association between executive functioning difficulties and binge-eating symptomatology severity in our study, this association changed when negative affect and reward sensitivity are introduced in the multivariate analysis, becoming either nonsignificant for boys or negative for girls, a phenomenon known as the suppression effect. Given the high correlation between negative affect and executive functioning difficulties, it is likely that negative affect acts as the suppressor variable in this study. One possible explanation for our results is that self-reported executive function difficulties may share overlapping variability with traits such as negative affectivity and sensitivity to reward. This overlap could account for the changes observed when these factors are examined together. This result suggests the hypothesis that, in emotionally challenging situations—where food may be viewed as a means of emotional relief—negative affect and reward sensitivity may play a more significant role in driving eating impulses than executive functioning alone in both younger and older adolescents. This perspective is consistent with previous research involving adult participants, which suggests that depressive symptoms may play a more significant role in driving binge-eating behaviors than difficulties with executive functioning [102].

In general, our findings underscore the critical role of age in shaping the relationship between the studied factors. One plausible explanation for the observed age-related differences is provided by Moore et al. (2017), who suggest that the rewarding effects of consuming large quantities of high-calorie foods decline over time due to decreased dopaminergic transmission in the ventral striatum [103]. Consequently, older adolescents with binge-eating symptomatology may transition from using food primarily to alleviate negative emotions to using it as a means of reactivating a weakened reward circuit. As Tanofsky-Kraff et al. (2020) emphasized, emotion regulation—the cognitive and behavioral processes involved in managing emotions and related behaviors—may be a key element in explaining these dynamics [6]. Specifically, deficits in emotion regulation could undermine adolescents' capacity to navigate negative affect and resist the impulse to consume highly palatable foods, particularly those with heightened reward sensitivity. In line with this hypothesis, a moderation analysis revealed a significant interaction between negative affect and reward sensitivity ($\beta = 0.44$, $p < .001$), indicating that the association between negative affect and binge-eating severity was stronger among individuals with higher reward sensitivity. The full results, including a graphical representation of this interaction, are provided in the supplementary material. For clinicians working with adolescents displaying binge-eating behaviors, it is crucial to assess the underlying mechanisms driving these behaviors to design

tailored treatment approaches that address the unique contributing factors at different developmental stages. Finally, future longitudinal research will be instrumental in unraveling how these relationships evolve throughout adolescence.

### Strenghts and limitations

This study has several strengths. First, the large sample size enhances the statistical power and generalizability of our findings. Second, the use of SEM allowed us to test complex relationships between variables, providing a more comprehensive understanding of the mechanisms underlying the severity of binge-eating symptomatology. Third, our study is firmly grounded in existing theoretical models, integrating well-established concepts from the literature on negative affect, reward sensitivity, and binge-eating. Finally, the study has important clinical implications, as it highlights potential targets for early intervention.

This study has several limitations. First, its cross-sectional design does not allow for causal inferences; thus, longitudinal research is needed to explore the temporal relationships between risk factors, LOC-eating symptoms, and their potential progression to BED. We cannot confirm whether participants with elevated negative affectivity, reward sensitivity, and executive function difficulties have developed or will develop BED, making longitudinal studies essential for these conclusions. Second, our model did not account for genetic, familial, cultural, or environmental factors, despite the acknowledgment that these multilevel factors surely contribute to the development of BED. Additionally, the constructs were assessed via self-reported measures, which may have been influenced by social desirability bias. The use of a self-reported measure of executive functioning (BRIEF-SR) may have influenced our findings. While previous studies using objective measures have found associations between executive functioning and binge-eating symptoms [31–33], others employing similar methods have not observed clear associations [34–35]. Similarly, studies using self-reported measures of executive functioning have yielded mixed results, with some reporting significant associations [14, 36–42], while others did not [e.g., 43]. Although there is some conceptual overlap between self-report and objective tools assessing executive functioning, these instruments measure related but distinct constructs. This distinction is reflected in the typically modest correlations between the BRIEF-SR and objective executive functioning tasks [35]. Some researchers argue that the BRIEF's behavioral focus makes it especially relevant for understanding real-world eating behaviors [104], but it remains possible that different results would have emerged had an objective measure been used instead. Furthermore, the BRIEF-SR assesses perceived difficulties in executive functioning, which may be subject to biases related to individual differences in self-perception. Specifically, adolescents with higher levels of negative affect, such as anxiety or depression, may be more likely to report executive functioning difficulties on both self-reported questionnaires [104] and performance-based tasks [105], regardless of their actual cognitive abilities. Finally, gender in our study was measured dichotomously as either male or female, limiting our ability to test the model's invariance across different gender identities. We recommend adopting an intersectional approach in future research, taking into account variables such as gender identity and cultural identity, to explore whether these factors may also influence the relationships between variables.

## Conclusion

This study is the first to empirically assess all individual components of the developmental model of BED in an adolescent population. Our findings indicate that the adolescents most at risk for severe binge-eating symptomatology are those with elevated negative affect and heightened reward sensitivity. Moreover, our findings suggest that binge-eating symptomatology may differ between younger and older adolescents, potentially reflecting distinct underlying mechanisms at each developmental stage. This research advances BED prevention efforts by identifying youth most at risk for more severe binge-eating symptoms and highlighting key constructs to target in preventive interventions.

Future research should expand on these findings by providing deeper insights into how the components of the model interact over time and contribute to the development of BED in adolescents with LOC-eating symptoms. As we advance our knowledge in this area, we can better support adolescents at risk and work toward reducing the incidence of BED.

## Supplementary Information

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Supplementary Material 1

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#### Author contributions

CC conducted the data analysis, interpreted the findings, and drafted the manuscript. CR contributed to the study's conception, oversaw data acquisition, provided substantial input to the analyses, interpretation of data and manuscript revisions. CB contributed to the study's conception and provided significant feedback on the manuscript. All authors reviewed and approved the final version of the manuscript.

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**Data availability**
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
The study received approval from the Laval University Research Ethics Committee. Consent was obtained directly from participants aged 14 to 18, whereas parental consent was obtained for those younger than 14 [59].

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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**References**

1. Davis C. Compulsive overeating as an addictive behavior: overlap between food addiction and binge eating disorder. Curr Obes Rep. 2013;2(2):171–8. https://doi.org/10.1007/s13679-013-0049-8.
2. World Health Organization. Obesity and overweight [Internet], World Health Organization. 2024 Mar 1 [cited 2024 Nov 22]. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight
3. Blundell JE, MacDiarmid JI. Fat as a risk factor for overconsumption: satiation, satiety, and patterns of eating. J Am Diet Assoc. 1997;97(7 Suppl):S63–9. https://doi.org/10.1016/S0002-8223(97)00733-5.
4. Goldschmidt AB. Are loss of control while eating and overeating valid constructs? A critical review of the literature. Obes Rev. 2017;18(4):412–49. https://doi.org/10.1111/obr.12491.
5. McCuen-Wurst C, Ruggieri M, Allison KC. Disordered eating and obesity: associations between binge-eating disorder, night-eating syndrome, and weight-related comorbidities. Ann N Y Acad Sci. 2017;1411(1):96–105. https://doi.org/10.1111/nyas.13467.
6. Tanofsky-Kraff M, Schvey NA, Grilo CM. A developmental framework of binge-eating disorder based on pediatric loss of control eating. Am Psychol. 2020;75(2):189–203. https://doi.org/10.1037/amp0000592.
7. Qian J, Wu Y, Liu F, Zhu Y, Jin H, Zhang H, Wan Y, Li C, Yu D. An update on the prevalence of eating disorders in the general population: a systematic review and meta-analysis. Eat Weight Disord. 2021;1–14. https://doi.org/10.1007/s40519-021-01162-z.
8. Kjeldbjerg ML, Clausen L. Prevalence of binge-eating disorder among children and adolescents: a systematic review and meta-analysis. Eur Child Adolesc Psychiatry. 2023;32(4):549–74. https://doi.org/10.1007/s00787-021-01850-2.
9. Udo T, Grilo CM. Psychiatric and medical correlates of DSM-5 eating disorders in a nationally representative sample of adults in the united States. Int J Eat Disord. 2019;52(1):42–50. https://doi.org/10.1002/eat.23004.
10. Appolinario JC, Sichieri R, Lopes CS, Moraes CE, da Veiga GV, Freitas S, Nunes MAA, Hay P. Correlates and impact of DSM-5 binge eating disorder, bulimia nervosa and recurrent binge eating: a representative population survey in a middle-income country. Soc Psychiatry Psychiatr Epidemiol. 2022;57(7):1491–503. https://doi.org/10.1007/s00127-022-02223-z.
11. Grilo CM, White MA, Barnes RD, Masheb RM. Psychiatric disorder co-morbidity and correlates in an ethnically diverse sample of obese patients with binge eating disorder in primary care settings. Compr Psychiatry. 2013;54(3):209–16. https://doi.org/10.1016/j.comppsych.2012.07.012.
12. Kessler RC, Berglund PA, Chiu WT, Deitz AC, Hudson JI, Shahly V, Aguilar-Gaxiola S, Alonso J, Angermeyer MC, Benjet C, Bruffaerts R, de Girolamo G, de Graaf R, Haro JM, Kovess-Masfety V, O'Neill S, Posada-Villa J, Sasu C, Scott K, Viana MC, Xavier M. Biol Psychiatry. 2013;73(9):904–14. https://doi.org/10.1016/j.biopsych.2012.11.020. The prevalence and correlates of binge eating disorder in the World Health Organization World Mental Health Surveys.
13. Hilbert A, Hartmann AS, Czaja J, Schoebi D. Natural course of preadolescent loss of control eating. J Abnorm Psychol. 2013;122(3):684–93. https://doi.org/10.1037/a0033330.
14. Smith KE, Wang WL, Mason TB. Facets of impulsivity and reward in relation to binge-eating disorder course of illness among children: findings from the adolescent brain cognitive development study. J Child Psychol Psychiatry. 2023;64(7):1056–66. https://doi.org/10.1111/jcpp.13789.
15. Tanofsky-Kraff M, Shomaker LB, Olsen C, Roza CA, Wolkoff LE, Columbo KM, Raciti G, Zocca JM, Wilfley DE, Yanovski SZ, Yanovski JA. A prospective study of pediatric loss of control eating and psychological outcomes. J Abnorm Psychol. 2011;120(1):108–18. https://doi.org/10.1037/a0021406.
16. Hartogsveld B, Quaedflieg CWEM, van Ruitenbeek P, Smeets T. Volume and connectivity differences in brain networks associated with cognitive constructs of binge eating. eNeuro. 2022;9(1). https://doi.org/10.1523/ENEURO.0080-21.2021.
17. Krog T, Duel M. Traume symptom checkliste (TSC): En validering Og revidering [Trauma symptom checklist: A validation and revision]. Psykologisk Studieskriftserie. 2003;6(4):1–162.
18. Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. J Pers Soc Psychol. 1988;54(6):1063–70. https://doi.org/10.1037/0022-3514.54.6.1063.
19. Wonderlich JA, Crosby RD, Engel SG, Crow SJ, Peterson CB, Le Grange D, Wonderlich SA, Fischer S. Negative affect and binge eating: assessing the unique trajectories of negative affect before and after binge-eating episodes across eating disorder diagnostic classifications. Int J Eat Disord. 2022;55(2):223–30. https://doi.org/10.1002/eat.23648.
20. Sinclair-McBride K, Cole DA. Prospective relations between overeating, loss of control eating, binge eating, and depressive symptoms in a school-based sample of adolescents. J Abnorm Child Psychol. 2017;45(4):693–703. https://doi.org/10.1007/s10802-016-0186-0.
21. Cook-Cottone C, Serwacki M, Guyker W, Sodano S, Nickerson A, Keddie-Olka E, Anderson L. The role of anxiety on the experience of peer victimization and eating disorder risk. Sch Ment Health. 2016;8:354–67. https://doi.org/10.1007/s12310-016-9178-z.
22. Lim MC, Parsons S, Goglio A, Fox E. Anxiety, stress, and binge eating tendencies in adolescence: a prospective approach. J Eat Disord. 2021;9(1):94. https://doi.org/10.1186/s40337-021-00444-2.
23. Schaumberg K, Zerwas S, Goodman E, Yilmaz Z, Bulik CM, Micali N. Anxiety disorder symptoms at age 10 predict eating disorder symptoms and diagnoses in adolescence. J Child Psychol Psychiatry. 2019;60(6):686–96. https://doi.org/10.1111/jcpp.12984.
24. Powers A, Casey BJ. The adolescent brain and the emergence and peak of psychopathology. J Infant Child Adolesc Psychother. 2015;14(1):3–15. https://doi.org/10.1080/15289168.2015.1004889.
25. Parker MN, LeMay-Russell S, Schvey NA, Crosby RD, Ramirez E, Kelly NR, Shank LM, Byrne ME, Engel SG, Swanson TN, Djan KG, Kwarteng EA, Faulkner LM, Zenno A, Brady SM, Yanovski SZ, Tanofsky-Kraff M, Yanovski JA. Associations of sleep with food cravings and loss-of-control eating in youth: an ecological momentary assessment study. Pediatr Obes. 2022;17(2):e12851. https://doi.org/10.1111/ijpo.12851.
26. Ranzenhofer LM, Engel SG, Crosby RD, Anderson M, Vannucci A, Cohen LA, Cassidy A, Tanofsky-Kraff M. Using ecological momentary assessment to examine interpersonal and affective predictors of loss of control eating in adolescent girls. Int J Eat Disord. 2014;47(7):748–57. https://doi.org/10.1002/eat.22333.
27. Allan JL, Johnston M, Campbell N. Missed by an inch or a mile? Predicting the size of intention-behaviour gap from measures of executive control. Psychol Health. 2011;26(6):635–50. https://doi.org/10.1080/08870441003681307.
28. Allan JL, McMinn D, Daly M. A bidirectional relationship between executive function and health behavior: evidence, implications, and future directions. Front Neurosci. 2016;10:386. https://doi.org/10.3389/fnins.2016.00386.
29. Hofmann W, Schmeichel BJ, Baddeley AD. Executive functions and self-regulation. Trends Cogn Sci. 2012;16(3):174–80. https://doi.org/10.1016/j.tics.2012.01.006.

30. Crone EA, Peters S, Steinbeis N. Executive function development in adolescence. In: Wiebe SA, Karbach J, editors. Executive function. Routledge; 2017. pp. 44–58.
31. Jarcho JM, Tanofsky-Kraff M, Nelson EE, Engel SG, Vannucci A, Field SE, Romer A, Hannallah L, Brady SM, Demidowich AP, Shomaker LB, Courville AB, Pine DS, Yanovski JA. Neural activation during anticipated peer evaluation and laboratory meal intake in overweight girls with and without loss of control eating. NeuroImage. 2015;108:343–53. https://doi.org/10.1016/j.neuroimage.2014.12.054.
32. Parker MN, Bloomer BF, Stout JD, Byrne ME, Schvey NA, Brady SM, Chen KY, Nugent AC, Turner SA, Yang SB, Stojek MM, Waters AJ, Tanofsky-Kraff M, Yanovski JA. A pilot randomized control trial testing a smartphone-delivered food attention retraining program in adolescent girls with overweight or obesity. Nutrients. 2024;16(20):3456. https://doi.org/10.3390/nu16203456.
33. Iceta S, Rodrigue C, Legendre M, Daoust J, Flaudias V, Michaud A, Bégin C. Cognitive function in binge eating disorder and food addiction: a systematic review and three-level meta-analysis. Prog Neuropsychopharmacol Biol Psychiatry. 2021;111:110400. https://doi.org/10.1016/j.pnpbp.2021.110400.
34. Rodrigue C, Iceta S, Bégin C. Food addiction and cognitive functioning: what happens in adolescents? Nutrients. 2020;12(12):3633. https://doi.org/10.3390/nu12123633.
35. Nelson TD, James TD, Nelson JM, Johnson AB, Mason WA, Yaroch AL, Espy KA. Associations between specific components of executive control and eating behaviors in adolescence: A study using objective and subjective measures. Appetite. 2020;154:104784. Available from: https://doi.org/10.1016/j.appet.2020.104784
36. Goldschmidt AB, Goldstein SP, Schmiedek F, Stalvey E, Irizarry B, Thomas JG. State-level working memory and dysregulated eating in children and adolescents: an exploratory ecological momentary assessment study. Int J Eat Disord. 2024;57(1):93–103. https://doi.org/10.1002/eat.24087.
37. Lee-Winn AE, Townsend L, Reinblatt SP, Mendelson T. Associations of neuroticism and impulsivity with binge eating in a nationally representative sample of adolescents in the united States. Pers Individ Differ. 2016;90:66–72. https://doi.org/10.1016/j.paid.2015.10.042.
38. Pearson CM, Zapolski TC, Smith GT. A longitudinal test of impulsivity and depression pathways to early binge eating onset. Int J Eat Disord. 2015;48(2):230–7. https://doi.org/10.1002/eat.22277.
39. Ramalho SM, Conceição E, Tavares AC, Freitas AL, Machado BC, Gonçalves S. Loss of control over eating, inhibitory control, and reward sensitivity in children and adolescents: a systematic review. Nutrients. 2023;15(12):2673. https://doi.org/10.3390/nu15122673.
40. Rozzell-Voss KN, Klimek-Johnson P, Eichen DM, Brown TA, Blashill AJ. Executive function differences as a function of parent-reported binge eating and weight: results from the adolescent brain cognitive development study. Obes Sci Pract. 2024;10(1):e703. https://doi.org/10.1002/osp4.703.
41. Van Malderen E, Goossens L, Verbeken S, Kemps E. Unravelling the association between inhibitory control and loss of control over eating among adolescents. Appetite. 2018;125:401–9. https://doi.org/10.1016/j.appet.2018.02.019.
42. Yan WS, Zheng DH, Liu MM. Trait impulsivity and choice impulsivity in young adult students with probable binge eating disorder. Front Psychiatry. 2022;13:838700. https://doi.org/10.3389/fpsyt.2022.838700.
43. Prunell-Castañé A, Jurado MÁ, García-García I. Clinical binge eating, but not uncontrolled eating, is associated with differences in executive functions: evidence from meta-analytic findings. Addict Behav Rep. 2021;13:100337. https://doi.org/10.1016/j.abrep.2020.100337.
44. Durston S, Thomas KM, Yang Y, Uluğ AM, Zimmerman RD, Casey BJ. A neural basis for the development of inhibitory control. Dev Sci. 2002;5(4):F9–16. https://doi.org/10.1111/1467-7687.00235.
45. Eimer M. The neural basis of attentional control in visual search. Trends Cogn Sci. 2014;18(10):526–35. https://doi.org/10.1016/j.tics.2014.05.005.
46. Gray JA, McNaughton N. The neuropsychology of anxiety. 2nd ed. Oxford: Oxford University Press; 2003.
47. Balodis IM, Kober H, Worhunsky PD, White MA, Stevens MC, Pearlson GD, Sinha R, Grilo CM, Potenza MN. Monetary reward processing in obese individuals with and without binge eating disorder. Biol Psychiatry. 2013;73(9):877–86. https://doi.org/10.1016/j.biopsych.2013.01.014.
48. Bodell LP, Wildes JE, Goldschmidt AB, Lepage R, Keenan KE, Guyer AE, Hipwell AE, Stepp SD, Forbes EE. Associations between neural reward processing and binge eating among adolescent girls. J Adolesc Health. 2018;62(1):107–13. https://doi.org/10.1016/j.jadohealth.2017.08.006.
49. English LK, Masterson TD, Fearnbach SN, Tanofsky-Kraff M, Fisher J, Wilson SJ, Rolls BJ, Keller KL. Increased brain and behavioural susceptibility to portion size in children with loss of control eating. Pediatr Obes. 2019;14(2):e12436. https://doi.org/10.1111/ijpo.12436.
50. Schmitz F, Naumann E, Trentowska M, Svaldi J. Attentional bias for food cues in binge eating disorder. Appetite. 2014;80:70–80. https://doi.org/10.1016/j.appet.2014.04.023.
51. Shank LM, Tanofsky-Kraff M, Nelson EE, Shomaker LB, Ranzenhofer LM, Hannallah LM, Field SE, Vannucci A, Bongiorno DM, Brady SM, Condarco TM, Demidowich A, Kelly NR, Cassidy O, Simmons WK, Engel SG, Pine DS, Yanovski JA. Attentional bias to food cues in youth with loss of control eating. Appetite. 2015;87(1):68–75. https://doi.org/10.1016/j.appet.2014.11.027.
52. Stojek M, Shank LM, Vannucci A, Bongiorno DM, Nelson EE, Waters AJ, Engel SG, Boutelle KN, Pine DS, Yanovski JA, Tanofsky-Kraff M. A systematic review of attentional biases in disorders involving binge eating. Appetite. 2018;123:367–89. https://doi.org/10.1016/j.appet.2018.01.019.
53. Cisler JM, Koster EH. Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. Clin Psychol Rev. 2010;30(2):203–16. https://doi.org/10.1016/j.cpr.2009.11.003.
54. Melo RDC, Schreuder MJ, Groen RN, Sarsembayeva D, Hartman CA. Reward sensitivity across the lifespan in males and females and its associations with psychopathology. Pers Individ Dif. 2023;204:112041. https://doi.org/10.1016/j.paid.2022.112041.
55. Altikulaç S, Bos MG, Foulkes L, Crone EA, Van Hoorn J. Age and gender effects in sensitivity to social rewards in adolescents and young adults. Front Behav Neurosci. 2019;13:171. https://doi.org/10.3389/fnbeh.2019.00171.
56. Duncan MJ, Kuzik N, Silva DAS, Bélanger RE, Carson V, Chaput JP, Faulkner G, Ferro MA, Turcotte-Tremblay AM, Leatherdale ST, Patte KA, Tremblay MS. Goldilocks days for adolescent mental health: movement behaviour combinations for well-being, anxiety and depression by gender. Ment Health Phys Act. 2024;26:100572. https://doi.org/10.1016/j.mhpa.2023.100572.
57. Shorey S, Ng ED, Wong CH. Global prevalence of depression and elevated depressive symptoms among adolescents: A systematic review and meta-analysis. Br J Clin Psychol. 2022;61(2):287–305. https://doi.org/10.1111/bjc.12333.
58. Littlefield AK, Stevens AK, Ellingson JM, King KM, Jackson KM. Changes in negative urgency, positive urgency, and sensation seeking across adolescence. Pers Individ Dif. 2016;90:332–7. https://doi.org/10.1016/j.paid.2015.11.024.
59. Ministère de la Santé et des Services sociaux. Recherche portant sur des personnes mineures ou majeures inaptes [Internet]. Gouvernement du Québec; 2024 Oct 1 [cited 2024 Nov 22]. Available from: https://www.msss.gouv.qc.ca/professionnels/ethique/ethique-de-la-recherche/recherche-portant-sur-des-personnes-mineures-ou-majeures-inaptes/
60. Schmitz C, LimeSurvey. An open source survey tool [Internet]. LimeSurvey Project; 2003 [cited 2024 Nov 22]. Available from: http://www.limesurvey.org
61. Gormally JIM, Black S, Daston S, Rardin D. The assessment of binge eating severity among obese persons. Addict Behav. 1982;7(1):47–55. https://doi.org/10.1016/0306-4603(82)90024-7.
62. Mina A, Hallit S, Rogoza R, Obeid S, Soufia M. Binge eating behavior in a sample of Lebanese adolescents: correlates and binge eating scale validation. J Eat Disord. 2021;9:1–11. https://doi.org/10.1186/s40337-021-00493-7.
63. Dikshit R, Karia S, Shah N, Sonavane S, DeSousa A. A study on binge eating behavior in urban adolescents. Asian J Psychiatry. 2020;50:101998. https://doi.org/10.1016/j.ajp.2020.101998.
64. Freizinger M, Jhe GB, Dahlberg SE, Pluhar E, Raffoul A, Slater W, Shrier LA. Binge-eating behaviors in adolescents and young adults during the COVID-19 pandemic. J Eat Disord. 2022;10(1):125. https://doi.org/10.1186/s40337-022-00650-6.
65. Pasold TL, McCracken A, Ward-Begnoche WL. Binge eating in obese adolescents: emotional and behavioral characteristics and impact on health-related quality of life. Clin Child Psychol Psychiatry. 2014;19(2):299–312. https://doi.org/10.1177/1359104513488605.
66. Bodell LP, Forney KJ, Chavarria J, Keel PK, Wildes JE. Self-report measures of loss of control over eating: psychometric properties in clinical and non-clinical samples. Int J Eat Disord. 2018;51(11):1252–60.
67. Beck AT, Steer RA, Brown GK. Beck depression inventory. 1996.
68. Hemmati A, Ghoreishy SM, Karami K, Imani H, Farsani GM, Mousavi SE, Asoudeh F, Shariati-Bafghi SE, Karamati M. The association between dietary patterns and depression in adolescents: A cross-sectional study. Clin Nutr ESPEN. 2021;46:271–5. https://doi.org/10.1016/j.clnesp.2021.09.743.

69. Wu PC. Longitudinal measurement invariance of Beck depression Inventory–II in early adolescents. Assess. 2017;24(3):337–45. https://doi.org/10.1177/1073191115608941.
70. Zabrina HK. The relationship between online game addiction and depression tendencies in Indonesian adolescents: online game addiction and depression tendencies. Indones J Health Sci Res Dev. 2023;5(1):101–5. https://doi.org/10.36566/ijhsrd/Vol5.Iss1/154.
71. March JS, Parker JD, Sullivan K, Stallings P, Conners CK. The multidimensional anxiety scale for children (MASC): factor structure, reliability, and validity. J Am Acad Child Adolesc Psychiatry. 1997;36(4):554–65. https://doi.org/10.1097/00004583-199704000-00019.
72. Gioia GA, Isquith PK, Guy SC, Kenworthy L. Behavior rating inventory of executive function: BRIEF. Psychological Assessment Resources; 2000.
73. Rodrigue C, Gearhardt AN, Begin C. Food addiction in adolescents: exploration of psychological symptoms and executive functioning difficulties in a non-clinical sample. Appetite. 2019;141:104303. https://doi.org/10.1016/j.appet.2019.05.034.
74. Cepeda-Benito A, Gleaves DH, Williams TL, Erath SA. The development and validation of the state and trait food-cravings questionnaires. Behav Ther. 2000;31(1):151–73. https://doi.org/10.1016/S0005-7894(00)80009-X.
75. Cohen J. Statistical power analysis for the behavioral sciences. Routledge; 2013.
76. Ullman JB. Structural equation modeling. In: Barbara GT, Linda SF, editors. Using multivariate statistics. 7th ed. Pearson; 2013. pp. 528–612.
77. Chatterjee S, Simonoff JS. Handbook of regression analysis. Wiley; 2013.
78. Muthén LK, Muthén BO. Mplus user's guide. 8th ed. 1998–2017.
79. Bentler PM, Chou CP. Practical issues in structural modeling. Sociol Methods Res. 1987;16(1):78–117. https://doi.org/10.1177/0049124187016001004.
80. Fornell C, Larcker DF. Evaluating structural equation models with unobservable variables and measurement error. J Mark Res. 1981;18(1):39–50. https://doi.org/10.1177/002224378101800104.
81. Bentler P. Comparative fit indexes in structural models. Psychol Bull. 1990;107(2):238–46. https://doi.org/10.1037/0033-2909.107.2.238.
82. Browne MW, Cudeck R. Alternative ways of assessing model fit. Test Struct Equation Model. 1993;21(2):136–62.
83. Marsh HW, Hau KT, Grayson D. Goodness of fit evaluation in structural equation modeling. In: Maydeu-Olivares A, McArdle JJ, editors. Contemporary psychometrics: A festschrift for Roderick P. McDonald. Multivariate applications book series. Lawrence Erlbaum Associates; 2005. pp. 275–340.
84. Schermelleh-Engel K, Moosbrugger H, Müller H. Evaluating the fit of structural equation models: tests of significance and descriptive goodness-of-fit measures. MPR-Online. 2003;8(2):23–74.
85. Centers for Disease Control and Prevention. Clinical Growth Charts [Internet]. Centers for Disease Control and Prevention; 2024 Sep 2 [cited 2024 Nov 22]. Available from: https://www.cdc.gov/growthcharts/clinical_charts.htm
86. Chen FF. Sensitivity of goodness of fit indexes to lack of measurement invariance. Struct Equ Model. 2007;14(3):464–504.
87. Cheung GW, Rensvold RB. Evaluating goodness-of-fit indexes for testing measurement invariance. Struct Equ Model. 2002;9(2):233–55.
88. Byrne BM, Shavelson RJ, Muthén B. Testing for the equivalence of factor covariance and mean structures: the issue of partial measurement invariance. Psychol Bull. 1989;105(3):456. https://doi.org/10.1037/0033-2909.105.3.456.
89. Dietitians of Canada. WHO growth charts set 1 [Internet]. Dietitians of Canada; 2014 Mar [cited 2024 Nov 22]. Available from: https://www.dietitians.ca/Advocacy/Interprofessional-Collaborations-(1)/WHO-Growth-Charts/WHO-Growth-Charts-Set-1
90. Institut de la statistique du Québec. Enquête québécoise sur la santé de la population, 2020–2021 [Internet]. Institut de la statistique du Québec; 2023 May [cited 2024 Nov 22]. Available from: https://statistique.quebec.ca/fr/fichier/enquete-quebecoise-sante-population-2020-2021.pdf
91. Kenardy J, Arnow B, Agras WS. The aversiveness of specific emotional States associated with binge eating in obese subjects. Aust N Z J Psychiatry. 1996;30:839–44. https://doi.org/10.3109/00048679609065053.
92. National Institute of Mental Health. Depression [Internet]. National Institute of Mental Health; 2024 Mar [cited 2024 Nov 22]. Available from: https://www.nimh.nih.gov/health/topics/depression
93. Kim AJ, Stewart SH, Sherry SB, McGrath DS, Mushquash CJ, Olthuis JV, Mushquash AR. Clarifying the pathway from anxiety sensitivity to binge eating: the mediating role of depressive symptoms in a 3-week, 3-wave longitudinal study of undergraduates. Eat Behav. 2024;52:101843. https://doi.org/10.1016/j.eatbeh.2024.101843.
94. National Institute of Mental Health. Social anxiety disorder: more than just shyness [Internet]. National Institute of Mental Health; 2022 [cited 2024 Nov 22]. Available from: https://www.nimh.nih.gov/health/publications/social-anxiety-disorder-more-than-just-shyness
95. Stevenson BL, Dvorak RD, Wonderlich SA, Crosby RD, Gordon KH. Emotions before and after loss of control eating. Eat Disord. 2018;26(6):505–22. https://doi.org/10.1080/10640266.2018.1453634.
96. Williams-Kerver GA, Steffen KJ, Smith KE, Cao L, Crosby RD, Engel SG. Negative affect and loss of control eating among bariatric surgery patients: an ecological momentary assessment pilot investigation. Obes Surg. 2020;30:2382–7. https://doi.org/10.1007/s11695-020-04503-6.
97. Salk RH, Hyde JS, Abramson LY. Gender differences in depression in representative National samples: Meta-analyses of diagnoses and symptoms. Psychol Bull. 2017;143(8):783. https://doi.org/10.1037/bul0000102.
98. Asher M, Asnaani A, Aderka IM. Gender differences in social anxiety disorder: A review. Clin Psychol Rev. 2017;56:1–12. https://doi.org/10.1016/j.cpr.2017.05.004.
99. Mills KL, Goddings AL, Herting MM, Meuwese R, Blakemore SJ, Crone EA, Dahl RE, Güroğlu B, Raznahan A, Sowell ER, Tamnes CK. Structural brain development between childhood and adulthood: convergence across four longitudinal samples. NeuroImage. 2016;141:273–81. https://doi.org/10.1016/j.neuroimage.2016.07.044.
100. Uhlhaas PJ, Roux F, Singer W, Haenschel C, Sireteanu R, Rodriguez E. The development of neural synchrony reflects late maturation and restructuring of functional networks in humans. Proc Natl Acad Sci U S A. 2009;106(24):9866–71. https://doi.org/10.1073/pnas.0900390106.
101. Fuhrmann D, Knoll LJ, Blakemore SJ. Adolescence as a sensitive period of brain development. Trends Cogn Sci. 2015;19(10):558–66. https://doi.org/10.1016/j.tics.2015.07.008.
102. Rania M, Aloi M, de Filippis R, Carbone EA, Caroleo M, De Fazio P, Segura-Garcia C. Executive functions and depressive symptoms interplay in binge eating disorder: A structural equation model analysis. Eur Eat Disord Rev. 2021;29(5):811–9. https://doi.org/10.1002/erv.2854.
103. Moore CF, Sabino V, Koob GF, Cottone P. Pathological overeating: emerging evidence for a compulsivity construct. Neuropsychopharmacology. 2017;42(7):1375–89. https://doi.org/10.1038/npp.2016.269.
104. Warren SL, Heller W, Miller GA. The structure of executive dysfunction in depression and anxiety. J Affect Disord. https://doi.org/10.1016/j.jad.2020.09.132
105. Kraft B, Bø R, Jonassen R, Heeren A, Ulset VS, Stiles TC, Landrø NI. The association between depression symptoms and reduced executive functioning is primarily linked by fatigue. Psychiatry Res Commun. 2023;3(2):100120. https://doi.org/10.1016/j.psycom.2023.100120.


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