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ORIGINAL ARTICLE

Modelling the effect of temperament on BMI through appetite reactivity and self-regulation in eating: a Structural Equation Modelling approach in young adolescents

V Godefroy¹, L Trinchera², L Romo¹ and N Rigal¹

BACKGROUND/OBJECTIVE: Appetitive traits and general temperament traits have both been correlated with adiposity and obesity in children. However, very few studies have tested structural models to identify the links between temperament, appetitive traits and adiposity in children. A validated structural model would help suggesting mechanisms to explain the impact of temperament on body mass index (BMI). In this study, we used Rothbart's heuristic definition of temperament as a starting point to define four appetitive traits, including two appetite reactivity dimensions (Appetite Arousal and Appetite Persistence) and two dimensions of self-regulation in eating (Self-regulation In Eating Without Hunger and Self-regulation in Eating Speed). We conducted a cross-sectional study in young adolescents to validate a structural model including these four appetitive traits, Effortful Control (a general temperament trait) and adiposity.

SUBJECTS/METHODS: A questionnaire assessing the four appetitive trait dimensions and Effortful Control was completed by adolescents from 10 to 14 years old ($n=475$), and their BMI-for-age was calculated ($n=441$). In total, 74% of the study participants were normal weight, 26% were overweight and 8% were obese. We then used structural equation modelling to test the structural model.

RESULTS: We identified a well-fitting structural model (Comparative Fit Index=0.91; Root Mean Square Error of Approximation=0.04) that supports the hypothesis that Effortful Control impacts both dimensions of self-regulation in eating, which in turn are linked with both appetite reactivity dimensions. Moreover, Appetite Persistence is the only appetitive trait that was significantly related to adiposity ($B=0.12$; $P < 0.05$).

CONCLUSIONS: Our model shows that Effortful Control is related to adiposity through the mediation of an individual's 'eating temperament' (appetite reactivity and self-regulation in eating). Results suggest that young adolescents who exhibit high appetite reactivity but a low level of self-regulation in eating are at higher risk for excess adiposity.

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INTRODUCTION

Although childhood obesity is associated with numerous factors, variations in adiposity generally arise as a result of interactions between individual susceptibility and environment.^{1–4} In this study, we focused on individual susceptibility to overweight at a behavioural level by investigating eating behaviours, which are also known as 'appetitive traits'.^{5,6}

Several different methods are used to assess appetitive traits in children, including questionnaires such as the children's eating behaviour questionnaire (CEBQ)⁷ or the Dutch eating behaviour questionnaire (DEBQ)⁸ and experimental tasks such as the eating in the absence of hunger task, which assesses children's tendency to eat, despite satiety, when offered palatable snack foods and play activities.⁹ Body mass index (BMI) generally increases linearly with the 'food approach' sub-scales of the CEBQ (food responsiveness, enjoyment of food and emotional overeating) and decreases with the 'food avoidant' sub-scales (satiety responsiveness, slowness in eating, emotional undereating and food fussiness).^{10,11} The three dimensions of the DEBQ (emotional, external and restrained eating) are significantly higher in 9–12-year-old children who are obese compared with children of the same age who are normal weight.¹² A high eating in the

absence of hunger score has been positively linked with adiposity and overweight.^{9,13} These cross-sectional studies could not exclude the possibility that differences in appetitive traits are due to differences in weight. However, a longitudinal analysis conducted in infants¹⁴ suggested that weight gain in childhood is strongly influenced by differences in appetitive traits. In fact, this longitudinal study showed that the correlation between appetitive traits and subsequent weight is stronger than the correlation between weight and subsequent appetite.

Like appetitive traits, general self-regulation temperament traits (capacity to control reactions to stress, maintain focused attention and interpret mental states) have been linked to overweight^{15–18} and weight gain in children,^{16,19–22} suggesting that strong self-regulation skills prevent overweight. The inhibitory control dimension of self-regulation (which describes the capacity to plan and suppress inappropriate responses) in particular can predict weight outcomes in girls between 5 and 15 years of age.²² Very few studies conducted in children have focused on the links between temperamental self-regulation, appetitive traits and adiposity, and to our knowledge, no one has attempted to test a theoretical model establishing the structure of these relationships.^{23,24}

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To construct a coherent model describing children's appetitive traits, we used Rothbart's definition of temperament as a starting point to define new 'eating temperament' dimensions. Rothbart's definition of temperament has a very strong heuristic value, with applications in a variety of fields such as children's mental health or social adjustment.^{25–27} According to this definition, temperament relies on constitutionally based individual differences in reactivity (that is, responses to internal and external stimuli) and self-regulation (that is, modulation of these responses). Self-regulation generally limits the risk of developmental pathologies that could arise owing to the level of reactivity.^{28,29}

The goal of our study was to establish two valid models in young adolescents: (1) a measurement model for the newly defined 'eating temperament' dimensions (two appetite reactivity dimensions and two dimensions of self-regulation in eating) and for the general self-regulation dimension of Effortful Control; and (2) a structural model describing the impact of Effortful Control on adiposity through these 'eating temperament' dimensions. To construct the structural model, we proposed three research hypotheses that correspond to 10 model hypotheses ('H'), which are described in the Subjects and Methods section. The three hypotheses are as follows:

- (1) Effortful Control positively impacts self-regulation in eating by affecting both Self-Regulation in Eating Without Hunger (H1) and Self-Regulation in Eating Speed (H2);
- (2) Self-regulation in eating negatively impacts appetite reactivity: Self-Regulation in Eating Without Hunger is linked with Appetite Arousal (H3), and Self-Regulation in Eating Speed is linked with Appetite Persistence (H4), which is correlated with Appetite Arousal (H5);
- (3) All four appetitive traits (that is, Appetite Arousal (H6), Appetite Persistence (H7), Self-Regulation in Eating Without Hunger (H8), Self-Regulation in Eating Speed (H9)) and Effortful Control (H10) are associated with adiposity.

This structural model represents a novel approach to appetitive traits through the conceptual framework of temperament, and allows us to describe the impact of Effortful Control on adiposity through 'eating temperament' dimensions. This model promotes a new perspective on food behaviours as inherent individual characteristics that can nevertheless be modulated, particularly

by enhancing the general capacity for Effortful Control. Moreover, this model provides insight into the mechanisms of overweight development and suggests that individuals who are the most at risk for excess adiposity are those displaying high appetite reactivity in the absence of high self-regulation in eating.

SUBJECTS AND METHODS

Study design and participants

This cross-sectional study was performed in young adolescents, and included both self-reported measurements (questionnaires) and anthropometric measurements (height and weight). The study participants were recruited in January 2014 from the sixth and seventh grade levels of two French state schools situated in two different towns of the Ile de France region. A total of 483 young adolescents (206 from school 1 and 277 from school 2) between 10 and 14-year-old agreed to complete the questionnaire. We selected young adolescents as the population of interest for several reasons. First, adolescence is a critical period for developing obesity and related complications,³⁰ which makes the onset of adolescence an important opportunity for obesity prevention. Furthermore, self-report methodology is well suited to this age group. Only native French speakers were included in the study, and none of the participants suffered from any severe food allergies or chronic medical problems that could affect food intake. Only questionnaires that were at least 80% complete were included ($n=475$). Only 441 children (224 girls, 217 boys) agreed to have their height and weight measured. The BMI-for-age of each of these children was calculated according to WHO guidelines.³¹

The Ile de France II Ethics Committee approved this study (see the file entitled 'IledeFranceII_EC_approval' in the supplemental data). Children were not recruited on the basis of their weight status. The parents were informed about the objective of the study (without giving any details, to limit selection bias), and parental consent was required for participation. In addition to parental consent, the children provided assent to participate, and to guarantee their privacy, the children's names were not shown on the questionnaire.

Construction of a theoretical model linking Effortful Control, 'food temperament' and adiposity

Conceptual definitions. Using Rothbart's definition of temperament as a starting point, we defined the reactivity and self-regulation dimensions as they relate to eating behaviour, that is, appetite reactivity and self-regulation in eating. These two concepts are underpinned by two principles that determine meal initiation and termination: (1) appetite reactivity is linked to the motivational processing of reward representation that integrates both homeostatic and sensory signals; and (2) self-

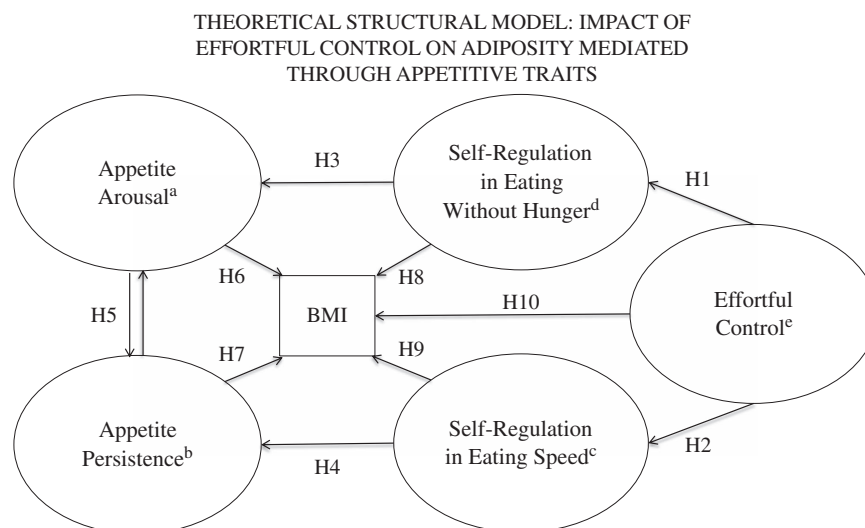


Figure 1. Theoretical model depicting the relationships between Effortful Control, appetitive traits and adiposity in children. ^aGeneral ease with which the desire to eat emerges and intensity of desire to eat; ^bDuration of desire to eat, assessed by the amount of food generally required to reach satiety; ^cAbility to avoid rushing to food and eating too quickly; ^dCapacity to refrain from eating very attractive food in the absence of true hunger; ^ePrimary form of general temperamental self-regulation.

regulation in eating corresponds to the attentional processing that allows an individual to adapt his or her eating behaviour to homeostatic signals.³²

Appetite reactivity describes the desire to eat in response to internal and external stimuli. As this response occurs during both eating initiation and continuation, we defined two separate appetitive traits: Appetite Arousal (initiation: threshold for and intensity of the desire to eat) and Appetite Persistence (continuation: time needed to recover from the desire to eat). Self-regulation in eating relies on modulation of eating during both eating initiation and continuation. We therefore defined two additional appetitive traits: Self-Regulation in Eating Without Hunger (initiation: the ability to refrain from eating palatable food in the absence of hunger) and Self-Regulation in Eating Speed (continuation: the ability to moderate eating speed).

The final element of the structural model was Effortful Control, a major form of general self-regulation as defined by Rothbart. This dimension corresponds to the ability to inhibit a dominant response to perform a subdominant response, as well as the ability to detect errors and engage in planning.³³ Effortful Control can therefore be particularly useful for refraining from eating palatable foods and eating too quickly, as these behaviours can both be considered dominant responses that lead to 'errors' in response to satiety cues.

Arguments supporting the hypothesis ('H') of the structural model. 1/Effortful Control has a positive effect on self-regulation in eating (Figure 1)

H1: Effortful Control positively impacts Self-Regulation in Eating Without Hunger

H2: Effortful Control positively impacts Self-Regulation in Eating Speed
According to Tan & Holub,²³ self-regulation in eating and Inhibitory Control (a subcomponent of Effortful Control) are positively correlated in children from three to nine years old. We therefore hypothesise that Effortful Control is linked with both dimensions of self-regulation in eating, which means that general temperamental self-regulation impacts not only children's emotional expression or sociability but also their food behaviours.

2/ Self-regulation in eating has a negative effect on appetite reactivity (Figure 1)

H3: Self-Regulation in Eating Without Hunger negatively impacts Appetite Arousal

Berridge's incentive-sensitisation model of obesity posits that chronic excessive intake of palatable foods sensitises the brain reward system to food stimuli, thus promoting approach tendencies towards food and food cues.³⁴ The hypothesis of a negative relationship between Self-Regulation in Eating Without Hunger and Appetite Arousal means that the inability to refrain from eating palatable food (without hunger) may imply an excessively frequent and intense desire to eat. This hypothesis is therefore consistent with the incentive-sensitisation model of obesity.

H4: Self-Regulation in Eating Speed negatively impacts Appetite Persistence
Kokkinos *et al.*³⁵ showed that eating slowly increases the subjective feeling of satiety due to higher postprandial levels of anorexigenic gut hormones. We therefore hypothesise that Self-Regulation in Eating Speed is negatively linked with Appetite Persistence, because of the modulation of satiation signals by eating speed during the meal.

H5: Appetite Arousal and Appetite Persistence are positively correlated
We previously defined Appetite Arousal and Appetite Persistence as two dimensions of appetite reactivity: they are, by definition, both linked to the desire to eat. We can thus hypothesise that they are positively correlated.

3/ Appetitive traits and Effortful Control are associated with adiposity (Figure 1)

H6: Appetite Arousal has a positive impact on BMI
H7: Appetite Persistence has a positive impact on BMI
H8: Self-Regulation in Eating Without Hunger has a negative impact on BMI

H9: Self-Regulation in Eating Speed has a negative impact on BMI
All of the appetitive traits assessed by the CEBQ have already been related to adiposity in children.¹⁰ The 'food approach' dimensions are positively correlated with BMI, which suggests that Appetite Arousal and Appetite Persistence may have a positive impact on BMI. The 'food avoidance' dimensions are negatively correlated with BMI, which supports the hypothesis that Self-Regulation in Eating Without Hunger and Self-Regulation in Eating Speed may have a negative impact on BMI. Moreover, a previous longitudinal analysis conducted in infants¹⁴ supports the hypothesis of a causal link between appetitive traits and adiposity.

H10: Effortful Control has a negative impact on BMI

Inhibitory control (a subcomponent of Effortful Control) is directly related to BMI outcome, as girls with higher inhibitory control exhibit lower BMIs.²² We thus expect that Effortful Control negatively impacts adiposity.

Self-report measures

Appetitive traits. We developed an initial 20-item questionnaire for young adolescents to measure the four dimensions of appetitive traits (available upon request). The six items related to Appetite Arousal were inspired by the DEBQ and were designed to assess either the general intensity of desire to eat or the ease with which a desire to eat emerges in response to internal or external stimuli (e.g., 'As soon as I think about food, I feel like eating'). The five items relative to Appetite Persistence were inspired by the CEBQ and measured how quickly the desire to eat disappears (e.g., 'I get full up easily'). Self-Regulation in Eating Speed was assessed through four items inspired by the slowness in eating dimension from the CEBQ (e.g., 'I eat slowly'). For Self-Regulation in Eating Without Hunger, we created five items inspired by the eating in the absence of hunger task¹⁴ (e.g., 'Even if I am no longer hungry, I tend to taste whatever looks good'). Answers were recorded using a 4-point frequency scale (1 = *never*; 2 = *sometimes*; 3 = *often*; 4 = *always*).

Interviews were conducted with a group of 20 children (10 boys and 10 girls, aged between 10 and 14 years old) to verify that they understood the items in the questionnaire. This pre-test enabled us to optimise the phrasing of the questionnaire items. Specifically, an affirmative form was preferred to interrogative and negative forms, and we revised expressions that implied a double negative response.

Effortful control. To evaluate Effortful Control, we used the short form of the Early Adolescent Temperament Questionnaire, which is adapted to the target age group.^{36,37} Items concerning both Attention and Inhibitory Control (for instance: 'It is easy for me to really concentrate on homework problems'; 'When someone tells me to stop doing something, it is easy for me to stop.'), were translated into French and then back-translated to determine the final French version after data harmonisation. After pre-testing, we selected six items for their relevance in French children. Answers were recorded using a 4-point Likert scale (1 = *absolutely false*; 2 = *rather false*; 3 = *rather true*; 4 = *absolutely true*).

Procedure. The children were asked to fill in the questionnaires in their classrooms, in the presence of their teacher and one researcher. The researcher gave them oral instructions and answered all questions about the questionnaire.

Anthropometric measurements

The children's height and weight were measured at school by a nurse and a researcher. The children were dressed in light clothing and were asked to remove their shoes before the measurements. Height and weight were measured to the nearest 0.1 cm and the nearest 0.1 kg, respectively. Participants' BMI-for-age was calculated using the R statistical package version 3.0.2 (R.3.0.2) with the *who2007* function, which is part of a package for the 5-19 year age group available on the World Health Organization (WHO) website.³¹

Statistical analysis

All statistical analyses were performed using R.3.0.2 to validate the measurement model and to validate the structural model linking Effortful Control, appetitive traits and adiposity (measured by BMI-for-age). Statistical analyses were conducted using the Lavaan R package³⁸ (code availability: computer code in the 'R' language is available on request).

Validation of the measurement model. We used a simple correlation analysis and an exploratory factor analysis to investigate the factorial structure and optimise the measurement model by removing unrelated items. We then used a Confirmatory Factor Analysis (CFA),³⁹ with a Maximum Likelihood Estimator, to validate this improved measurement model. Four indexes were used to assess model fit, including the Non-Normed Fit Index (NNFI), the Comparative Fit Index (CFI), the Standardised Root Mean Square Residual (SRMR) and the Root Mean Square Error of Approximation (RMSEA). The NNFI and CFI indexes compare the hypothesised model to a so-called 'baseline' model (in which all variables are assumed to be independent), and a value >0.90 indicates a good fit. The SRMR and the RMSEA correspond to the average difference between the sample variance/covariance matrix and the variance/covariance matrix estimated by the model. A satisfactory fit is indicated by an SRMR value <0.08 and an RMSEA value <0.05.^{40,41} The internal consistency of the

four constructs was assessed using Cronbach's alpha (α). We used the default Lavaan option to suppress any participants with missing data for the selected items, which reduced the sample size ($n=428$).

Validation of the structural model. A structural equation modelling (SEM) method,³⁹ with a Maximum Likelihood Estimator, was used to test a structural model linking Effortful Control, appetitive traits and adiposity. The minimum size of the study was determined based on published guidelines for SEM sample size.⁴² SEM is very useful for testing theories that involve causal processes and is well suited to managing cross-sectional data for inferential purposes.⁴⁰ Model fit was assessed using the same indexes used to assess the CFA model: NNFI (>0.90), CFI (>0.90), SRMR (<0.08) and RMSEA (<0.05).^{40,41} The P -values associated with the regression coefficients were used to determine the significance of the relationships (P -values ≤ 0.05 were considered to be significant). We used the default Lavaan option to suppress any participants with missing data for the selected items and/or BMI, which reduced the sample size ($n=402$).

RESULTS

Participants

Four hundred and seventy-five subjects (234 girls, 241 boys) from 10.08 to 14.58-year-old (mean=12.23, s.d.=0.72) were included in this study. The socio-economic backgrounds of the participants were heterogeneous, as indicated by their parents' socio-professional categories: 34.2% were from upper socio-professional categories and 33.2% from lower socio-professional categories (32.6% were not specified). Only 441 children (224 girls, 217 boys) agreed to have their height and weight measured. The BMI-for-age of these children ranged from -2.8 to 3.83 (mean=0.25, s.d.=1.19). Seventy-four percent of the participants were normal weight, 26% were overweight, and 8% were obese, according to WHO definitions.³¹

Validation of the measurement model

Conducting a simple correlation analysis allowed us to suppress two items whose correlation with other items (which were

expected to measure the same dimension) was <0.25 . Preliminary exploratory factor analysis (detailed results available on request) then allowed us to obtain a more accurate measurement model for appetitive traits by eliminating two items with loadings of <0.3 for all of the dimensions. All of the remaining items were distributed as expected between four dimensions, accounting for 41% of the total variance ($R^2=0.41$).

The results of the CFA, including the Effortful Control dimension, are shown in Table 1. The CFA reveals an adequate fit (NNFI=0.94; CFI=0.95; SRMR=0.05; and RMSEA=0.03) for this model, which indicates that our questionnaire can accurately measure appetitive traits and Effortful Control. We also performed a reliability analysis, which showed that the Appetite Arousal ($\alpha=0.69$), Appetite Persistence ($\alpha=0.73$), Self-Regulation in Eating Speed ($\alpha=0.74$), Self-Regulation in Eating Without Hunger ($\alpha=0.65$) and Effortful Control ($\alpha=0.64$) measurements are reliable. These coefficients are consistent with those reported for the validation of a food questionnaire for children (that is, Kids' Child Feeding Questionnaire)^{43,44} and for validation of the Early Adolescent Temperament Questionnaire.³⁷

The correlation matrix between the different appetitive traits and Effortful Control (Table 2) shows that:

- (1) The two dimensions of appetite reactivity are positively correlated, as are the two dimensions of self-regulation in eating;
- (2) Effortful Control is positively correlated with Self-Regulation in Eating Without Hunger and Self-Regulation in Eating Speed but negatively correlated with Appetite Arousal.
- (3) The appetite reactivity dimensions are negatively correlated with the self-regulation in eating dimensions, and specific appetite dimensions showed a strong negative correlation with specific self-regulation dimensions. In particular, Appetite Arousal is strongly negatively correlated with Self-Regulation

Table 1. Validation of the measurement model^a

Items	Factor loadings				
	AA	AP	SREWH	SRES	EC
When I see someone eating, it makes me feel like eating ^b	0.60				
When I feel like eating, I strongly insist to get something to eat, even if it is complicated	0.53				
As soon as I think about food, I feel like eating	0.62				
As soon as I arrive at table, even before knowing what we eat, I feel like eating	0.45				
When I feel stressed, sad or bored, I feel like eating ^b	0.48				
When I feel like eating, craving is so strong that it is hard for me to wait	0.55				
I have a big appetite ^c		0.57			
I leave food on my plate at the end of the meal ^{c,d,e}		0.61			
I get full before my meal is finished ^{c,d,e}		0.75			
I get full up easily ^{c,d,e}		0.64			
When it is good, I tend to keep on eating even if I am not hungry anymore ^e			0.60		
Even if I am no longer hungry, I tend to taste whatever looks good ^e			0.64		
Even if I am not really hungry, I tend to rush to eat something I like ^e			0.62		
I finish my meal quickly ^{c,d,e}				0.79	
I eat slowly ^c				0.79	
I take more than 30 minutes to finish a meal ^c				0.52	
It is easy for me to really concentrate on homework problems ^d					0.48
When someone tells me to stop doing something, it is easy for me to stop ^d					0.57
When trying to study, I have no difficulty tuning out background noise and concentrating ^d					0.41
The more I try to stop myself from doing something I shouldn't, the more likely I am to do it ^{d,e}					0.49
I pay close attention when someone tells me how to do something ^d					0.45
I tend to get in the middle of one thing, then go off and do something else ^{d,e}					0.52

Abbreviations: AA, Appetite Arousal; AP, Appetite Persistence; CEBQ, Children's Eating Behaviour Questionnaire; CFA, Confirmatory Factor Analysis; DEBQ, Dutch Eating Behaviour Questionnaire; EC, Effortful Control; SRES, Self-Regulation in Eating Speed; SREWH, Self-Regulation in Eating Without Hunger. ^aValues are the standardized estimates of factor loadings of the CFA. $n = 428$. ^bItems inspired from DEBQ. ^cItems inspired from CEBQ. ^dItems from Early Adolescent Temperament Questionnaire. ^eReversed items.

in Eating Without Hunger, and Appetite Persistence is strongly negatively correlated with Self-Regulation in Eating Speed.

According to Kenny & Kashy,⁴⁵ a correlation of 0.85 or more (in absolute value) between two latent variables indicates poor discriminant validity. All of the correlations shown in Table 2 are below this threshold, indicating adequate discriminant validity. We further assessed discriminant validity between the two most closely correlated dimensions (Appetite Arousal and Self-Regulation in Eating Without Hunger) using a χ^2 difference test ($P < 0.001$) to compare a smaller model collapsing these two dimensions into a single dimension ($\chi^2 = 341.63$; $df = 203$) to our larger model with four dimensions ($\chi^2 = 290.7$; $df = 199$). The results support our hypothesis that Appetite Arousal and Self-Regulation in Eating Without Hunger are two different constructs.

Validation of the structural model

The first structural model tested presented a good fit (NNFI=0.90; CFI=0.91; SRMR=0.06; and RMSEA=0.04), but contrary to our

Factors	AA	AP	SREWH	SRES	EC
AA					
AP	0.41***				
SREWH	-0.69***	-0.37***			
SRES	-0.26***	-0.43***	0.26***		
EC	-0.45***	0.02	0.41***	0.19**	

Abbreviations: AA, Appetite Arousal; AP, Appetite Persistence; SREWH, Self-Regulation in Eating Without Hunger; SRES, Self-Regulation in Eating Speed; EC, Effortful Control. ^aValues are the standardized correlation coefficients. $n = 428$. ***Significant correlations at $P < 0.001$. **Significant correlations at $P < 0.01$.

initial hypothesis, only Appetite Persistence was significantly related to adiposity ($B = 0.17$; $P < 0.05$). The effect of Appetite Persistence on Appetite Arousal was not significant ($B = 0.07$; $P = 0.34$; detailed results available on request). For this reason, we tested a second structural model in which only Appetite Persistence directly impacts adiposity, and where Appetite Arousal has an effect on Appetite Persistence, but not the converse.

The results for this second model are shown in Figure 2. This model also exhibits a good fit (NNFI=0.90; CFI=0.91; SRMR=0.06; and RMSEA=0.04), and unlike the first model tested, all the tested relationships are significant (based on their P -values). The validation of this second model supports the idea that:

- (1) Effortful Control significantly impacts both Self-Regulation in Eating Speed (H2) and Self-Regulation in Eating Without Hunger (H1), but has a much stronger impact on the latter;
- (2) Self-Regulation in Eating Without Hunger has a strong negative effect on Appetite Arousal (H3), and Self-Regulation in Eating Speed negatively impacts Appetite Persistence (H4);
- (3) Appetite Persistence has a modest but significant positive impact on adiposity (H7), whereas Appetite Arousal, Self-Regulation in Eating Without Hunger and Self-Regulation in Eating Speed have are only indirectly linked with adiposity. Effortful Control also has an indirect impact on adiposity both through its direct effect on Self-Regulation in Eating Without Hunger and through its direct effect on Self-Regulation in Eating Speed.

Model comparison for subjects who are overweight and subjects who are normal weight

Next, we compared our model linking temperament and appetitive traits in two groups: overweight vs normal weight (as defined by WHO³¹). We first tested for measurement invariance (Table 3) by comparing nested models with an increasing level of

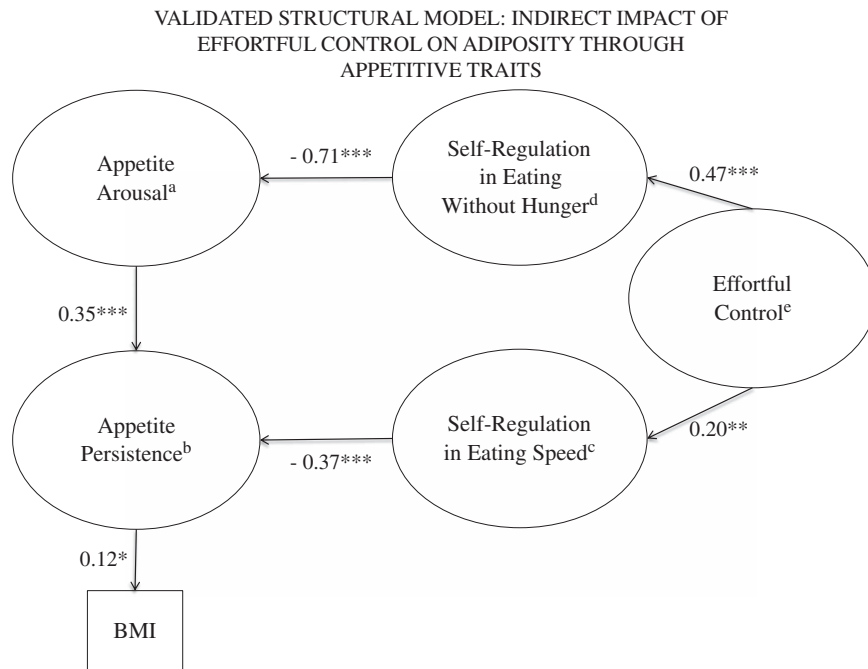


Figure 2. Validated structural model with standardised path coefficients. Significance of the relationship: *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$. ^aGeneral with which the desire to eat emerges and intensity of desire to eat; ^bDuration of desire to eat, assessed by the amount of food generally required to reach satiety; ^cAbility to avoid rushing to food and eating too quickly; ^dCapacity to refrain from eating very attractive food in the absence of true hunger; ^ePrimary form of general temperamental self-regulation. $n = 402$.

Table 3. Tests for measurement and structural invariance^a

	χ^2	df
Model 1: configural invariance	603.25	408
Model 2: weak invariance (equal loadings)	618.34	425
Model 3: strong invariance (equal loadings+intercepts)	645.22	442
Model 4: complete structural invariance (equal loadings+intercepts+equal structural coefficients)	654.53	447
Model 5: partial structural invariance (equal loadings +intercepts+some equal structural coefficients)	649.32	446

^aValues are the χ^2 and the degree of freedom of the nested models with different levels of invariance.

invariance. We verified weak invariance (models 1 vs 2) and strong invariance (models 2 vs 3), which implies that the measurement model is similar for the two groups. We then tested for structural invariance (Table 3), and found no evidence for complete structural invariance (models 3 vs 4). We therefore tested partial structural invariance (models 4 vs 5) by comparing a first model in which all the path coefficients were forced to be equal for the two groups, and a second model in which all the path coefficients were forced to be equal except the one measuring the effect of Self-Regulation in Eating Without Hunger on Appetite Arousal. We found a significant difference between these two models (χ^2 difference = 5.29, $P < 0.05$), suggesting that **the inhibitory effect of Self-Regulation in Eating Without Hunger on Appetite Arousal is significantly stronger in young adolescents who are overweight than in those who are normal weight.**

DISCUSSION

In this study, we generated a valid structural model that supports two out of our three research hypotheses: first, that Effortful Control is positively linked with self-regulation in eating; and second, that self-regulation in eating is negatively associated with appetite reactivity. In contrast to previous studies,^{10,22} Appetite Arousal, Self-Regulation in Eating Without Hunger, Self-Regulation in Eating Speed and Effortful Control were not directly linked with adiposity; only Appetite Persistence was related to adiposity. We also established the validity of our measurement model for appetitive traits and Effortful Control, thereby validating our novel questionnaire.

The validation of the structural model suggests that Effortful Control has a significant impact on both Self-Regulation in Eating Without Hunger and Self-Regulation in Eating Speed. Effortful Control is more strongly associated with Self-Regulation in Eating Without Hunger than with Self-Regulation in Eating Speed, most likely because the latter involves more unconscious homeostatic regulation than Self-Regulation in Eating Without Hunger. Validation of this model also implies that Self-Regulation in Eating Without Hunger is strongly and negatively linked with Appetite Arousal, and that Self-Regulation in Eating Speed negatively impacts Appetite Persistence. The negative relationship between Self-Regulation in Eating Without Hunger and Appetite Arousal is significantly stronger in young adolescents who are overweight than in subjects who are normal weight, which suggests that Self-Regulation in Eating Without Hunger could prevent weight gain more efficiently in individuals who are already overweight. However, further studies are needed to investigate this hypothesis.

The lack of a significant link between Effortful Control and BMI may be due to the fact that the proposed model accounts for the overall effect of Effortful Control on BMI through the appetitive trait dimensions. Moreover, Appetite Arousal, Self-Regulation in Eating Without Hunger and Self-Regulation in Eating Speed were

not directly related to adiposity. This was unexpected, given previous results obtained from the CEBQ.¹⁰ The fact that only Appetite Persistence is directly linked with BMI suggests that the quantitative aspect of food behaviour has an important influence on adiposity. If we consider the conceptual elements underlying the four dimensions that we defined for appetitive traits, Appetite Persistence is most directly linked to meal portion size. Our observations are therefore consistent with a previous study that concluded that meal patterns (portion size and energy intake) may have a greater role than snack patterns in weight regulation, at least for children aged 12–19.⁴⁶ The increase in Appetite Persistence, potentially associated with an increase in BMI, might be due to a dysfunction of the reward system⁴⁷ that leads to a more lasting anticipation of the reinforcing value of food. Indeed, it has been shown that subjects who are obese exhibit a slower decline in salivation in response to repeated food cues compared with subjects who are normal weight.⁴⁸ Appetite Persistence thus seems to be a 'key' appetitive trait, although further studies are needed to confirm this result.

Establishing the validity of the measurement model enabled us to validate a self-report questionnaire, suitable for use in young adolescents (from 10 to 14 years of age), which we refer to as the 'Adolescent Eating Temperament Questionnaire' (or AETQ). The CEBQ assesses food approach vs food avoidance behaviours,⁷ whereas the AETQ can assess the related traits of appetite reactivity and self-regulation in eating. Like the CEBQ, the AETQ offers a broad approach to eating styles, but it targets a different age group and relies on different methodology (that is, self-report vs parent-report for CEBQ). The AETQ can be used as a prevention tool in young adolescents, alongside the DEBQ: while the DEBQ focuses more on detecting the early signs of eating disorders (such as bulimia),¹² the AETQ detects early risk signs for obesity (that is, excessive appetite reactivity and/or lack of self-regulation in eating).

It is important to note that these measurement and structural models were validated for a very specific population, that is, young adolescents (aged from 10 to 14 years) from the suburbs of Paris, where there is a high prevalence of obesity among teenagers.⁴⁹ Investigating the validity of this model in other populations (such as other age groups and geographical regions) could be of further interest. Another potential limitation is the use of a self-report format, which may have introduced a social desirability bias. However, it is unlikely that this effect was significant, due to the anonymous nature of the study. In future studies, it could be beneficial to include implicit measurements of attitudes towards food, or even physiological measurements (salivation, gastric activity or brain activity), to the self-report measurements. It would also be worth developing a parent-report version of our questionnaire, which could be useful in the context of medical appointments with parents who are concerned about their children's eating behaviours. Finally, an additional limitation of this study is linked with its cross-sectional design: although our statistical analysis using SEM is well suited to managing cross-sectional data for inferential purposes,⁴⁰ there is a need for longitudinal designs to confirm causal relationships between the variables of our model.

Research implications

Despite similarities to general temperamental traits,^{50,51} children's appetitive traits have not yet been described within the conceptual framework of temperament. Our novel approach to appetitive traits as components of an 'eating temperament' enabled us to describe them in a more coherent manner.

Previous studies have shown correlations between some appetitive traits and adiposity, as well as between general temperamental self-regulation and adiposity, but no one has investigated the structure of the relationships between all these

dimensions. The validation of our structural model therefore provides insight into the potential mechanisms by which general self-regulation and appetitive traits together may impact adiposity in young adolescents. Our model specifically suggests that the impact of Effortful Control on adiposity is mediated by appetitive traits and that self-regulation in eating only has an indirect effect on adiposity, through appetite reactivity. Nevertheless, our model could be improved, for example by including environmental factors that could help explain the variance in adiposity. It would also be interesting to investigate parental influence, which is known to drive the development of appetitive traits.⁵²

Clinical implications

Our results have clinical implications for health care practitioners and parents, who should be made aware that temperamental behavioural tendencies impact not only children's emotional expression or sociability but also their food behaviours. Knowing that these are innate behavioural tendencies, parents should feel less guilty about their child's eating behaviour.

Our results also have clinical implications for overweight prevention and tailoring treatment to individuals. The structural model validated in this study suggests that individuals at the highest risk for excess adiposity display high appetite reactivity, and especially high Appetite Persistence, without the moderating effect of a high level of self-regulation in eating. On the basis of our structural model, we propose two strategies for reducing the risk of excess adiposity: (1) reinforcing the general capacity for self-regulation (for example, the capacity for compliance with orders); and (2) strengthening the capacity for self-regulation in eating by focusing on satiety cues and reducing eating speed. Interventions helping children recognize internal cues of hunger and fullness have already been shown to improve their ability to regulate energy intake.⁵³ Our results could thus be useful for practitioners to advise parents who are concerned about their child's eating behaviour. However, further studies are needed to investigate the impact of parenting practices on a child's eating behaviour, depending on the child's eating temperament. Use of the AETQ questionnaire within the context of a medical appointment could help target treatment more effectively by identifying the problematic components of a child's eating temperament. In particular, existing clinical methods focusing on behavioural⁵⁴ and/or emotional regulation⁵⁵ could be adapted to impact specific components of eating temperament, but further research is needed to determine the efficacy of this type of clinical approach.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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