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ORIGINAL ARTICLE

The interaction between impulsivity and a varied food environment: its influence on food intake and overweight

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Objective: The current study tests the influence of two factors, the obesogenic environment and impulsivity, on food intake in primary school children. Our current food environment offers a large variety of cheap and easily available sweet and fatty foods. This obesogenic environment is believed to be a cause of the recent obesity epidemic. Impulsive people are generally less successful at inhibiting prepotent responses and they are reward sensitive. We investigate whether the interaction between an obesogenic environment and an impulsive person leads to overeating.
Design: A quasi-experimental 2 (reward sensitive versus not reward sensitive) by 2 (successful response inhibitors versus unsuccessful response inhibitors) by 2 (monotonous versus varied food environment) between-subjects design with caloric intake during a taste test as the main dependent variable. The link between impulsivity and overweight was also examined.
Subjects: 78 healthy primary school children (age: 8–10 years).
Measurements: We measured two aspects of impulsivity: reward sensitivity and deficient response inhibition. Subsequently, one aspect of the obesogenic environment was manipulated; half of the participants received monotonous food during a bogus taste test whereas the other half tasted food that was varied in colour, form, taste and texture.
Results: As expected, reward sensitivity interacted with variety. In the monotony group there was no difference in food intake between the less and more reward-sensitive children (183 kcal ± 23 s.d. versus 180 kcal ± 21 s.d.). However, in the variety group the more reward-sensitive children ingested significantly more calories than the less reward-sensitive children (237 kcal ± 30 s.d. versus 141 kcal ± 19 s.d.). Reward sensitivity was not linked to overweight. Deficient response inhibition did not interact with variety, but it was linked to overweight.
Conclusion: It is suggested that reward sensitivity could be a causal mechanism for overeating in an obesogenic environment whereas prepotent response inhibition may be a maintaining factor of the problem of overeating.
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Keywords: response inhibition; reward sensitivity; impulsivity; variety; food intake; children

Introduction

In the United States and in Western Europe the prevalence of overweight and obesity is rising problematically.[1] Even very young children are increasingly confronted with weight problems. Although this 'obesity epidemic' has many adverse health consequences,[1,2] little is known about its causes.[1] If we want to stop or even reverse this obesity epidemic, children are a potentially valuable target group. Tracking studies indicate that most children with high BMI become adults with high BMI.[3,4] Information about the causes of rising prevalences of childhood overweight and obesity would enable us to tackle weight problems during childhood so that we can prevent these children from becoming weighty adults.

What are potential causes of the obesity epidemic? One factor that is frequently referred to is the environment.[5] Sweet and fatty foods have never been more varied, cheaper or more available and have never been offered in larger portion sizes.[6] This constant confrontation with palatable food activates the hedonic system that promotes food intake not due to energetic needs, but due to environmental or emotional reasons.[7] Consequently, a positive energy balance is likely, which could lead to weight gain.

However, a substantial amount of people manage to remain lean despite the temptations in our environment. This is where individual differences come into play: a person's reaction to the environment is moderated by certain

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character traits.[8] One such trait is impulsivity. Generally, impulsivity is defined as the tendency to think, control and plan insufficiently, resulting in an inaccurate or maladaptive response.[9] Impulsive behaviours are very diverse, but they can be narrowed down to two main aspects: reward related impulsivity and insufficient prepotent response inhibition.[9] Reward-sensitive people detect more rewarding stimuli and are more likely to approach these stimuli.[10] Insufficient prepotent response inhibition reflects a slower response of impulsive people to inhibition signals.[11,12]

Despite these differences both aspects of impulsivity have been linked to obesity: Nederkoorn and colleagues[13] found that obese children were more reward sensitive and worse at prepotent response inhibition than control children. Obese adult women also appeared to be worse response inhibitors than lean controls, especially towards the end of the computer task.[14] Moreover, insufficient response inhibition was an obstacle in the treatment of the obese children: the most impulsive children lost less weight.[15] Obesity has also been linked to attention deficit/hyperactivity disorder, a disorder that is hallmarked by an excess of impulsive behaviour.[16–18]

However, this sort of research only allows us to conclude that impulsivity and obesity are linked. Whether impulsivity makes one obese or obesity makes one impulsive or both cannot be determined. To investigate whether impulsivity could lead to overweight or obesity through overeating, Guerrieri conducted two studies with normal-weight women. In the first study[19] participants performed the Stop Signal Task (SST) which measures response inhibition.[12] This task was followed by a bogus taste test. Participants were presented with a bowl of 'sugar beans', almond-shaped chocolate candies covered in a layer of sugar, and were asked to taste these and to fill in a bogus taste perception questionnaire. Participants in the variety group received 14 different colours of sugar beans whereas the monotony group received an equal amount of white sugar beans. The sugar beans were thus varied in colour, but not in taste, form and texture. After the taste test, participants filled out the Barratt Impulsiveness Scale[20] (BIS), which measures three kinds of impulsive behaviour: motor impulsiveness (acting without thinking), attentional impulsiveness (not focusing on the task at hand) and nonplanning impulsiveness (lack of orientation to the future). High self-report of impulsive behaviours, but not response inhibition was associated with a significantly higher caloric intake. This effect was not moderated by variety.

The second study,[21] in which variety was not manipulated, consisted of four sessions. The first day SST was performed, followed by a taste test. Two days later participants returned for a second taste test, followed by a third taste test another two days later. Three to four weeks later the participants filled in self-report impulsivity measures. The results were that response inhibition as well as self-report impulsivity significantly predicted the cumulative food intake during the three taste tests.

The aim of the current study was to find out whether impulsivity, possibly in combination with exposure to (aspects of) an obesogenic environment, leads to overeating in healthy children. We recruited a group of 78 primary school children. We measured the two aspects of impulsivity: reward sensitivity and deficient prepotent response inhibition. Subsequently, one aspect of the obesogenic environment was manipulated: half of the children received monotonous food during a taste test whereas the other half tasted varied food.

We expected that response inhibition would interact with variety in the sense that poor response inhibitors would overeat especially when varied food was offered and not when bland food was offered. Davis and colleagues[16] contend that poor inhibitory control could lead to unrestrained eating, especially in our obesogenic environment. In a previous study,[19] we found that impulsivity measured as insufficient prepotent response inhibition did not influence food intake and did not interact with variety. However, in this study only the colour of the presented food was varied. Consequently, the manipulation may not have been strong enough. In the current study colour, taste, form and texture were all varied.

As far as reward sensitivity is concerned, we expected that reward-sensitive children would have a difficult time resisting varied food compared to children that are relatively insensitive to reward. For monotonous food no differences were expected. Blundell and colleagues[8] agree with this hypothesis; they see a high food-induced pleasure response as a behavioural risk factor for overconsumption and they also predict that this risk factor will only lead to excessive food intake in an obesogenic environment.

Based on the results of Nederkoorn and colleagues[14] we expected that the overweight children in this sample would exhibit poorer response inhibition skills than the lean children, especially towards the end of the computer task. Since the aspect of reward sensitivity has also been linked to obesity,[13] we expected that, besides being poor response inhibitors, the overweight children would also be more reward sensitive.

In sum, we had three hypotheses: (1) response inhibition will interact with variety—poor response inhibitors will overeat especially when varied food is offered and not when bland food is offered; (2) reward sensitivity will interact with variety—reward-sensitive children will overeat especially when varied food is offered and not when bland food is offered and (3) the overweight children in this sample will be less effective response inhibitors and more reward sensitive than the lean children.

Method

Participants

Five primary schools in the area of Maastricht participated in a study on 'Nutrition and Health'. All children in the third and fourth grade (children between 8 and 10 years old) received a consent form. About 50% of the parents gave consent for their child to participate. The exclusion criteria were allergy or dislike of the specific candy, being on a diet or language problems. This left us with 78 eligible children between 8 and 10 years of age (45 boys versus 33 girls; mean age: 9 years ± 0.60 years; mean BMI 17.36 ± 2.58).

Materials

At the beginning of the experimental session the experimenter had a *short interview* with the participant asking several questions concerning hunger and the last meal. Hunger was measured by asking the children how full their stomach felt at that moment. They could choose one of three options: (1) my stomach is very full—I cannot eat anything; (2) my stomach is comfortably full—it is not too full, but also not empty (3) my stomach is empty—I could eat a lot of food. This led to a hunger score ranging from 0 (not hungry at all) to 2 (very hungry). The experimenter also asked the children when they had their last meal: the night before, at breakfast, during their morning break, at lunch or during their afternoon break. The children also reported what their last meal had consisted of and their age and sex were noted.

Measure of response inhibition. The *Stop Signal Task* (*SST*)[12] is based on the notion that impulsive behaviour can be operationalized as a diminished ability to inhibit prepotent responses. In order to measure inhibitory control a behavioural computer task was developed.[12] This computer task contains two sorts of trials: gotrials (75%) and stoptrials (25%). During the gotrials the participant performs a choice reaction time task: the participant learns to press a certain button as fast as possible dependent on the stimulus that is presented (an X on the right or an O on the left for 1500 ms). This learned response has to be inhibited during the stoptrials; a tone serves as a stop signal and tells the participant *not* to push the button in response to the stimulus. At the start of the task the delay between the go signal (X or O) and the stop signal is set to 250 ms. A tracking procedure adapts the delay dynamically depending on the participant's behaviour. If the participant inhibits successfully, the task is made more difficult by increasing the delay by 50 ms. Following an unsuccessful inhibition the delay is decreased by 50 ms, making the task easier. The task consists of four blocks of 64 trials each and a practice block of 10 trials. Two variables are measured: reaction time (RT) and stop delay. The stop signal reaction time (SSRT), the main independent variable, is calculated by subtracting the stop delay from RT.[12] The longer the SSRT, the more impulsive a participant is thought to be. In the current study we used a child-friendly version of the task. Instead of an X or an O, the stimulus was a clown that popped up at the right or at the left of the screen. Moreover, because we suspected that 10 practice trials would not suffice for the children, the first block was also considered a practice block. Consequently, in the current study SST consisted of three blocks instead of four. SST has been administered to children, starting from 6 years of age.[22] Consequently, we did not expect any problems in administering this task to our sample of 8 to 10-year-olds.

Measure of reward sensitivity. The *Door Opening Task* aims to measure reward dominance in children aged 8–13 years. It is a slightly adapted version of the task used by Matthys and colleagues[23] that was also used by Nederkoorn and colleagues.[13] The participant is told that he or she can earn points within this task and should try to collect as many points as possible. The participant earns a point when the door on the computer screen reveals a smiling face. However, when this door reveals a sad face, the participant loses a point. In total, there are 100 doors to open. The probability of getting a winning door drops from 90 to 10% as the participant opens more doors. Since the participant has to collect as many points as possible, he or she should quit opening doors once the probability of a winning door drops below 50%. If the participant keeps opening the doors in search for reward in spite of punishment, the reward system is thought to be dominant. A participant that is easily discouraged by the encounter of a few losing doors is thought to be sensitive to punishment.

Food intake was measured via a *Bogus Taste Test*. In the variety group participants were confronted with a dish that contained five sorts of marshmallows: white-pink marshmallows (± 95 g), pink marshmallows covered in coconut (± 40 g), white marshmallows covered in coconut (± 40 g), marshmallows covered in milk chocolate (± 80 g) and yellow and green marshmallows in different forms (± 90 g). In the monotony group a dish with an equal amount (± 350 g) of the regular white-pink marshmallows was served. Participants were left alone for 10 min and asked to taste the candy. In order to indicate how much they liked the taste of the candy, they could colour one of three faces. If they coloured the smiling face, this indicated that they liked the candy. If they coloured the neutral face, this indicated that they did not find it particularly palatable, but also not particularly unpalatable. If they coloured the sad face, this indicated that they did not like the taste of the candy. We did not use different types of sweets because we wanted to keep the testing situation in both groups as equal as possible. Both groups received one bowl of sweets and one taste test colouring card to report their liking of the sweets.

The primary interest of the authors was not how participants rated the taste of the food, but how much they ingested of the food that was offered. Without the participants' knowledge the bowls of food were weighed before and after the taste test in order to establish food intake. The amounts eaten of each food were converted to calories. The sum of these calories was the dependent variable: total caloric intake. Participants could drink some water if they got thirsty during the taste test. Participants were told to stay in their seat and wait for the experimenter to come back in case they finished their tasting early.

Procedure

The children were tested individually in a separate room within their school somewhere between their morning break (±1000 hours) and their afternoon break (±1400 hours). The experimenter went to the classroom and took the child to the test room. The experimenter started with an interview that lasted about 2 min. After the interview the experimenter explained to the child that they would play two computer games. She then gave the instructions for the SST. The SST took about 20 min to complete. After this task the child got a short break while the experimenter started up the Door Opening Task. When the child was ready to proceed, the Door Opening Task was explained. The Door Opening Task took 5–10 min. After the Door Opening Task the laptop was put away and the marshmallows and a glass of water were put on the table. The child received instructions (see Materials) and was left alone for 10 min. Afterwards, the child was weighed and measured without shoes and heavy clothing. The child was invited to choose a small present for participating. After the session the experimenter took the child back to the classroom before picking up the next child. Each testing session lasted 40–45 min.

We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. Approval of the Maastricht University Ethical Committee was obtained.

Statistics

Participants were randomly assigned to the monotony or variety group by the tossing of a coin. Pre-existing differences between the monotony group and the variety group should be ruled out, but they were checked via independent sample *t*-tests and a χ^2-test.

A 2 (monotony versus variety) by 2 (successful versus less successful response inhibitors) by 2 (more reward sensitive versus less reward sensitive) between-subjects ANCOVA with caloric intake as the dependent variable and age as a covariate was conducted to look at the effects of variety, reward sensitivity and response inhibition on food intake. We used a median-split (median SSRT: 174 ms) to separate successful response inhibitors (SSRT <174 ms) from less successful response inhibitors (SSRT$\geqslant 174$ ms). Likewise, we used a median-split (median number of doors opened: 46) to separate more reward-sensitive (opened doors >46) from less reward-sensitive children (opened doors $\leqslant 46$). *Post-hoc* tests on interactions consisted of independent sample *t*-tests.

In order to look at the relationship between overweight and insufficient response inhibition, a 2 (normal weight versus overweight) by 3 (block 1 versus block 2 versus block 3 of SST) mixed-model ANOVA was conducted with SSRT as the dependent variable. To determine whether the overweight children opened more doors compared to the lean children, an independent sample *t*-test was conducted for the factor overweight and with the number of opened doors as the dependent variable.

Unless stated otherwise, all means are expressed with their standard deviations.

Results

Pre-existing differences between the monotony group and the variety group

The amounts of boys and girls did not differ between groups, 18 girls versus 22 boys in the monotony group and 15 girls versus 23 boys in the variety group, $\chi^2(1)=0.24$, $P>0.6$. Moreover, there were no differences in hunger (ranging from 0–2), 1 ± 0.32 in the monotony group versus 1.05 ± 0.32 in the variety group, $t(76)=0.72$, $P>0.4$ and BMI, 17 ± 2.5 for the monotony group versus 17.7 ± 2.6 for the variety group, $t(76)=1.3$, $P\geqslant0.2$. There was a significant age difference between the groups; the children in the variety group (9.1 years $\pm$ 0.6) were slightly older than the children in the monotony group (8.7 years $\pm$ 0.5), $t(76)=3.19$, $P<0.01$.

Variety, response inhibition, reward sensitivity and food intake

Successful response inhibitors had a SSRT of 147 ms $\pm$ 32 whereas unsuccessful response inhibitors had a SSRT of 233 ms $\pm$ 64. The two groups differed significantly in mean SSRT, $t(76)=7.56$, $P<0.001$. More reward-sensitive children opened 79 doors ($\pm$11), whereas less reward-sensitive children opened 34 doors ($\pm$11). Again, the two groups differed significantly in the number of opened doors, $t(76)=17.83$, $P<0.001$.

Variety did not have a main effect on ingested calories, $F(1, 69)=0.1$, $P>0.7$. The covariate 'age' had a marginally significant effect, $F(1, 69)=2.99$, $P<0.1$ (8 years: 133 kcal $\pm$ 65; 9 years: 193 kcal $\pm$ 107; 10 years: 166 kcal $\pm$ 84).

The main effect of *response inhibition* was not significant, $F(1, 69)=0.21$, $P>0.6$. Likewise, the interaction between response inhibition and variety was not significant, $F(1, 69)=1.91$, $P>0.15$. Hence, hypothesis 2 was not supported. See Figure 1 for Estimated Marginal Means plots of the interaction effects between variety and reward responsiveness and variety and response inhibition.

The main effect of *reward sensitivity* was marginally significant, $F(1, 69)=3.95$, $P\leqslant0.06$. Children that were reward sensitive ingested more calories compared to children that were not reward sensitive (209 kcal $\pm$ 18 versus 162 kcal $\pm$ 14; estimated marginal means $\pm$ s.e.m.). The interaction between reward sensitivity and variety was significant, $F(1, 69)=4.45$, $P<0.05$. In the monotony group there was no difference in food intake between the less and more reward-sensitive children, $t(38)=0.27$, $P>0.7$. However, in the Variety Group the more reward-sensitive children

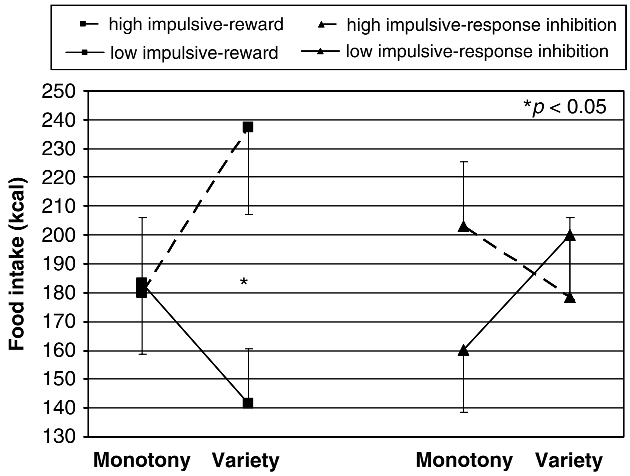

Figure 1 Means plot for the interaction between variety and reward sensitivity (F(1, 69) = 4.45, $P<0.05$) and variety and response inhibition (F(1, 69) = 1.91, $P>0.15$). The means are ± s.e.m.

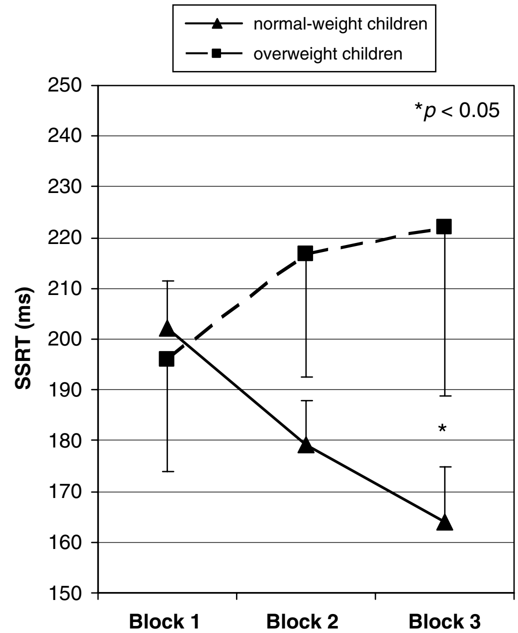

Figure 2 Means plot for the interaction effect between overweight and Stop Signal Block (F(1, 76) = 2.96, $P<0.06$). The means are ± s.e.m.

ingested significantly more calories than the less reward-sensitive children, $t(36) = 2.48$, $P<0.05$.

The three-way interaction between variety, response inhibition and reward sensitivity did not reach significance, F(1, 69) = 0.54, $P>0.4$.

Overweight and impulsivity

There were 15 children in our sample of 78 who were overweight according to the national development curve (BMI overweight children 21.75 ± 1.62 versus BMI lean children 16.32 ± 1.38).

There was a marginally significant interaction effect between overweight and stop signal block, F(1, 76) = 2.96, $P<0.06$. *Post-hoc* tests revealed a pattern; during the first block there was no difference between normal-weight and overweight children, $t(76) = 0.29$, $P>0.7$. However, during the second block the SSRT of the overweight children increased whereas the SSRT of the normal-weight children decreased, $t(76) = 1.76$, $P<0.1$. For the third block the difference between overweight and normal-weight children is significant, $t(76) = 2.14$, $P<0.05$. See Figure 2 for an Estimated Marginal Means plot.

Overweight children did not open more doors than lean children, 50 ± 19 doors versus 53 ± 26 doors, $t(76) = 0.42$, $P>0.6$.

Discussion

In the current study we tested whether two aspects of impulsivity, reward sensitivity and response inhibition affected food intake, especially in interaction with variety. Both aspects affected food intake quite differently.

Reward sensitivity interacted with variety as expected. When monotonous food was offered, reward sensitivity did not really affect caloric intake. However, when varied food was offered, reward-sensitive children ingested significantly more calories than their less reward-sensitive counterparts. In this sense the obesogenic environment, or at least the aspect of variety of this environment, could play a key role in the recent obesity epidemic. To our knowledge, this hypothesis has been formulated by multiple authors, but it was never investigated experimentally. Hence, this study is the first study in which this hypothesis is empirically supported. Due to this empirical support one can begin to take more seriously the combined effects of reward sensitivity and variety in the food environment as a mechanism towards overweight and obesity. However, this finding needs to be replicated under different circumstances and in different populations in order to gain more strength as a potential obesity mechanism. Analyses of self-report reward sensitivity and (monotonous or varied) food intake data of young women in our own databases (Guerrieri, Nederkoorn and Jansen, 2007, unpublished data) did lead to a replication of the results of the current study. Reward sensitivity, measured via self-report in young women with the BIS/BAS scales,[24] interacted with variety as expected. When monotonous food (that is, chocolates with a white sugar layer) was offered, reward sensitivity did not really affect caloric intake. However, when varied food (that is, the same chocolates in a variety of colours) was offered, reward-sensitive women ingested significantly more calories than their less reward-sensitive counterparts. In both studies the variety of the food was very limited. The food that is offered in our obesogenic environment is much more widely varied and as such the effect found here is probably an underestimation of the effect outside the lab.

The current study has identified a group of children who are sensitive to a varied food environment although they do not (yet?) show signs of weight problems. The next step should be a longitudinal study to investigate whether increased reward sensitivity early in life predicts weight problems later on. If this is the case and if it is possible to teach people to deal with reward sensitivity, this might be a useful contribution to weight loss therapies and preventive measures.

For the interaction between response inhibition and variety we expected the same pattern as for the interaction between reward sensitivity and variety. However, it turned out to be quite different. Response inhibition did not affect food intake, and it did not matter whether monotonous or varied food was offered. This is again in accordance with one of our previous studies.[19] However, in another study[21] we found that in healthy women response inhibition did predict food intake during bogus taste tests. This inconsistency is hard to explain. A main difference was that in this last study[21] the cumulated food intake over *several* taste tests was measured. Perhaps a single short taste test is insufficient to differentiate between people who are more or less effective at response inhibition. Perhaps the effect of less effective response inhibition is only noticeable in longer term food intake patterns.

Comparisons of the overweight children and the lean children showed that the overweight children in this study were characterized by less effective response inhibition, especially towards the end of the computer task. This is in line with the performance of the obese women in the study of Nederkoorn and colleagues.[14] The performance of the Door Opening Task did not differ between overweight and lean children, hence in the present study there seemed to be no direct relationship between overweight and reward responsiveness. This is against our hypothesis that was based on the findings of Nederkoorn and colleagues.[13] A difference between the two studies is that in the present study we tested overweight children, whereas Nederkoorn and colleagues[13] tested obese children. There is some recent evidence[25] for a nonlinear relationship between reward sensitivity and BMI in adult participants, but the exact form of the relationship differs from the current findings with children. Whether the association between reward sensitivity and BMI changes with age, or whether the use of different measures of reward sensitivity can explain these contrary findings, needs to be determined in future research.

The finding that unsuccessful response inhibition is linked to overweight, but not to food intake, could indicate that it is a mechanism that kicks in later in the process of becoming overweight or obese. It is worth investigating whether reward sensitivity is the basic mechanism that can lead people to overeat in an obesogenic environment, whereas unsuccessful response inhibition will start to affect food intake only after a prolonged period of overeating and/or gaining weight.

Although weight problems are caused by a combination of many factors, teaching people to deal with their reward sensitivity, and possibly their prepotent response inhibition, could bring us a step closer to solving the obesity epidemic.

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