Appetite 59 (2012) 738–747

Contents lists available at SciVerse ScienceDirect

Appetite

journal homepage: www.elsevier.com/locate/appet

Research report

Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults ☆

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ARTICLE INFO

Article history:
Received 9 June 2012
Received in revised form 23 July 2012
Accepted 1 August 2012
Available online 8 August 2012

Keywords:
Cognitive control
Executive function
Response inhibition
Decision making
Eating
Obesity
Structural equation modeling

ABSTRACT

Heightened impulsivity and inefficient inhibitory control are increasingly recognized as risk factors for unhealthy eating and obesity but the underlying processes are not fully understood. We used structural equation modeling to investigate the relationships between impulsivity, inhibitory control, eating behavior, and body mass index (BMI) in 210 undergraduates who ranged from underweight to obese. We demonstrate that impulsivity and inhibitory control deficits are positively associated with several facets of unhealthy eating, including overeating in response to external food cues and in response to negative emotional states, and making food choices based on taste preferences without consideration of health value. We further show that such unhealthy eating is, for the most part, associated with increased BMI, with the exception of Restraint Eating, which is negatively associated with BMI. These results add to our understanding of the impact of individual differences in impulsivity and inhibitory control on key aspects of unhealthy eating and may have implications for the treatment and prevention of obesity.

Introduction

The prevalence of weight problems in the U.S. has become alarmingly high, with over 30% of the adult population overweight and another 30% obese (Flegal, Carroll, Ogden, & Curtin, 2010). The current environment, with its abundance of highly palatable, high caloric density foods, is known to play a major role in promoting obesity (Hill & Peters, 1998). But not all individuals exposed to this obesogenic environment become overweight or obese. Thus, understanding the factors that predispose people to unhealthy eating – including overeating in response to external food cues or negative emotional states, and choosing “junk foods” in favor of healthier food options – is a critical challenge in behavioral and neuroscience research on obesity and in promoting population health.

Decades of research show that eating behaviors in humans are regulated by a complex interplay of metabolic and cognitive control processes in the brain (Berthoud, 2007). Metabolic control processes initiate food intake in response to low-energy states via hunger signaling, and terminate food intake when energy needs have been satisfied via satiety signals. Since eating behaviors are to a large degree shaped by experience, the cognitive processes involved in regulating food intake include reward-based learning (Petrovich, Holland, & Gallagher, 2005; Petrovich, Ross, Holland, & Gallagher, 2007; Petrovich, Setlow, Holland, & Gallagher, 2002) as well as top–down control over such learned responses in the service of more abstract goals such as to maintain a healthy weight (Hare, Camerer, & Rangel, 2009; Hare, Malmaud, & Rangel, 2011). While metabolic control processes are a strong defense against body weight loss in an environment where food is scarce, which is the environment in which the human brain evolved, they are insufficient to guard against body weight gain when food is

☆ *Acknowledgments:* A.J.J. was funded by the Postdoctoral Translational Scholar Program (Grant UL1RR024986 from the National Center for Research Resources) and by the Center of Excellence in Cancer Communication Research (Grant P50-CA-101451 from the National Cancer Institute). This research was made possible in part by the Michigan Nutrition Obesity Research Center (Grant P30 DK089503 from the NIDDK), directed by C.F.B. The authors extend warm thanks to Dr. Pamela Davis-Kean for a helpful discussion of SEM results, to Drs. Hare and Rangel for generously sharing their task protocol, and to the Communication Studies subject pool participants for participating in the study. The authors have no competing financial interests to disclose.

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http://dx.doi.org/10.1016/j.appet.2012.08.001

abundant (Hill & Peters, 1998). Thus, in obesogenic environments, cognitive factors may override metabolic regulation and become a critical determinant of eating behavior and the risk of obesity (Berthoud, 2007). Consistent with this view, human neuroimaging studies suggest that unhealthy eating habits may share neurobiological bases with substance addiction, including hyper-reactivity to rewarding stimuli as well as impaired cognitive control (Mathes, Brownley, Mo, & Bulik, 2009; Volkow, Wang, Fowler, Tomasi, & Baler, 2011).

The current study examined the role of impulsivity and inhibitory control in eating behavior. Although impulsivity is known to be a multi-faceted construct (Whiteside & Lynam, 2001), it is typically defined as a general tendency towards quick, unplanned reactions to internal or external stimuli without a consideration of the consequences of these actions to self or others. It is thought to encompass a broad set of behaviors including rapid decision-making, inattention, lack of perseverance, acting without thinking, lack of planning, sensation seeking, and risk-taking (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Furthermore, heightened impulsivity is thought to arise, at least in part, from impairments in inhibitory control (Logan, Schachar, & Tannock, 1997), defined as the ability to stop or suppress responses that are no longer required, inappropriate, or in conflict with current goals (Verbruggen & Logan, 2009).

Impulsivity and inhibitory control have long been postulated to play a key role in the ability to maintain a healthy diet and a healthy weight (Wardle, 1988). Growing evidence suggests that heightened impulsivity and reduced inhibitory control are associated with overeating (Guerrieri et al., 2007), including overeating in response to negative emotional states (Bekker, van de Meerendonk, & Mollerus, 2004; Racine, Culbert, Larson, & Klump, 2009), as well as with a higher risk of eating disorders characterized by binge eating (for reviews, see (Fischer, Smith, & Cyders, 2008; Waxman, 2009)). Individuals who are more impulsive and have worse inhibitory control are more likely to be overweight or obese (Guerrieri, Nederkoorn, & Jansen, 2008; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Nederkoorn, Guerrieri, Havermans, Roefs, & Jansen, 2009; Nederkoorn, Jansen, Mulkens, & Jansen, 2007), and inhibitory control efficiency is inversely correlated with body mass index (BMI) (Batterink, Yokum, & Stice, 2010; Cohen, Yates, Duong, & Convit, 2011). The emerging consensus is that heightened impulsivity and the associated inhibitory control deficits may lead to elevated BMI by undermining the person's ability to resist the temptations of tasty but unhealthy foods (Appelhans, 2009; Nederkoorn et al., 2006), a trait also referred to as disinhibition in eating (Bryant, King, & Blundell, 2008). However, the impact of individual differences in impulsivity and inhibitory control on specific aspects of eating behavior is still incompletely understood, and may be critical for estimating risk and selecting optimal treatment for individuals at risk for obesity.

Consequently, the goal of the current study was to investigate the role of impulsivity and inhibitory control in key aspects of eating behavior, including both stable eating characteristics as assessed with self-report, and food-related decisions as assessed with a laboratory task. To accomplish this, we used a series of established measures in a sample of participants with an extended weight range, and conducted structural equation modeling analyses to test the relationships between impulsivity, inhibitory control, unhealthy eating, and BMI. We hypothesized that both heightened impulsivity (Hypothesis 1) and deficient inhibitory control (Hypothesis 2) should be associated with higher measures of unhealthy eating, and that unhealthy eating would in turn be associated with elevated BMI (Hypothesis 3).

Methods

Participants

Participants were 210 undergraduates recruited from the Communications Studies subject pool at the University of Michigan, who participated for course credit. Participants did not know the topic of the study prior to participation (up until the informed consent process immediately prior to the study session), which increased the probability of a representative sample of that population and reduced the possibility of potential self-selection biases (e.g., participants with suspected weight or eating problems choosing not to participate).

Protocol

Participants were instructed to refrain from eating and drinking (except water) for at least two hours prior to the study in order to induce hunger and heightened reactivity to food-related stimuli. Participants rated their hunger using a 0–10 scale, with 0 corresponding to ‘‘not hungry at all’’ and 10 corresponding to ‘‘extremely hungry/starving’’ at the beginning of the study ($hunger_1$) and rerated it towards the end of the study ($hunger_2$). Participants performed a battery of computerized and paper-and-pencil tasks. This report focuses on the Go/NoGo task which was used to assess inhibitory control. Participants also completed a questionnaire packet, including the Dutch Eating Behavior Questionnaire (DEBQ) (van Strien, Frijters, Bergers, & Defares, 1986) and the Barratt Impulsiveness Scale (BIS-11) (Patton, Stanford, & Barratt, 1995), in addition to other measures not directly relevant to the hypotheses tested in the current study. Each participant also completed a computerized Food Choice task (Hare et al., 2009) and received a randomly chosen food item from the list of items they accepted during this task. For the purpose of calculating BMI, participants reported their height and were weighed using an electronic scale at the end of the study. The computerized tasks were programmed in and administered using E-Prime 2.0 software (Psychology Software Tools, www.pstnet.com), and included high-resolution color food images collected online.

Measures of eating behavior

Dutch Eating Behavior Questionnaire (DEBQ)

The Dutch Eating Behavior Questionnaire (DEBQ) (van Strien et al., 1986; Wardle, 1987) contains 33 items that are formulated as questions, such as ‘‘Do you watch exactly what you eat?’’ or ‘‘Do you have a desire to eat when you are emotionally upset?’’ The response alternatives are Never (=1), Seldom (=2), Sometimes, (=3), Often (=4), and Very Often (=5). The DEBQ contains three subscales: External Eating (10 items), Emotional Eating (13 items), and Restraint Eating (10 items). The three DEBQ subscales assess three key characteristics of unhealthy eating: External Eating refers to (over)eating in response to food cues; Emotional Eating refers to (over)eating in response to negative emotional states and events; and Restraint Eating refers to intentional restriction of food intake, which in some cases may be associated with overeating when the resolve to control food intake is abandoned (van Strien et al., 1986; Wardle, 1987).

Food Choice task

To assess decision-making about food, we employed a version of the Food Choice task (Hare et al., 2009). The task included three separate blocks: decision block, taste-rating block, and healthiness-rating block, in that order. On each trial, one food item was presented in the middle of the screen, with a block-specific question above the image and a block-specific response scale below the image. In the decision block, the question asked "How much do you want to eat it?" about each food item and participants indicated their decision with a key press: Strong No (=1), No (=2), Yes (=3), or Strong Yes (=4). In the taste-rating blocks, participants were asked "How tasty is it?" about each food item and responded with a key press: Very Tasty (=1), Untasty (=2), Tasty (=3), or Very Tasty (=4). In the healthiness-rating block, participants were asked "How healthy is it?" about each food item and again responded with a key press: Very Unhealthy (=1), Unhealthy (=2), Healthy (=3), or Very Healthy (=4). These subjective ratings were then used to classify all food items into four categories at the individual-subject level: Tasty–Healthy, Tasty–Unhealthy, Untasty–Healthy, and Untasty–Unhealthy. At the end of the study, all participants received one randomly selected food item from the food items they accepted in the decision block. All participants decided about and rated the same 60 food items. The food items included both healthy snacks (e.g., apple, banana, carrots) and "junk foods" (e.g., potato chips, nachos, candy bars). We limited the selection of food images to simple snacks that we could easily store in the laboratory and keep on hand to give to participants after they completed the task. The order of the food items was randomized across the three blocks of the task for each participant and between participants. The food item, question, and response scale remained on the screen for 4 s and participants had 4 s to respond on each trial.

Measures of impulsivity and inhibitory control

Barratt Impulsiveness Scale (BIS-11)

Impulsivity was assessed with the Barratt Impulsiveness Scale, Version 11 (BIS-11) (Patton et al., 1995). The BIS-11 contains 30 items which assess impulsivity in daily life, including common impulsive and non-impulsive (for reverse scored items) behaviors and preferences. Items are rated on a 4-point scale: Rarely/Never (=1), Occasionally (=2), Often (=3), and Almost Always/Always (=4). The BIS-11 has three subscales: Attentional Impulsiveness (8 items), Motor Impulsiveness (11 items), and Non-Planning Impulsiveness (11 items) (Patton et al., 1995). The three subscales assess Attentional Impulsiveness (i.e., a tendency to rapid shifts in attention and to impatience with complexity), Motor Impulsiveness (i.e., a tendency to rash, immediate actions), and Non-Planning Impulsiveness (i.e., a tendency not to plan ahead and to ignore long-term consequences of one's actions). These three aspects of impulsivity are postulated to independently contribute to impulsive behavior in daily life.

Go/NoGo task

To assess the efficiency of inhibitory control in the presence of food cues, we employed a Go/NoGo task (Rubia et al., 2001) modified to include flanker food distracters. The Go/NoGo task measures the efficiency of response inhibition or inhibitory control, as indexed by the number of false alarms on NoGo trials. A higher rate of false alarms indicates a greater deficit in inhibitory control. Only food-distracter trials were included to maximize the number of false alarms committed per this category. Participants saw a target letter in the middle of the screen, flanked by two identical food distracter images, and were instructed to press the space bar to all letters except the letter X (Go trials, 66% of all trials) and to inhibit their response to the letter X (NoGo trails, 33% of all trials). The Go targets included letters G, Q, R, S, T and W. Each trial consisted of a target stimulus and two flanker food distracters presented for 500 ms, followed by a white screen presented for 1000 ms, for the total response limit of 1500 ms (Fig. 1). After receiving instructions and completing a short practice, participants completed three runs of the task, with 90 trials per run (60 Go trials and 30 NoGo trials), for a total of 270 trials (180 Go trials and 90 NoGo trials). The instructions emphasized both speed and accuracy. The order of trials was randomized across the three blocks for each participant and between participants. All participants saw the same 90 food distracter images.

Statistical analyses

First, we interrogated the data with *t*-tests and correlations to identify nuisance covariates which were associated with at least one of the dependent measures (e.g., sex, hunger ratings). We then tested our hypotheses about the relationships between impulsivity, inhibitory control, eating behavior, and BMI using a structural equation model (Fig. 2), as implemented in SPSS Amos 19.0. The model contained 11 continuous measured variables of interest, including: three BIS-11 subscales as a measure of trait impulsivity (Attentional Impulsiveness, Motor Impulsiveness, and Non-Planning Impulsiveness); Go/NoGo false alarm rates as a measure of inhibitory control deficits; three DEBQ subscales (Emotional Eating, External Eating, and Restraint Eating) and Food Choices made in the Food Choice task per food category (Tasty–Unhealthy, Tasty–Healthy, and Untasty–Healthy) as measures of eating behavior; and BMI. Hunger_1 ratings (continuous) and sex (dichotomous) were included as nuisance covariates. The advantage of using structural equation modeling is that it allows us to test the entire model, and all the relationships between variables specified in the model, with one statistical test of model fit; if the model shows a significant fit to the data, the regression weights for specific paths are then estimated post hoc. In addition, we tested for indirect effects using a bootstrapping method (Preacher & Hayes, 2008).

Results

Final sample

Out of the 210 participants recruited for the study, data from one participant were lost due to technical problems, and five other participants were excluded from analyses due to extreme outlier status (i.e., individual means more than three standard deviations from the group mean on the Go/NoGo task) and suspicion of task non-compliance (e.g., no food choices accepted in the Food Choice task). Thus, we report the results from the final sample of 204 participants (mean age 19.0 ± .9 years, range 17–22 years; 128 females and 76 males; 150 or 73.5% Caucasian, 19 or 9.3% African American, 21 or 10.3% Asian/Pacific Islander; mean weight 153.2 ± 30.3 lbs, range 89.7–268.1 lbs; mean BMI 23.5 ± 4.0 kg/m^2, range 15.9–45.0 kg/m^2). In accordance with BMI-based categories, 8 or 3.9% participants were underweight (BMI < 18.5 kg/m^2; 7 females), 142 or 69.6% participants were healthy weight (BMI 18.5–25 kg/m^2; 89 females), 42 or 20.6% participants were overweight (BMI 25–30 kg/m^2; 26 females), and 12 or 5.9% participants were obese (BMI > 30 kg/m^2; 6 females). Men were significantly heavier and taller than women (ps < .0001), but no sex difference in BMI was found ($p = .117$) (Table 1).

Hunger ratings

In order to induce hunger and a heightened reactivity to food-related cues, we had asked the participants to refrain from eating and drinking anything other than water for two hours prior to the experiment. The manipulation was successful. On average, on a 0–10 scale, participants reported being moderately hungry when they arrived, with mean hunger_1 rating of 4.7 ± 2.4 (range 0–10), and became significantly hungrier in the course of the study, with mean hunger_2 rating of 6.2 ± 2.5 (range 0–10), $t\ (203) = 16.283$, $p < .0001$. Men and women did not differ in hunger ratings

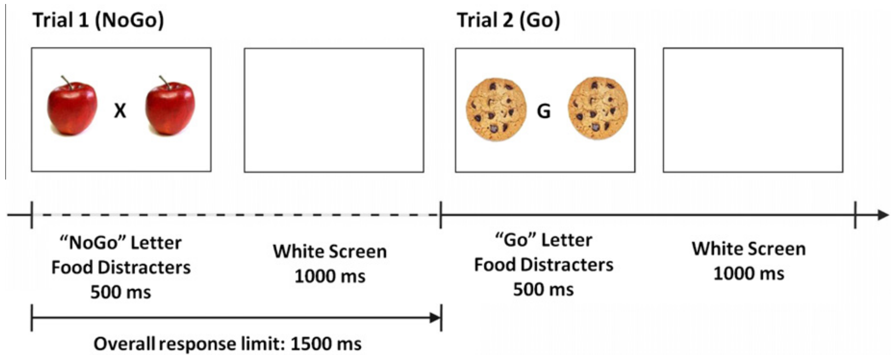

Fig. 1. Anatomy of a trial in the food-distracter Go/NoGo task. Each trial consisted of a target letter and two flanker food distracters presented for 500 ms, followed by a white screen presented for 1000 ms, for the total response limit of 1500 ms. Participants pressed the space bar to "Go" letters (G, Q, R, S, T; 66% of trials) and inhibited their response to the "NoGo" letter (X; 33% of trials). The food-distracter Go/NoGo task measures the efficiency of inhibitory control in the presence of food cues, as indexed by the number of false alarms on the NoGo trials. A higher number of false alarms indicates a greater deficit in inhibitory control.

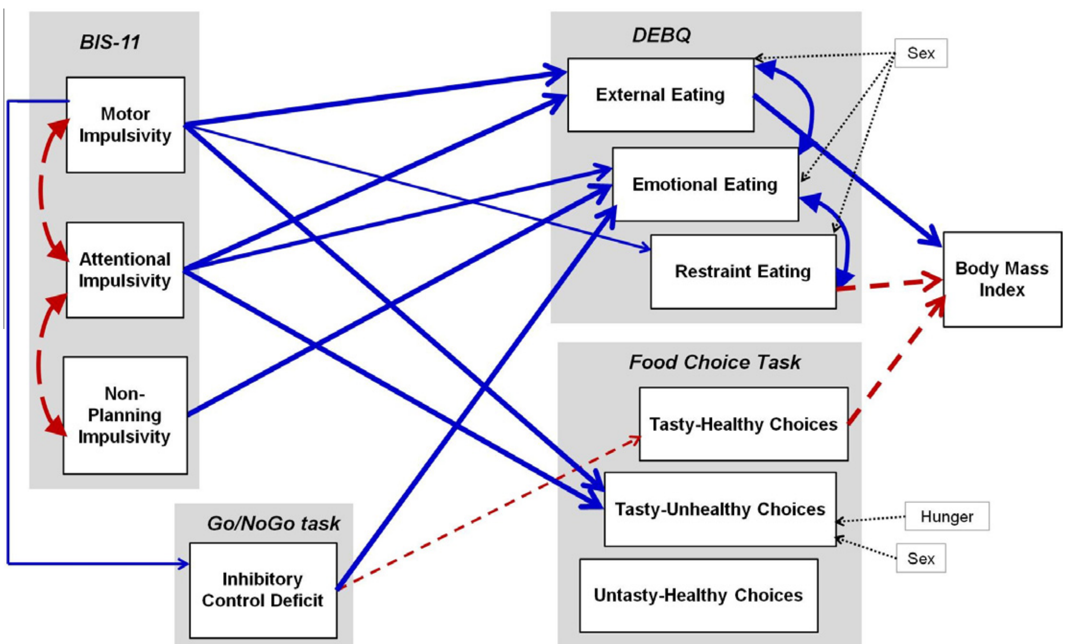

Fig. 2. The results of the structural equation model investigating the relationships between impulsivity, inhibitory control, eating behavior, and body mass index in healthy young adults ($N = 204$). Large boxes represent eleven continuous, measured variables of interest, grouped by task or questionnaire (grey blocks). Two nuisance variables (sex and hunger ratings) are represented as small boxes. Solid blue arrows indicate positive associations (thick arrows: $p < .05$; thin arrows: $p < .07$), dotted red arrows indicate negative associations (thick arrows: $p < .05$; thin arrow: $p < .10$), and absence of arrows indicates lack of associations ($p > .10$). BIS-11, Barratt Impulsiveness Scale, Version 11; DEBQ, Dutch Eating Behavior Questionnaire.

Table 1
Summary of eating-related measures. $N = 204$.

	Overall (M ± SD) $N = 204$	Men (M ± SD) $n = 76$	Women (M ± SD) $n = 128$	Men vs. Women	
				T statistic	*P* value
Hunger 1 (on 0–10 scale)	4.7 ± 2.4	5.1 ± 2.2	4.5 ± 2.5	1.604	.110
Hunger 2 (on 0–10 scale)	6.2 ± 2.5	6.4 ± 2.3	6.1 ± 2.5	1.056	.292
DEBQ					
External eating	2.72 ± 1.01	2.25 ± .95	3.00 ± .94	−5.538	**<.0001**
Emotional eating	2.59 ± .90	2.16 ± .79	2.84 ± .87	−5.596	**<.0001**
Restraint eating	3.50 ± .52	3.35 ± .48	3.58 ± .52	−3.192	**.002**
Food choice task					
Tasty–healthy food choices	.249 ± .121	.252 ± .118	.247 ± .123	.284	.776
Tasty–unhealthy food choices	.248 ± .119	.273 ± .121	.232 ± .118	2.397	**.017**
Untasty–healthy food choices	.020 ± .029	.020 ± .031	.019 ± .028	.233	.816
BMI (kg/m^2)	23.5 ± 4.0	24.1 ± 4.2	23.2 ± 3.8	1.576	.117

BMI, body mass index; DEBQ, Dutch eating behavior questionnaire; M, mean; SD, standard deviation independent-sample *t*-tests significant at the .05 level are shown in bold. All *t*-tests are two-tailed.

(ps > .11) (Table 1). Hunger$_1$ and hunger$_2$ ratings were significantly positively correlated ($r = .855$, $p < .0001$) but did not correlate with BMI (hunger$_1$, $r = -.094$, $p = .181$; hunger$_2$, $r = -.019$, $p = .786$) (Table 2).

DEBQ results

We used the DEBQ (van Strien et al., 1986; Wardle, 1987) to assess three key aspects of unhealthy eating in our sample: overeating in response to external food cues (External Eating), overeating in response to negative emotional states (Emotional Eating), and intentional restriction of food intake which may lead to overeating when the diet is abandoned (Restraint Eating). The DEBQ results are summarized in Table 1. The average External Eating score was 2.72 ± 1.01 (range 1.00–5.00). The average Emotional Eating score was 2.59 ± .90 (range 1.00–5.00). The average Restraint Eating score was 3.50 ± .52 (range 2.20–4.70). Correlations between External Eating, Emotional Eating, and Restraint Eating scores are given in Table 2. Emotional Eating scores were significantly positively correlated with External Eating scores ($r = .318$, $p < .0001$), consistent with previous reports (van Strien et al., 1986; Wardle, 1987). Emotional Eating scores were also significantly positively correlated with Restraint Eating scores ($r = .513$, $p < .0001$). External Eating scores were uncorrelated with Restraint Eating scores ($r = .078$, $p = .269$), again consistent with previous reports (van Strien et al., 1986; Wardle, 1987). Only External Eating scores were significantly negatively correlated with hunger$_1$ ratings ($r = -.161$, $p = .021$) and showed a trend towards such negative association with hunger$_2$ ratings ($-.124$, $p = .078$) (Table 2). In addition, women scored significantly higher than men on all three DEBQ subscales (ps < .005) (Table 1).

Food Choice task results

In addition to the DEBQ, which is a self-report measure of stable eating behavior characteristics, we also assessed food-related decisions using a computerized Food Choice task (Hare et al., 2009). Of particular relevance to unhealthy eating, the Food Choice task measures the tendency to choose foods based on their palatability rather than on their health value (Tasty–Unhealthy food choices). The results of the Food Choice task from the final sample of participants are provided in Table 1. The results include the proportion of food items accepted per Tasty–Healthy, Tasty–Unhealthy, and Untasty–Healthy category (no Untasty–Unhealthy snacks were accepted). On average, participants accepted 25 ± 12% of Tasty–Healthy snacks, 25 ± 12% of Tasty–Unhealthy snacks, and 2 ± 3% of Untasty–Healthy snacks. There were no significant correlations in the proportion of snacks accepted between Tasty–Healthy, Tasty–Unhealthy, and Untasty–Healthy food categories (ps > .18) (Table 2). A significant positive correlation between hunger ratings and the proportion of Tasty–Unhealthy food items accepted was found (hunger$_1$, $r = .240$, $p = .001$; hunger$_2$, $r = .303$, $p < .0001$). However, hunger ratings were not correlated with the proportion of Tasty–Healthy or Untasty–Healthy food items accepted (ps > .24) (Table 2). On average, men accepted a significantly greater proportion of Tasty–Unhealthy snacks than women, $t(202) = 2.397$, $p = .017$; but there were no sex differences in the proportion of Tasty–Healthy and Untasty–Healthy snacks accepted (ps > .77) (Table 1).

BIS-11 results

In order to assess trait impulsivity across attentional, motor, and non-planning domains, we employed the BIS-11 questionnaire (Patton et al., 1995), a validated and widely used self-report measure of impulsive behavior. Average BIS-11 subscales scores were: Attentional Impulsiveness, 20.4 ± 2.3 (range 15–27); Motor Impulsiveness, 27.8 ± 3.4 (range 19–38); Non-Planning Impulsiveness, 26.5 ± 3.0 (range18–36) (Table 3). The average BIS-11 total score in the final sample was 74.7 ± 4.6 (range 63–87). The correlations between the BIS-11 subscale scores are given in Table 4. Attentional Impulsiveness scores were significantly negatively correlated with both Motor Impulsiveness scores ($r = -.240$, $p = .001$) and Non-Planning Impulsiveness scores ($r = -.154$, $p = .028$), whereas Motor Impulsiveness and Non-Planning Impulsiveness scores did not correlate ($r = .040$, $p = .568$). BIS-11 total scores and subscale scores were uncorrelated with hunger ratings (ps > .10). Men and women did not differ in the BIS-11 total score or subscale scores (ps > .32) (Table 3).

Go/NoGo task results

In order to assess the efficiency of inhibitory control, we employed a version of the Go/NoGo response inhibition task (Rubia et al., 2001), with added food-related distracters. The Go/NoGo task measures the number of false alarm errors, and these errors serve as an index of inhibitory control deficit. Average rate of false alarms on the NoGo trials in the final sample was 22.1 ± 10.9% (range 1–63%). False alarm rates were uncorrelated with hunger ratings (ps > .48). There were no sex differences in false alarm rates ($p = .626$) (Table 3).

Structural equation model results

The structural equation model used to test our hypotheses about the relationships between heightened impulsivity, impaired

Table 2
Correlation matrix of eating-related measures. $N = 204$.

	Measure	1	2	3	4	5	6	7	8	9
1	Hunger 1	1								
2	Hunger 2	.855[d]	1							
3	External eating	−.161[b]	−.124[a]	1						
4	Emotional eating	−.036	.090	.318[d]	1					
5	Restraint eating	−.002	−.015	.078	.513[d]	1				
6	TH food choices	−.043	−.083	.074	−.030	.012	1			
7	TU food choices	.240[d]	.303[d]	−.067	−.006	.086	.026	1		
8	UH food choices	.018	−.004	−.022	−.021	.010	.079	−.095	1	
9	BMI (kg/m^2)	−.094	−.019	.152[b]	−.044	−.209[c]	−.133[a]	−.007	−.029	1

BMI, body mass index; TH, tasty–healthy; TU, tasty–unhealthy; UH, untasty–healthy. Two-tailed Pearson's correlations.
[a] $p < .10$.
[b] $p < .05$.
[c] $p < .01$.
[d] $p \leqslant .001$.

Table 3
Summary of impulsivity and inhibitory control accuracy measures. $N = 204$.

	Overall (M ± SD) $N = 204$	Men (M ± SD) $n = 76$	Women (M ± SD) $n = 128$	Men vs. Women	
				T statistic	*P* value
Barratt impulsiveness scale (BIS-11)					
BIS-11 total score	74.7 ± 4.6	74.5 ± 4.9	74.8 ± 4.4	−.542	.588
Attentional impulsiveness	20.4 ± 2.3	20.3 ± 2.0	20.5 ± 2.4	−.481	.631
Motor impulsiveness	27.8 ± 3.4	27.5 ± 3.4	28.0 ± 3.4	−.995	.321
Non-planning impulsiveness	26.5 ± 3.0	26.7 ± 3.2	26.4 ± 2.9	.663	.508
Go/NoGo Task					
False alarm rates	22.1 ± 10.9	21.6 ± 10.7	22.4 ± 11.0	−.489	.626

M, mean; SD, standard deviation. Two-tailed independent-sample *t*-tests.

Table 4
Correlation matrix of impulsivity and inhibitory-control measures. $N = 204$.

	Measure	1	2	3	4	5
1	BIS-11 attentional impulsiveness	1				
2	BIS-11 motor impulsiveness	−.240[d]	1			
3	BIS-11 non-planning impulsiveness	−.154[b]	.040	1		
4	BIS-11 total score	.213[c]	.655[d]	.614[d]	1	
5	GNG false alarm rates	−.012	.128[a]	−.037	.065	1

BIS-11, Barratt impulsiveness scale, Version 11; GNG, Go/NoGo task. Two-tailed Pearson's correlations.
[a] $p < .10$.
[b] $p < .05$.
[c] $p < .01$.
[d] $p \leqslant .001$.

inhibitory control, unhealthy eating, and increased BMI is shown in Fig. 2. Following Kline's procedure (Kline, 2011), the estimated model showed a very good fit to the data, chi-square (31 N = 204) = 23.727, $p = .822$, with the comparative fit index (CFI) of 1.000, and the root mean square error of approximation (RMSEA) of <.0001. The results of the model are provided in Table 5 and graphically depicted in Fig. 2.

The results of the model were consistent with our hypothesis that heightened impulsivity should be associated with higher measures of unhealthy eating (Hypothesis 1), as assessed with both the DEBQ and the Food Choice task. With respect to the DEBQ measures, higher Attentional Impulsiveness scores ($B = .063$, SE = .029, beta = .141,$p = .033$) and higher Motor Impulsiveness scores ($B = .048$, SE = .019, beta = .162, $p = .014$) were significantly and independently associated with higher External Eating scores, indicating that individuals who reported being more impulsive also reported being more prone to overeating in response to external food cues. Both higher Attentional Impulsiveness scores ($B = .052$, SE = .026, beta = .132, $p = .044$) and higher Non-Planning Impulsiveness scores ($B = .044$, SE = .019, beta = .148, $p = .020$) were also significantly and independently associated with higher Emotional Eating scores, suggesting that individuals who reported being more impulsive also reported being more likely to overeat in response to negative emotional states. We also found a trend towards a positive association between Motor Impulsiveness scores and Restraint Eating scores ($B = .019$, SE = .011, beta = .126, $p = .074$). Convergent results were obtained with the Food Choice task measures. Both higher Attentional Impulsiveness scores ($B = .007$, SE = .004, beta = .137, $p = .047$) and higher Motor Impulsiveness scores ($B = .005$, SE = .002, beta = .146, $p = .034$) significantly and independently predicted a greater proportion of Tasty–Unhealthy food items accepted, supporting a link between heightened impulsivity and a tendency to make food-related decisions based on taste preferences rather than based on longer-term health considerations. Furthermore, the associations with impulsivity measures were specific to Tasty–Unhealthy food choices and were not observed for either Tasty–Healthy or Untasty–Healthy food categories.

We also found partial support for our prediction that deficient inhibitory control, as assessed with the rate of false alarms in the Go/NoGo task, should be associated with higher measures of unhealthy eating (Hypothesis 2). False alarm rates were significantly positively associated with Emotional Eating scores ($B = .014$, SE = .005, beta = .170, $p = .008$), although not with External Eating or Restraint Eating scores (ps > .20), suggesting that deficient inhibitory control may predispose to overeating specifically in response to negative emotional states. There was also a trend towards a negative association between false alarm rates and the proportion of Tasty–Healthy food items accepted in the Food Choice task ($B = -.001$, SE = .001, beta = −.117, $p = .095$), which would indicate that individuals with better inhibitory control may be more likely to consider health consequences of specific foods when making food choices. But we did not find the predicted positive association between false alarm rates and Tasty–Unhealthy food choices ($p = .378$). In addition, we did not observe robust associations between the measures of impulsivity and measures of inhibitory control in our model, except for a trend towards a positive association between Motor Impulsiveness scores and false alarm rates in the Go/NoGo task ($B = .421$, SE = .227, beta = .133, $p = .064$).

The results of the model also partially supported our hypothesis that higher measures of unhealthy eating should be associated with a higher BMI (Hypothesis 3). Higher External Eating scores were a significant predictor of a higher BMI ($B = .642$, SE = .285, beta = .162, $p = .025$), supporting the notion that a tendency to overeat in response to external food cues contributes to a higher BMI. Furthermore, External Eating partially mediated the effects of Motor Impulsiveness on BMI, as indicated by a significant indirect effect of Motor Impulsiveness scores on BMI through External Eating scores, controlling for sex differences (mean indirect effect = .029, SE = .020, $p < .05$). In addition, the indirect effect of Attentional Impulsiveness on BMI through External Eating, controlling for sex differences, showed a trend towards significance (mean indirect effect = .037, SE = .029, $p < .10$). In contrast, Restraint Eating scores were significantly negatively associated with BMI ($B = -1.711$, SE = .606, beta = −.222, $p = .005$). We also observed a significant negative association between BMI and the proportion of Tasty-Healthy food items accepted in the Food Choice task ($B = -5.003$, SE = 2.201, beta = −.152, $p = .023$). In contrast, and contrary to our predictions, Emotional Eating scores and Tasty-Unhealthy food choices were not associated with BMI in our sample (ps > .73). We also failed to detect any direct relationships between BMI and impulsivity or inhibitory control deficits (ps > .20).

Discussion

Impulsivity and inhibitory control deficits have long been postulated as key factors in the ability to maintain a healthy diet

Table 5
Results of the structural equation model testing the relationships between impulsivity, inhibitory control, eating behavior, and BMI. Unstandardized regression weights (B), standard errors, *p* values, and standardized regression weights (betas) are given. *N* = 204.

Variables of interest	*B*	S.E.	*P*	Beta
Attentional impulsiveness → GNG false alarms	.066	.347	.849	.014
Motor Impulsiveness → GNG false alarms	.421	.227	*.064*	.133
Non-planning impulsiveness → GNG false alarms	−.143	.252	.570	−.040
GNG false alarms → External eating	−.008	.006	.195	−.083
GNG false alarms → Emotional eating	.014	.005	**.008**	.170
GNG false alarms → Restraint eating	.002	.003	.487	.047
GNG false alarms → Tasty–healthy choices	−.001	.001	*.095*	−.117
GNG false alarms → Tasty–unhealthy choices	.001	.001	.378	.059
GNG false alarms → Untasty–healthy choices	.000	.000	.632	.034
Attentional impulsiveness → External eating	.063	.029	**.033**	.141
Attentional impulsiveness → Emotional eating	.052	.026	**.044**	.132
Attentional impulsiveness → Restraint eating	−.002	.016	.912	−.008
Motor impulsiveness → External eating	.048	.019	**.014**	.162
Motor impulsiveness → Emotional eating	.023	.017	.186	.087
Motor impulsiveness → Restraint eating	.019	.011	*.074*	.126
Non-planning impulsiveness → External eating	.020	.021	.351	.060
Non-planning impulsiveness → Emotional eating	.044	.019	**.020**	.148
Non-planning impulsiveness → Restraint eating	.009	.012	.436	.053
Attentional impulsiveness → Tasty–healthy choices	.004	.004	.335	.070
Attentional impulsiveness → Tasty–unhealthy choices	.007	.004	**.047**	.137
Attentional impulsiveness → Untasty–healthy choices	−.001	.001	.237	−.086
Motor impulsiveness → Tasty–healthy choices	−.001	.003	.831	−.015
Motor impulsiveness → Tasty–unhealthy choices	.005	.002	**.034**	.146
Motor impulsiveness → Untasty–healthy choices	.000	.001	.552	.043
Non-planning impulsiveness → Tasty–healthy choices	−.002	.003	.426	−.056
Non-planning impulsiveness → Tasty–unhealthy choices	−.001	.003	.830	−.014
Non-planning impulsiveness → Untasty–healthy choices	.000	.001	.813	.017
GNG false alarms → BMI	−.020	.025	.420	−.056
Attentional impulsiveness → BMI	.160	.125	.202	.091
Motor impulsiveness → BMI	.010	.083	.904	.009
Non-planning impulsiveness → BMI	.096	.089	.284	.073
External eating → BMI	.642	.285	**.025**	.162
Emotional eating → BMI	.026	.374	.944	.006
Restraint eating → BMI	−1.711	.606	**.005**	−.222
Tasty-healthy choices → BMI	−5.003	2.201	**.023**	−.152
Tasty–unhealthy choices → BMI	.796	2.271	.726	.024
Untasty–healthy choices → BMI	−.099	9.035	.991	−.001

BMI, body mass index; GNG, Go/NoGotask. Tests significantat the .05 level are shown in bold; tests with trend–significance at the .10 level are shown in italics.

and a healthy weight (Wardle, 1988). In this report, using structural equation modeling and measures of impulsivity, inhibitory control, eating behavior, and BMI, we demonstrated that both heightened impulsivity and deficient inhibitory control are associated with increases in unhealthy eating, as assessed with both self-report and task performance measures in young adults. With regard to impulsivity, we demonstrated that heightened impulsivity, as assessed with the Attentional Impulsiveness, Motor Impulsiveness, and Non-Planning Impulsiveness subscales of the BIS-11, was associated with a stronger tendency to overeat in response to external food cues and to negative emotional states, as assessed with the External Eating and Emotional Eating subscales of the DEBQ. We also demonstrated that heightened impulsivity was associated with a stronger tendency to make Tasty–Unhealthy food choices in a laboratory task of food-related decision-making, an association specific to Tasty–Unhealthy food options and not observed for Tasty–Healthy or Untasty–Healthy food categories. In sum, we found support for an association between unhealthy eating and all three aspects of impulsive behavior (Attentional Impulsiveness, Motor Impulsiveness, and Non-Planning Impulsiveness) in the predicted direction: namely, higher measures of impulsivity being associated with higher measures of unhealthy eating.

A growing body of evidence also underscores the critical importance of efficient inhibitory control for healthy eating and weight management (for review, see (Appelhans, 2009)). In partial support of this view, we found that greater deficits in inhibitory control, as indexed by higher rates of false alarm in the Go/NoGo task, were associated with a greater tendency towards overeating in response to negative emotional states, as assessed with the Emotional Eating subscale of the DEBQ. In contrast, we found no associations between inhibitory control deficits and External Eating or Restraint Eating. Likewise, we did not detect the hypothesized positive association between inhibitory control deficit and Tasty–Unhealthy food choices, although we did observe a negative association between inhibitory control deficit and Tasty–Healthy food choices.

The notion that overeating should be associated with increased BMI is intuitive. In the current study, we demonstrated that higher External Eating scores on the DEBQ were a significant predictor of increased BMI, supporting the notion that a tendency to overeat in response to external food cues is associated with a higher BMI. We also showed that External Eating partially mediated the effects of Motor Impulsiveness on BMI, and a trend towards a similar indirect effect through External Eating was observed for Attentional Impulsiveness. In contrast, Restraint Eating scores as well as the proportion of Tasty–Healthy food items accepted in the Food Choice task were negatively associated with BMI. In addition, and contrary to our predictions, Emotional Eating scores and Tasty–Unhealthy food choices were not associated with BMI in our sample. We also failed to detect any direct relationships between BMI and impulsivity or inhibitory control deficits.

Our results are consistent with, and extend, existing evidence suggesting that heightened impulsivity and reduced inhibitory control are associated with different forms of unhealthy eating, including overeating (Guerrieri et al., 2007), particularly overeating in response to negative emotional states (Bekker et al., 2004;

Racine et al., 2009). However, we did not detect a direct relationship between impulse control and BMI in our data. This is in contrast to prior studies showing that individuals who are more impulsive and have worse inhibitory control have higher BMI (Batterink et al., 2010; Cohen et al., 2011) and are more likely to be overweight or obese (Guerrieri et al., 2008; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010; Nederkoorn et al., 2006, 2007, 2009) compared to individuals who have better impulse control. The reasons for this discrepancy are unclear and future studies will be needed to clarify the relation of an individual's impulse control and their weight across the lifespan.

Two findings are particularly intriguing. We found that inhibitory control deficits were negatively associated with the proportion of Tasty-Healthy food items accepted, and that the proportion of Tasty–Healthy food items accepted was negatively associated with BMI. These findings suggest that inefficient inhibitory control may contribute to unhealthy diet, and to increased BMI, in multiple ways, instead of only by undermining the person's ability to resist the temptation of tasty but unhealthy food choices. In particular, individuals with less efficient inhibitory control may also choose *fewer* healthy foods, compared to individuals with better inhibitory control. This idea is consistent with findings reported by Riggs and colleagues (Riggs, Chou, Spruijt-Metz, & Pentz, 2010) who used self-report measures of cognitive control and food intake in children: lower cognitive control was associated with *higher* intake of less healthful snack foods (equivalent to Tasty–Unhealthy foods in our study), as well as with *lower* intake of more healthful fruit and vegetables (equivalent to Tasty–Healthy or Untasty–Healthy foods in our study). Our data support the latter finding that individuals with greater inhibitory control deficits accept fewer healthy snacks than their peers with better inhibitory control. Similarly, Allan and colleagues (Allan, Johnston, & Campbell, 2011) examined whether cognitive control measures could predict intention-behavior gap in food choices in adults, and showed that individuals with lower cognitive control efficiency ate more snacks and less fruit and vegetables than they intended.

Despite compelling theoretical arguments and experimental evidence supporting the link between impulsive actions and impairment in response inhibition (Logan et al., 1997; Verbruggen & Logan, 2009), we did not observe robust associations between the measures of impulsivity and measures of inhibitory control in the current study, except for a trend towards a positive association between BIS-11 Motor Impulsiveness scores and false alarm rates in the Go/NoGo task. However, low or non-significant correlations between different measures of inhibitory functions have been commonly reported, and may partially be due to the fact that no measure is a pure measure of the underlying process (Friedman & Miyake, 2004). In addition, self-report measures and task-performance measures may have different sensitivity to state characteristics, including the levels of hunger, fatigue, and stress when completing the measure. But overall, our data are more consistent with the idea that impulsivity and inhibitory control reflect at least partially distinct and independent constructs. Nevertheless, both impulsivity as assessed with self-report and, to a lesser extent, inhibitory control efficiency as assessed with task performance, showed some significant associations with eating-related measures, and the direction of these associations was consistent with our predictions. The lack of robust association between impulsivity and inhibitory control in our data, coupled with the fact that both of these variables were associated with eating behavior, also underscores the challenge of clarifying the relationship between impulsivity and inhibitory functions in health behaviors.

We also did not observe any associations between the External, Emotional, and Restraint Eating (as measured through self-report with the DEBQ) and food choices in any of the food categories (as measured with the Food Choice task). Indeed, the results suggest that the DEBQ and the Food Choice task may assess different, but complementary, aspects of eating behavior. In particular, the DEBQ provides more insight into eating style characteristics, including internal and external triggers for overeating (e.g., overeating when in a negative emotional state or when food is readily available). In contrast, the Food Choice task provides more insight into food-related decision-making, such as a tendency to choose or refuse unhealthy snacks. To our knowledge the measures of food-related decision-making produced by the Food Choice task (Hare et al., 2009, 2011) has not been combined or compared with the DEBQ measures before. Our results support the utility of collecting both of these measures to assess eating behavior.

A critical challenge for future research will be to elucidate the brain processes underlying the observed behavioral associations between heightened impulsivity and reduced inhibitory control on the one hand, and specific forms of unhealthy eating behavior on the other hand. Neuroimaging studies of inhibitory control point to a distributed inhibitory control network in the brain, which typically includes the dorsolateral prefrontal cortex (DLPFC), the inferior frontal gyrus (IFG), and the pre-supplementary motor area (pre-SMA), as well as subcortical regions such as the subthalamic nucleus of the basal ganglia (Aron & Poldrack, 2006; Rubia et al., 2001; Wager et al., 2005). Recent neuroimaging evidence demonstrates that the DLPFC and IFG regions within the inhibitory control network are engaged when dieters deliberately exert self-control during food choices (Hare et al., 2009), and when non-dieters are prompted to consider the long-term health consequences of their diet when deciding about which snacks they want to consume (Hare et al., 2011). The same regions within the inhibitory control network are also engaged when people attempt to control their desire for preferred foods (Hollmann et al., 2011). Although a causal link is difficult to establish, growing evidence suggests that the varied efficiency of inhibitory control processes may contribute to the individual differences in healthy eating and in BMI. The magnitude of activation in the inhibitory control network during dietary choices (Hare et al., 2009) or following a satisfying meal (DelParigi et al., 2007) is positively associated with the degree of dietary self-control, with successful dieters engaging the inhibitory control network to a larger degree than unsuccessful dieters or non-dieters. The magnitude of activation in the inhibitory control network when inhibiting motor responses to appetizing foods is also negatively correlated with BMI, with leaner individuals showing greater activation than more overweight individuals (Batterink et al., 2010). Thus, in concert with the behavioral evidence, the neuroimaging evidence supports the view that impulsivity and inhibitory control play a key role in dietary decision-making, and that individual differences in impulse control may contribute to the risk for being overweight or obese.

Some limitations of the current study should be acknowledged. Dietary decisions and BMI are known to be affected by a number of cognitive and metabolic processes other than inhibitory control, and that were unmeasured in our study. First, it is well known that social and environmental factors (e.g., access to healthy vs. unhealthy foods) have a powerful influence on food choices and on the risk of obesity (Larson, Story, & Nelson, 2009; Story, Kaphingst, Robinson-O'Brien, & Glanz, 2008). We did not measure these factors in the current study. Furthermore, it has long been recognized that the risk for obesity is also determined by the interactive effects of the reactivity to external food-related cues on the one hand, and the reactivity to the internal satiety and hunger signals on the other hand (Schachter, 1968). Neuroimaging evidence confirms that lean individuals differ from overweight and obese individuals in their brain response to highly palatable, high-calorie foods, with overweight and obese individuals demonstrating greater reactivity to food cues in a number of cortical and subcortical regions associated with reward processing and motivation, including the orbitofrontal cortex and nucleus accumbens (Bruce et al., 2010; Stoeckel et al., 2008). Greater reactivity to food cues in the reward- and motivation-associated regions has also been shown to predict greater future weight gain (Stice, Yokum, Bohon, Marti, & Smolen, 2010) or worse outcome in a weight-loss program (Murdaugh, Cox, Cook, & Weller, 2012). Similarly, brain response to hunger and satiety signals, including in the regions within the inhibitory control network, has been shown to differ between lean individuals and individuals who are overweight or obese (Del Parigi et al., 2002). Thus, an important goal for future studies will be to examine the relative impact as well as the interactive effects of heightened impulsivity and inefficient inhibitory control on the one hand, and heightened reactivity to external food cues and to internal hunger and satiety signals on the other hand, on food-related decision-making and BMI in the same participants. In addition, the overweight and obese groups were underrepresented in our sample with respect to the general population, suggesting that a majority of our participants were already efficient in controlling their weight. Thus, because our sample was predominantly composed of healthy-weight participants, we may have been underpowered to detect some associations between impulsivity/inhibitory control, eating behavior, and BMI.

In conclusion, using structural equation modeling and measures of impulsivity, inhibitory control, eating behavior, and BMI in a sample of young adults, we demonstrate that heightened impulsivity and inefficient inhibitory control are associated with several different facets of unhealthy eating, including overeating in response to external food cues and in response to negative emotional states, and making food choices based on taste preferences without consideration of the foods' health value. We further show that such unhealthy eating is, for the most part, associated with increased BMI, with the exception of Restraint Eating, which is negatively associated with BMI. These results add to our understanding of the impact of individual differences in impulsivity and inhibitory control on eating behavior and may have implications for the treatment and prevention of obesity.

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