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Original Article

Characterizing motor impulsivity of individuals classified as overweight to obese

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ABSTRACT

Deficits in the impulse control system are an important predictor of energy intake and body weight. Adults classified as overweight to obese may possess these deficits as a general behavioral trait or they may be food-specific. The present study assessed motor impulsivity (ability to suppress a pre-potent response) when presented with food and neutral (non-food) cues, testing if deficits in motor impulsivity is specific to food cues or a general trait among participants classified as overweight to obese. The proportion of inhibitory failures to no-go targets following food cues (10.8%) was significantly greater than the proportion of inhibitory failures to no-go targets following neutral cues (1.9%, $p < 0.001$). These differences remained when covering for sex and hunger. This indicates deficits in food-specific impulse control (as opposed to general impulse control) are present in those classified as overweight to obese. Understanding the specific aspect of impulse control that is present in this population is needed for the development of future impulse control training interventions that seek to change eating behaviors as a means for weight control.

1. Introduction

Obesity is a major risk factor for type 2 diabetes mellitus, cardiovascular disease and certain cancers.[1–5] Obesity is thus tightly linked to all-cause mortality, contributing to nearly 520 000 deaths in America each year resulting in a cost of nearly $1.4 trillion.[6,7] A great deal of research has been devoted to identifying factors (physiological, social, and environmental) that have prompted the dramatic rise in obesity.[8] One such factor gaining attention as an important predictor of energy intake and over consumption is deficits in the impulse control system.[9]

Poor impulse control, also referred to impulsivity, is the tendency to think, control, and plan insufficiently-a multi-faceted construct with various laboratory tasks developed to study different aspects.[10,11] The present study specifically focused on participants' ability to suppress pre-potent responses to cues (motor impulsivity), traditionally measured using Stop Signal and Go/No-Go tasks.[11–16] In the context of eating, the pre-potent response when presented with food (especially highly rewarding, energy-dense food) is to eat it. This is an evolutionarily conserved trait, once serving as an important survival mechanism when food was often more difficult to obtain.[17] This trait can present a problem in today's obesogenic society, where motor impulsivity must be controlled to avoid over consumption. Having the ability to control, or curb, one's motor impulsivity can be viewed as having good response inhibition, where one can overrule impulsive reactions. Poor response inhibition has indeed been associated with increased food intake, overeating, and obesity.[18–20] These associations are strongest when individuals also have a robust desire, or urge, to eat such as when they are hungry, have strong preferences for energy-dense food, or find these foods highly reinforcing.[21–23] Individuals classified as overweight to obese are less able to inhibit appetitive responses towards food cues, which are also often elevated in these individuals.[24–28] This is the basis of the hedonic-inhibitory model of obesity, which proposes overconsumption of palatable foods is the result of inadequate response inhibition over the hedonic, appetitive system.[23]

Recent trials have evaluated how motor impulsivity can vary as a function of weight status. A recent study demonstrated that individuals classified as obese did not respond impulsively (better response inhibition) when presented with non-food cues but did respond impulsively when presented with energy-dense foods.[29] This supports earlier work where separate assessments of motor impulsivity revealed only images of energy dense foods elicited deficits in response inhibition.[9] Other evidence points to general impulsiveness influencing eating behaviors, such as where Binge Eating Disorder patients display greater response inhibition for non-food items compared to controls.[30] This has also been observed in children classified as obese, where they were not able to

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Abbreviations

BMI	Body Mass Index, kg/m^2
kg	Kilograms
m	Meters
IRB	Institutional Review Board
ms	Milliseconds
DPI	Dots per inch
VAS	Visual analog scales
ANOVA	Analysis of variance
SD	Standard Deviation
SE	Standard Error

inhibit responding towards non-food items.[19] Others have also demonstrated general deficits in impulsivity (measured via stop signal response time) is related to ad lib food intake.[18] It therefore appears weight status and food intake can be influenced by both general response inhibition and food-specific response inhibition, likely depending on parameters of the study and method used to assess impulsivity. Further understanding the dynamics of response inhibition and how it may relate to weight status is important for the development of future interventions that may use impulse control training to modify eating behaviors as a treatment for obesity or eating disorders.[31,32]

Comparing general and food-specific motor impulsivity in a sample of individuals classified, as overweight to obese using a single test has not been accomplished and thus the objective of the present study. As noted, some of the prevailing literature has demonstrated a link between general motor impulsivity and body weight status, while others citing food-specific motor impulsivity being different between those classified as normal weight and those classified as overweight to obese. We hypothesized individuals classified as overweight to obese exhibit greater deficits in motor impulsivity specific to food cues compared to general (non-food) motor impulsivity. Comparing these two types of motor impulsivity in a single sample of participants classified as overweight to obese may lead to important information that could inform future impulse control training methods. For instance, if motor impulsivity is determined to be a general trait (present for both neutral and food-specific cues) future impulse control training interventions may not need to be focused on food cues. However, if motor impulsivity is specific to food cues, future impulse control interventions must be focused on food cues in order to target eating behaviors.

The majority of eating behavior research has focused on females, including those assessing response inhibition and other aspects of impulsivity.[9,18,21,22,30,33–36] Only limited evidence suggests males classified as overweight also display greater general impulsivity (assessed via questionnaire) compared to males classified as normal weight.[37] The primary focus on females in this line of research likely stems from the greater prevalence of disordered eating behaviors and attitudes among females, and the stronger effect impulse control has on eating behaviors in this population.[38,39] The current study enrolled a near-equal number of males and females to better generalize this response.

2. Methods

The present manuscript is a secondary analysis of a trial assessing the effects of exercise on attentional bias and motor impulsivity towards food cues. As the initial analysis demonstrated no effect of exercise on motor impulsivity, the current analysis focused on the differences between motor impulsivity between food and neutral cues.[40] Recruitment occurred from May to October 2021. Participants were a sample who responded to recruitment media (fliers, online advertisements). All participants were classified as overweight to obese (defined as having a Body Mass Index [BMI] between 25 and 45 kg per meter squared [kg/m^2]) non-smoking, free of chronic diseases (such as diabetes or heart disease), never diagnosed with an eating disorder, and not currently engaging in a weight loss diet. Participants were not made aware of the true purpose of the study to avoid any potential bias towards the food cues. Participants were instead told this task assessed their attention and reaction time.

2.1. *Ethical approval*

This study was approved by the University of Kentucky Institutional Review Board (IRB), protocol #52127. As part of this IRB approved protocol, each participant participated in the informed consent process, providing his or her written informed consent prior to enrollment. This trial is registered with clinicaltrials.gov, NCT04651218.

2.1. *Motor impulsivity task*

Motor impulsivity was assessed via a go/no-go task tailored from.[16] Participants in the present trial were required to respond to food-related images or neutral (non-food) images that were presented on a computer screen. Each assessment included five blocks of 50 trials (250 trials total, 125 neutral cues, 125 food cues). A trial involved a sequence of events during which a fixation point (+) was presented for 800 ms, followed by a blank white screen for 500 ms, a cue image (food or neutral) was presented for 500 ms, and finally a go or no-go target was displayed until a response occurred or 1 000 ms elapsed. There was a 700 ms interval between all trials. All images had dimensions of 680 x 491 pixels and were 96 dots per inch (dpi) resolution. Food-related images included highly rewarding, energy-dense foods such as desserts, candy, or high-fat main entrees such as cheeseburgers or other fried foods. Neutral images included those not associated with eating such as office supplies or nature. After the cue image was presented, it turned either solid green (go) or blue (no-go). All participants were assigned to the food go condition, where 80% of responses following food cues was the “go” response.[16,41] Participants were instructed to respond as quickly as possible by pressing a keyboard button when the green target appeared and withhold responding when the blue target appeared. Failing to withhold responding (responding when the NoGo/blue signal is presented) after a food-related image is indicative of poor inhibitory control (poor response inhibition) for food cues. Failing to withhold responding to the NoGo (blue) signal after neutral image is presented is indicative of poor inhibitory control in general.[16] The final outcomes were percentage of inhibitory failures, or “false alarms” following a food cue (responding when presented with a the blue signal after a food cue is presented), percentage of inhibitory failures following a neutral cue (responding when presented with a blue signal after a neutral image is presented), and reaction time to the cues. Each participant completed the assessment in the afternoon, between lunch and dinner, 3–5 h post-prandial. This was done to avoid assessing participants in either very hungry or vary satiating conditions.

2.2. *Other measures*

2.2.1. *Height and weight*

Height was measured in triplicate to the nearest 0.1 cm using a stadiometer (Seca; Chino, California). Body weight was measured using a calibrated digital scale connected to the BodPod (Cosmed, Chicago, Illinois) to the nearest 0.01 kg. Measures were completed with participants wearing spandex shorts and sports bra (females) or no shirt (males) as required for the BodPod assessment (below). BMI was calculated during the screening and enrollment visit to ensure participants qualified for the study.

2.2.2. *Body composition*

Body fat and fat-free mass (measured in kg) was determined via air displacement plethysmography (BodPod) and percent body fat calculated. Participants were assessed in the fasted condition at a separate visit prior to any assessment visit. The BodPod is a reliable and valid assessment tool for body composition in adults, offering a quick and non-invasive assessment of body composition.[42] The Siri or Schutte density model was used, depending on race, to convert body density to percent body fat.[43,44] Thoracic gas volume was measured according to manufacture recommendations.

2.2.3. Hunger and satiety

Visual analog scales (VAS) were completed to assess hunger at the beginning of each assessment. Participants were asked “how hungry do you feel right now”, on a computer program where they were instructed to drag a bar along a line that ranged from “not hungry at all” to “extremely hungry”. Hunger scores were used as covariates in statistical models.

2.3. Analytic plan and power considerations

Independent sample *t*-tests were used to test for differences in demographics between males and females as previously reported.[40] The number of incorrect responses to a NoGo (blue) signal was tallied for each condition (food and neutral) and converted into a percentage to yield percentage of inhibitory fails for food and neutral cues for each participant. Shapiro-Wilk and Kolmogorov-Smirnov tests for normality indicated both percent inhibitory fails and hunger were non-normally distributed. Thus, the Kruskal-Wallis test was used to determine differences in inaccuracy percentage between food and neutral cues and hunger between males and females. Quantile Regression was then used to investigate if hunger and/or sex were significant predictors (covariates). Reaction time was tested via One-way analysis of variance (ANOVA) for differences between conditions (food vs. neutral cues).

2.4. Sample size calculations

Sample size was determined from a previous study that used the Go/NoGo task the current study adapted for food and neutral cues.[16] This prior study demonstrated cocaine cues produced significantly more inhibitory fails than neutral cues among cocaine abusers ([18% ± 4%] vs. [7% ± 2%]). Using a 90% confidence level, 80% power, and assuming a Standard Deviation (*SD*) of 3 (halfway between the *SD*s of 2 and 4 for the two groups in the prior study), 30 participants were needed to have adequate power to detect differences in percent inhibitory fails between conditions.

3. Results

Study completers included 16 male and 14 female participants with a mean ± *SD* age of (32.9 ± 7.6) year-old, BMI of (32.7 ± 5.2) kg/m^2 and percent body fat of (38.5% ± 8%).

Shapiro-Wilk (0.623) and Kolmogorov-Smirnov (0.296) tests revealed data of the percentage of inhibitory fails were not normally distributed ($p < 0.01$). Hunger scores were also not normally distributed (Shapiro-Wilk: 0.943 and Kolmogorov-Smirnov: 0.104, both $p < 0.01$). Percentage of inhibitory fails was different between conditions (food vs. neutral cues) as depicted in Fig. 1, with the proportion of inhibitory failures to no-go targets reaching (10.8% ± 1.4%) while the proportion of inhibitory failures to no-go targets following neutral cues only reaching 1.9% ± 0.2, (Mean ± *SE*, Kruskal-Wallis test statistic 60.9, $p < 0.01$). Although the present trial was not power to determine a sex effect, exploratory analysis indicated that females were significantly hungrier than males (Kruscal-Wallis test statistic 8.84, $p < 0.01$), Fig. 2. For this reason, quantile regression was performed with cue (food vs. neutral) as the independent variable and inaccuracy percentage as the dependent variable while including hunger and sex (both together and solely in separate models) as predictors. As depicted in Table 1, neither sex nor hunger were significant predictors while the significant relationship between percentage of inhibitory fails and condition (food vs. neutral) held in all models $p < 0.01$.

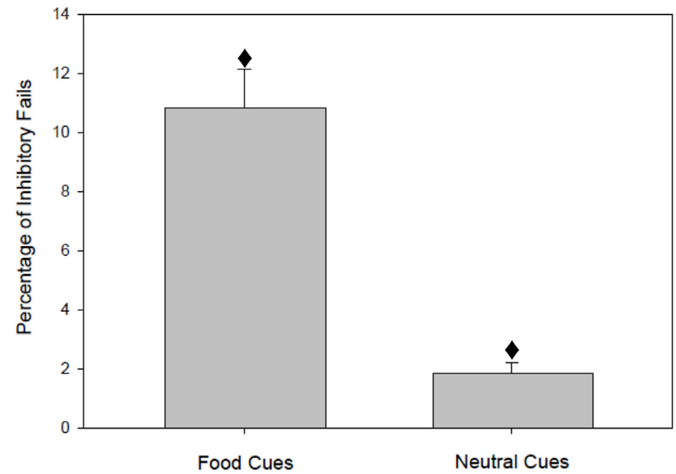

Fig.1. Percentage of inhibitory fails between food and neutral cue conditions-unadjusted. A greater percentage of inhibitory fails (press Go button when NoGo signal is presented) is indicative of poor impulse control.
◆ Indicates significant differences between conditions ($p < 0.01$).

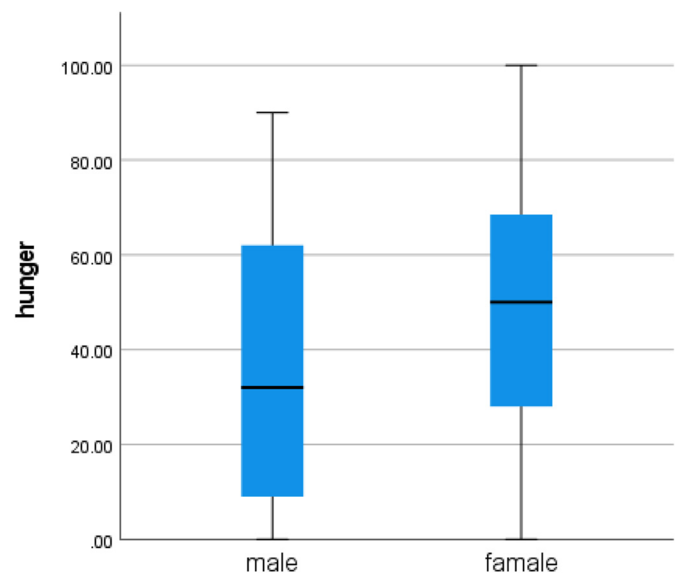

Fig.2. Hunger scores (1–100 Linkert scale) between sex.
Females were significantly hungrier than males, Kruscal-Wallis test statistic 8.84, $p < 0.01$.

4. Discussion

Results of the present study indicate individuals classified as overweight to obese display greater deficits in motor impulsivity specific to food cues, compared to general response inhibition. It is important to note that with a lack of normal-weight control group, we cannot state that individuals with overweight/obesity have deficits in motor impulsivity compared to their lean counterparts. However, others have demonstrated deficits in general response inhibition in populations such as adults and children classified as obese and binge eating disorder patients compared to normal weight controls.[19,30,45] It is very possible that our sample of individuals would display deficits in general response inhibition too if we compared to a sample of normal weight controls; however, the present study aimed to determine the specific aspect of impulsivity that those classified as overweight to obese are most prone to deficits in. This is important information for future impulse control training interventions, indicating these interventions must be tailored to

Table 1
Quantile Regression with condition and inaccuracy percentage

Effect	Coefficient	*SE*	*p*
Full model with both sex and hunger as predictors			
Intercept	0.30	0.10	< 0.01
Condition (food vs neutral)	7.82	0.06	< 0.01
Hunger	< −0.01	0.10	0.34
Sex	−0.10	0.06	0.10
Reduced model with sex as predictor			
Intercept	0.10	0.07	0.18
Condition (food vs neutral)	3.90	0.04	< 0.01
Sex	< 0.01	0.04	1.00
Reduced model with hunger as predictor			
Intercept	0.01	0.05	0.04
Condition (food vs neutral)	7.90	0.05	< 0.01
Hunger	< −0.01	< 0.01	1.00

Quantile Regression with condition (food vs. neutral) as the independent variable and inaccuracy percentage as the dependent variable. Three models are presented. The Full model includes both hunger and sex as additional predictors while two reduced models test if sex or hunger alone are significant predictors.

target food-specific impulse control to change eating behaviors. Such interventions are currently underway with varying levels of success.[31,32,46] Additional research is needed to improve the utility of these training interventions, and the current finding that individuals classified as overweight to obese have greater food-specific deficits in motor impulsivity, adds to this knowledge base. Although general response inhibition can still be a relevant construct and related to ad lib food intake in normal weight individuals,[18] other aspects of general impulsivity (impulsive personality traits, delayed discounting) are predictive of obesity.[35,45] The present study, to our knowledge, is the first to demonstrate those classified as overweight to obese had better response inhibition for neutral cues compared to food cues, thus making their lack of response inhibition towards food cues a potentially larger problem.

Another novelty to the present study is the use of both male and female participants and the inclusion of sex as a covariate in the statistical models. As noted, the overwhelming majority of studies on impulsivity and eating behaviors focus solely on females.[9,18,21,22,30,33–36] To our knowledge, only two studies have assessed such sex effects, demonstrating the link between impulse control and obesity is driven by females,[38,39] We were not adequately powered to test for differences in impulse control between males and females and thus cannot confidently conclude any differences exist in our sample, thus representing a gap in the literature future trials must focus on.

It is also important to note that hunger did not have any influence on the relationship between response inhibition and condition (food or neutral). Hunger was assessed on a 100-point linkert VAS scale (100 being most hungry) with overall mean values at 41.97. This indicates participants were neither particularly hungry nor satiated when assessed, which was our intention. Loeber et al. demonstrated that hunger plays a role in food-specific Go/NoGo task performance whereas hungry participants commit significantly more errors compared to satiated participants.[47] The present results do not necessarily counter these of Loeber et al. as we did not look at very hungry vs. very satiated states. The present results indicate that when individuals classified as overweight to obese are in a neutral state (neither exceptionally hungry nor satiated) they still have deficits in food-specific response inhibition compared to general response inhibition. If we assessed our participants in a hungrier state, it is uncertain if we would have seen worse response inhibition in both conditions, making this an interesting future research question.

This study was not without limitations. A normal-weight control group would have allowed weight status to be included into the models for additional analysis. This would have allowed us to determine differences in impulse control between those with overweight/obesity to those classified as normal weight. Although, as noted, this question has already been addressed, while the current trial aimed to assess differences in neutral vs food specific motor impulsivity in those with overweight/obesity. The possibility does remain, however, that those classified as normal weight also display the same pattern of greater deficits in impulse control for food cues compared to neutral. However, future impulse control training interventions designed to target eating behaviors are concerned with weight loss, thus the focus on those classified as overweight to obese in the present trial. It may also have been stronger to have hunger under experimental control. Although we presented instructions on when to eat prior to the assessment visit, providing food would ensure participants were matched in this way. Only younger adults were included in this study, with a mean age just under 33 years. We are therefore uncertain if similar effects would be seen in older adults or children. We also did not screen for eating disorders, only asking participants if they were ever diagnosed with a clinical eating disorder as part of our exclusion criteria. It is possible that some of our participants had disordered eating behaviors but not a diagnosed condition. Related to this, many of our participants have likely experienced weight issues their whole lives and have dieted in the past while others have not. This could have caused a different outlook or relationship with food. Since this information was not collected, we are uncertain if this is an additional source of variation. Additionally, our Go/NoGo task only featured energy dense, highly palatable foods. It is unknown if the same results would have been observed if we utilized more typical foods in our task.

5. Conclusions and future directions

Results of the present study support the concept that deficits in response inhibition specific to food cues are present among individuals classified as overweight to obese. This is an important consideration for future research, providing strong support for use of food-specific inhibitory control training interventions designed to modify eating behaviors. Additional research elucidating other clinical or individual aspects that may influence response inhibition are needed to further understand the magnitude of this behavioral construct in promoting uncontrolled eating and weight gain. With the dearth of literature on the effects of response inhibition among males, additional studies focusing on sex differences are needed. Longitudinal trials may also be warranted, evaluating if changes in response inhibition predict weight gain. Further assessing factors related or predicting food-specific response inhibition may also positively serve such future inhibitory control training research.

Authors' contributions

Kyle D. Flack: Conceptualization, Formal analysis, Funding acquisition, Project administration, Software support, Writing-original draft.Robert E. Anderson III: Data curation, Investigation, Validation, Writing: review and editing.Kylie F. McFee: Data curation, Investigation, Validation, Writing: review and editing Bridgette T. Day: Data curation, Validation.

Submission statement

The manuscript is an original research article that has not been published previously, it is not under consideration for publication elsewhere, its publication is approved by all authors who have read and followed the instructions for Authors set forth by Sports Medicine and Health Sciences, and tacitly or explicitly by the responsible authorities where the work was carried out.

Ethics approval statement

This study was approved by the University of Kentucky Institutional Review Board (IRB), protocol #52127. As part of this IRB approved protocol, each participant participated in the informed consent process, providing his or her written informed consent prior to enrollment. This trial is registered with clinicaltrials.gov, NCT04651218.

Conflict of interest

All authors have no conflicts of interest to report.

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