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ORIGINAL ARTICLE

The interactive effect of hunger and impulsivity on food intake and purchase in a virtual supermarket

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Objective: It has been shown repeatedly that impulsivity, obesity and food intake are related; obese people are more impulsive than lean people and impulsive people eat more than less impulsive people. The relation between impulsivity and food intake might be state dependent; hunger motivates food seeking behaviour and food consumption, especially of high caloric food. Difficulties to overrule automatic behavioural tendencies might make impulsive people more susceptible to the effects of hunger on food selection. Therefore, they are expected to increase their intake more than low impulsive people when feeling hungry.
Study 1: Fifty-seven female participants were randomly assigned to a hunger or sated condition. Response inhibition (a measure of impulsivity) and food intake were measured. Results show that impulsive participants ate significantly more, but only when feeling hungry.
Study 2: Ninety-four undergraduate students participated. Hunger, response inhibition and the purchase of food in a virtual supermarket were measured. The same interaction was found: impulsive participants bought most calories, especially from snack food, but only when feeling hungry.
Conclusion: Hunger and impulsivity interact in their influence on consumption. These data suggest that reducing hunger during calorie restricting diets is important for successful weight loss, particularly for the impulsive dieters.
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Keywords: response inhibition; impulsivity; hunger; eating disorders; consumption

Introduction

The incidence of overweight and obesity has increased dramatically over the past few decades. The increase in obesity is primarily caused by relatively recent changes in our environment. However, not everyone becomes overweight while experiencing the same food overexposure. Some people appear better equipped to deal with the overabundance than others. This individual difference in weight gain sensitivity can predominantly be ascribed to differential food intake. Obese people are found to show a preference for energy dense, high-fat food[1–3] and eat more of these fatting foods compared with lean people.[4–6] Importantly, only 12% of the variability in weight gain can be explained by corresponding individual differences in metabolism.[7] Most overweight people (>95%) burn more calories than people with normal weight do.[8] In addition, review studies do not show a reduction of physical activity over recent decades.[9] So, it appears that the obesity epidemic is mainly due to a high dietary intake. An important question is therefore what personality characteristics cause overeating.

A personality trait that is related to overeating and obesity is impulsivity.[10–12] In general, impulsivity is defined as the tendency to think, control and plan insufficiently.[13] Precise behaviours that are considered impulsive are very diverse, but they can be categorized into two main aspects of impulsivity: reward-related impulsivity (sensitivity to reward/inability to delay reward) and insufficient inhibitory control over behaviour (the possibility to overrule automatic intentions to respond to stimuli).[13,14] Both impulsive aspects have been linked to obesity. For instance, obese children are more sensitive to reward compared with lean children: they keep gambling for a given reward, even when the chances of winning decrease and stopping would lead to greater gain.[14] Earlier research showed that obese children have an intolerance for delay of gratification.[15] Sensitivity to reward was also found to be related to craving for food and BMI in a female sample.[16] When considering the other aspect of impulsivity, insufficient response inhibition, it was found

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that obese children and women are less able to inhibit their response to infrequent stop signals, when the dominant task was to respond as fast as possible.[12,17] Interestingly, obese children show comorbidity with attention deficit/hyperactivity disorder, which is indicative of less impulse control,[18] and vice versa, attention deficit/hyperactivity disorder children have higher weights and higher incidences of obesity than norm groups.[19]

The association between impulsivity and obesity might suggest that impulsivity causes overeating, especially in the current food abundant environment and as argued above, frequent overeating in turn leads to body weight increase. This line of reasoning further suggests that impulsivity and food intake will also be positively correlated in lean people. Indeed, a few studies support this idea. Guerrieri *et al.*[20,21] showed that highly impulsive lean people eat more than less impulsive lean people during a taste test. In addition, it was found that insufficient response inhibition predicts consumption of milkshakes in lean female participants[11]. In another study, impulsive, highly restrained eaters ate more after cue exposure or a control condition, although not after a preload.[22] Davis *et al.*[10] found that sensitivity to reward predicts overeating and a preference for high caloric food, which in turn predicts a higher BMI. Moreover, experimentally induced impulsivity in lean participants causes them to eat more,[23,24] suggesting that impulsivity is indeed a cause of overeating.

In conclusion, converging evidence exists that impulsivity and food intake are related and that impulsivity may even cause overeating. It is still unclear, however, whether this relation is state or context dependent. It is conceivable that hunger interacts with impulsivity, in its effect on food intake. Hunger motivates food seeking behaviour and food consumption[25] and promotes a positive automatic association with food.[26] If you experience difficulty to overrule automatic behavioural tendencies, hunger might affect food intake more prominently than when you are able to control behaviour effectively. This might apply especially to high caloric, energy dense food; when hungry, people choose energy dense food more frequently[27] and find it more rewarding.[28] Hence, it can be hypothesized that (1) hunger increases food intake in everyone, though especially in highly impulsive people and (2) that highly impulsive and hungry people are especially prone to overeat when presented with high caloric, palatable foods.

In brief, both impulsivity and hunger are related to food intake. If and how these two factors interact, is not clear yet. In this paper, two studies are presented in which the interactive effects of hunger and a tendency towards response inhibition (as a personality trait) on food intake were tested. We hypothesized that participants with less effective response inhibition (that is, the more impulsive people) are more responsive to a current state of hunger, and consequently will eat more during a taste test of high caloric food (study 1) and will purchase more high caloric food items in a virtual supermarket (study 2).

Study 1

Method

Participants. Fifty-seven female students with a normal BMI (between 19 and 25 years) were asked to participate in an experiment on taste and smell perception. Mean age was 20.0 (s.d. = 1.4), mean BMI was 22.0 (s.d. = 1.6). Participants in the hunger condition ($n = 25$) were asked to eat a sandwich or bread roll 4 h before the experiment and refrain from eating thereafter, until the experiment began. Participants in the sated condition ($n = 32$) were asked to eat a sandwich or bread roll half an hour before the start of the experiment. Condition was assigned randomly, which caused a slight unequal distribution of participants.

Measures. *The stop signal task*[29] was used to measure response inhibition. Response inhibition, measured with this task, has been shown to be related to impulsivity[29] and to discriminate between obese and lean participants.[12] The stop signal task is a choice reaction time paradigm in which the participants must respond as fast as possible to a visual go-signal (an X or an O), unless an auditory stop signal is presented (through headphones) in which case the response must be inhibited (25% of the trials). Initially, the stop signal delay was set at 250 ms after the presentation of the go signal and then adjusted dynamically depending on the participant's responses, hereby enabling the participant to stop on approximately 50% of the stop trials. The two variables measured in this task are reaction time and mean stop delay. The stop signal reaction time (SSRT, measured in ms) was calculated by subtracting the stop delay from reaction time. Higher SSRTs mean less inhibitory control. The participants completed two practice blocks without stop signals (6 and 12 trials) and one with stop signals (24 trials). Afterwards, they completed four test blocks of 128 trials successively. Between blocks, the participants could take a short break.

The Three Factor Eating Questionnaire (TFEQ[30]) is a 51-item questionnaire consisting of three different subscales: cognitive restraint, disinhibition and trait hunger. The cognitive restraint subscale consists of 21 items concerning conscious control of food intake, with scores ranging from 0 to 21. The disinhibition subscale consists of 16 items relating to loss of control over eating, with scores ranging from 0 to 16. The final subscale on trait hunger consists of 14 items about the susceptibility to hunger feelings with scores ranging from 0 to 14.

During the *Taste test*, participants received six bowls, containing large amounts of unwrapped food of two variations of three different kinds of food: two kinds of cookies (Lu Bastogne Duo and Lu Bastogne Original), two flavours of crisps (Lay's Paprika and Lay's Natural) and two kinds of chocolate (Milka Alpen milk chocolate extra creamy and Milka Alpen milk chocolate). They were asked to rate differences in smell and taste between the two variations and were left alone for 10 min.

State Hunger was measured on a 100 mm visual analogue scale, ranging from 0 (not hungry at all at this moment) to 100 (very hungry at this moment).

Procedure. The study was approved by the Maastricht University, Faculty of Psychology and Neuroscience Ethical Committee. Each participant was tested individually, between 12.00 and 18.00 h. Participants first performed the stop signal task, then rated their current hunger and were instructed to perform the taste test. Food was weighed before and after the taste test, so intake could be calculated. Afterwards, the participants filled in the questionnaires, weight and height were measured and they were thanked for participation and received a small fee.

Statistical analyses. The participants in the hunger condition felt significantly hungrier (M hunger = 76.0; s.d. 18.6; range 7–100) than participants in the sated condition (M hunger = 19.9; s.d. 20.1; range 0–72), $t(55) = 10.9$, ($P < 0.001$). However, the variance in hunger was large and there was some overlap. A few participants in the sated condition reported more hunger than participants in the hunger condition. Therefore, the continuous measure of state hunger was used in the analyses.

A hierarchical linear regression model was used to analyze the effects of hunger and response inhibition on food intake. In the first step, control variables (BMI, age, TFEQ-scales) were entered, but only when they correlated significantly with food intake (see Table 1). In the second step, hunger and response inhibition were entered and in the third step, the response inhibition × hunger interaction term was entered. All variables were centered before entering in the hierarchical linear regression model.

Results

Table 1 shows the correlations between food intake, the control variables (BMI, age, TFEQ-scales), hunger and response inhibition. The control variables did not correlate with caloric intake and were not entered in the regression analyses. Caloric intake was significantly correlated with impulsivity and hunger.

Table 1 Correlations between caloric intake and the control variables, hunger and response inhibition

	Caloric intake	*Mean (s.d.)*
BMI	0.16	22.0 (1.6)
Age	−0.04	20.0 (1.4)
TFEQ-rs	0.10	6.1 (2.9)
TFEQ-dis	0.07	6.8 (2.9)
TFEQ-hunger	0.068	6.1 (2.8)
Hunger	0.30*	51.4 (34.0)
Response inhibition (SSRT)	0.28*	211.07 (51.3)

Abbreviations: BMI, body mass index; SSRT, The stop signal reaction time; TFEQ, The Three Factor Eating Questionnaire. *$P < 0.05$.

Table 2 Summary of hierarchical regression analysis for variables predicting caloric intake ($n = 57$)

Variable	*B*	*B (s.e.)*	*β*
Step 1			
Hunger	0.73	0.38	0.24*
Response inhibition	1.2	0.57	0.27#
Step 2			
Hunger	0.84	0.07	0.28*
Response inhibition	1.14	0.55	0.25*
Hunger × response inhibition	0.26	0.01	0.29*

Note: $R^2 = 0.15$ for step 1 ($P < 0.05$); $\Delta R^2 = 0.08$ for step 2 ($P < 0.01$). *$P < 0.05$; $^{\#}P = 0.06$.

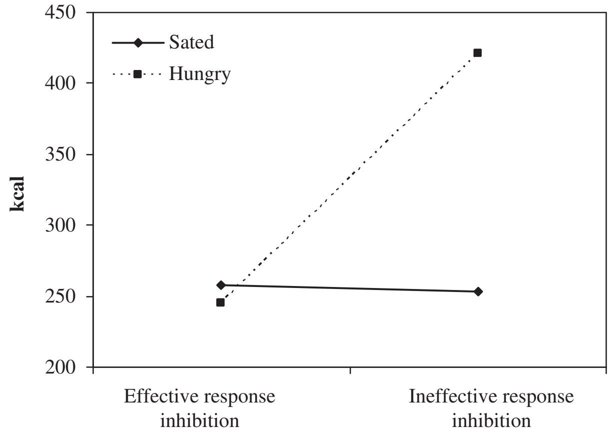

Figure 1 Caloric intake in participants with effective or ineffective response inhibition (1 s.d. below or above the mean SSRT), who are currently sated or hungry (1 s.d. below or above the mean of self-reported hunger). Study 1.

The hierarchical linear regression model is presented in Table 2. Hunger was a significant predictor of food intake and response inhibition was a marginally significant predictor. As hypothesized, hunger and response inhibition interacted ($\Delta R^2 = 0.08$, $P < 0.01$): participants who were both hungry and impulsive ate the most (see Figure 1).

Trait hunger, as measured with the TFEQ, did not correlate with state hunger (total group [$n = 57$]: $r = 0.04$, $P = 0.8$; within hunger condition [$n = 32$]: $r = 0.2$, $P = 0.2$; within the sated condition [$n = 25$]: $r = 0.2$, $P = 0.2$). When trait hunger, instead of state hunger, was used in the regression model, neither trait hunger nor the interaction between trait hunger and response inhibition predicted food intake ($P > 0.4$), only response inhibition did ($B = 0.827$, s.d. = 0.4, $\beta = 0.278$, $P = 0.043$).

Discussion study 1

In this study, we found that women with less effective response inhibition eat more during a taste test, effectively replicating earlier findings.[11] Interestingly, this effect was moderated by momentary hunger. Particularly when hungry, participants with less effective response inhibition consumed more calories, thus confirming our main hypothesis that the effect of impulsivity on eating behaviour is state dependent. Still the present pattern of results does not provide any inside on whether hungry impulsive people will be particularly sensitive to high caloric snacks as compared with normal foods. That is why we devised a second study, hypothesizing that when hungry, highly impulsive people, but not less impulsive people, will be more inclined to obtain high-caloric foods than when sated. Furthermore, study 2 was designed to extend the results of study 1 by using a different dependent variable: food purchase in a virtual computerized supermarket. In this supermarket, we ensured that participants could buy a wide variety of food items, including both high caloric foods and low energy dense foods. We predicted that impulsive participants (that is, those participants with less effective response inhibition), especially when hungry would purchase more calories as compared with both sated and less impulsive participants. In addition, we expected that this surplus of calories would consist of palatable, high caloric food ('snack food').

Study 2

Method

Participants. Maastricht University undergraduate students were recruited by advertisements at the university building. A total of 94 students participated (17 males and 77 females; mean age 20.3 [s.d. 3.1]; mean BMI 22.1 [s.d. = 2.9]). As opposed to study 1, participants did not receive any explicit instructions to eat something some time before their participation. Instead, state hunger was just measured.

Measures. The *stop signal task*, as described in the method section of study 1, was again used to measure response inhibition.

State hunger was measured with a 100 mm visual analogue scale, as described in the method section of study 1.

Dietary restraint was measured with the Dutch version of the Restraint Scale (RS),[31] a self-report questionnaire consisting of 11 items assessing attitudes towards weight, degree and frequency of dieting, disinhibition of eating and weight fluctuations.

A web-based *internet supermarket task* (programmed by the first author) was used to measure food purchase behaviour. Participants received the following instructions on screen (translated from Dutch):

> 'Imagine that you have decided to stay in a holiday house for three whole days in the middle of nowhere, to study for upcoming exams. Apart from butter, oil, vinegar and spices, there is no food in the house and there are no restaurants or any other sources of food in the near vicinity. This means that you need to buy your food beforehand. To this end, you now receive an imaginary budget of €50 that you may spend in the web shop. Buy as much food and drinks as you believe will be necessary for your stay at the house. You do not have to spend your entire budget. Note that the house has a kitchen and is fully equipped with all the cooking utensils you may need'.

The web shop contained 23 main food categories (for example, vegetables, fruits, candy, dairy products, etc). When selecting a main category, 2–6 subcategories were shown (for example, fresh vegetables, washed and sliced vegetables, canned vegetables and frozen vegetables), each represented by the category name and a picture of a typical food item. When selecting a subcategory, all available food products of that category were shown in a list, including weight and price of the product. When selecting a food product, a picture and description was shown (no caloric information was provided). The participant could add products to a virtual shopping basket (or delete products from the basket). Products in the shopping basket and their summed price were shown on the right side of the screen. In total, 640 products were available from the supermarket, consisting of only foods and drinks. When participants finished shopping (no time restraints were implemented), they selected the cash register icon. They were asked if they were sure they had all they needed for 3 whole days and if confirmed, the shopping task was ended.

The dependent variables calculated from this task were: (1) the total calories a participant bought (including food and drinks), (2) the calories from snack foods, that is palatable high caloric products, like pizza, crisps, chocolate and cookies and (3) the calories from other foods, calculated by subtracting the snack calories from the total calories.

Procedure. The study was approved by the Maastricht University, Faculty of Psychology and Neuroscience Ethical Committee. The participants were tested in groups of one to five people, each seated in a separate cubical. First, they were asked to read and fill in the informed consent. Next, they performed the stop signal task. Then they rated their hunger and started with the supermarket shopping task. Afterwards, they filled in the Restraint Scale, weight and height was measured, they were thanked for participation and received a small compensation fee.

Statistical analysis. Three hierarchical linear regression models were used to analyze the effects of hunger and response inhibition on total calories, snack calories and normal calories. In the first step, control variables (BMI, age, gender and dietary restraint (RS) that correlated significantly with food intake were entered (see Table 3). In the second step, hunger and response inhibition were entered and in the third step, the interaction term of response inhibition × hunger was entered. All variables were centered before entering in the model.

Table 3 Correlations between purchased calories and the control variables, hunger and response inhibition

	Total calories	*Snack calories*	*Non-snack calories*	*Mean (s.d.)*
BMI	−0.29**	−0.35**	−0.04	22.0 (2.8)
Age	−0.01	−0.05	−0.04	20.4 (3.1)
RS	−0.43**	−0.30**	−0.30**	10.4 (5.3)
Gender (Spearman's rho)	0.31**	0.19#	0.31**	17 males, 77 females
Hunger	0.19#	0.28*	−0.02	50.9 (24.5)
SSRT	0.15	0.24*	−0.03	199.8 (45.4)
Mean (s.d.)	13976 (4078)	3980 (2997)	9816 (2845)	

Abbreviations: BMI, body mass index; SSRT, The stop signal reaction time. *$P<0.05$, **$P<0.01$, #$P<0.08$.

Table 4 Summary of hierarchical regression analysis for variables predicting total purchased calories ($n=94$)

Variable	*B*	*B (s.e.)*	*β*
Step 1			
Gender	−2758.9	1049.6	−0.26**
BMI	−241.5	149.7	−0.17
RS	−197.6	85.0	−0.26*
Step 2			
Gender	−2797.6	1047.7	−0.27**
BMI	−260.8	149.9	−0.18
RS	−167.8	88.6	−0.22
Hunger	11.4	15.9	0.07
Response inhibition	10.8	8.3	0.12
Step 3			
Gender	−3109.8	1018.1	−0.30**
BMI	−270.7	144.7	−0.19
RS	−162.0	85.6	−0.21*
Hunger	9.1	15.4	0.06
Response inhibition	5.7	8.2	0.06
Hunger × response inhibition	1.0	0.38	0.25**

Abbreviation: BMI, body mass index. $R^2=0.25$ for step 1 ($P<0.001$); Δ $R^2=0.02$ for step 2 (NS); Δ $R^2=0.06$ for step 3 ($P<0.01$). *$P<0.05$; **$P<0.01$.

Table 5 Summary of hierarchical regression analysis for variables predicting calories from snack food ($n=94$)

Variable	*B*	*B (s.e.)*	*β*
Step 1			
Gender	−753.8	818.9	−0.1
BMI	−308.2	116.8	−0.29**
RS	−76.1	66.5	−0.14
Step 2			
Gender	−824.0	78.1	−0.11
BMI	−336.6	112.0	−0.32**
RS	−22.9	66.2	−0.04
Hunger	24.2	11.9	0.20*
Response inhibition	14.4	6.2	0.22*
Step 3			
Gender	−1146.2	731.2	−0.15
BMI	−346.8	103.9	−0.33**
RS	−16.9	61.5	−0.03
Hunger	21.9	11.0	0.18#
Response inhibition	9.1	5.9	0.14
Hunger × response inhibition	1.1	0.3	0.35**

Abbreviation: BMI, body mass index. $R^2=0.16$ for Step 1 ($P<0.01$); Δ $R^2=0.09$ for Step 2 ($P<0.01$.); Δ $R^2=0.11$ for Step 3 ($P<0.001$). *$P<0.05$; **$P<0.01$; #$P<0.06$.

Results

BMI, gender and restraint correlated significantly with purchase behaviours (see Table 3) and were entered as control variables in the first step of the hierarchical linear regression models (see Table 4). Eating restraint correlated negatively with all three measures of purchase behaviour: the more restrained the participant was, the fewer calories (s)he bought, both from snack and non-snack food. BMI was negatively correlated with the total purchased calories and calories from snack food, with participants with a higher BMI buying fewer calories. Gender also influenced the purchase of calories: men bought more calories, attributable to an increased purchase of non-snack food items.

When predicting the total number of purchased calories with a hierarchical linear regression model (see Table 4), it appeared that men purchased more calories than women do (respectively 16 896 vs 13 113 kcal) and that high-restrained eaters purchased fewer calories. Response inhibition and hunger did not predict purchased calories, but their interaction did (Δ $R^2=0.06$, $P<0.05$) implying that participants who were both hungry and impulsive bought the most calories.

Subsequently, the type of purchased calories was studied more closely; respectively the purchased snack calories and non-snack calories were analyzed using hierarchical linear regression models (Tables 5 and 6). It was found that BMI predicted the purchase of snack calories (participants with higher BMI purchased fewer snack calories) and also hunger and response inhibition predicted the purchase of snack calories: the more hungry participants and the less effective response inhibitors purchased more snack calories. Confirming our hypothesis, the interaction of hunger and response inhibition qualified both main effects. Especially the participants who showed less effective response inhibition and were hungrier at that time, purchased the most snack calories (Δ $R^2=0.11$, $P<0.01$; see Figure 2).

Table 6 Summary of hierarchical regression analysis for variables predicting calories from non-snack food ($n = 94$)

Variable	*B*	*B (s.e.)*	*β*
Step 1			
Gender	−2005.2	775.4	−0.27*
BMI	−66.7	110.6	0.07
RS	−121.5	63.0	−0.23#
Step 2			
Gender	−1973.6	777.3	−0.27*
BMI	75.8	111.2	0.08
RS	−144.9	65.7	−0.27*
Hunger	−12.8	11.8	−0.11
Response inhibition	−3.5	6.1	−0.06
Step 3			
Gender	−1963.6	786.7	−0.27*
BMI	76.1	111.8	0.08
RS	−145.1	66.1	−0.27*
Hunger	−12.8	11.9	0.11
Response inhibition	−3.4	6.3	0.05
Hunger × response inhibition	−0.03	0.3	0.01

Abbreviation: BMI, body mass index. $R^2 = 0.16$ for step 1 ($P < 0.01$); $\Delta R^2 = 0.02$ for step 2 (NS); $\Delta R^2 = 0.0$ for step 3 (NS). $^*P < 0.05$; $^\# P < 0.06$.

As noted above, gender influenced the purchase of non-snack foods, with men purchasing more non-snack items than women. Restraint influenced purchase marginally significantly, with high-restrained eaters buying fewer calories from non-snack food. Neither hunger and impulsivity, nor their interaction, influenced the purchase of calories from non-snack food (when only women were included in the three hierarchical linear regression models, the pattern of results remains the same, with the interaction between hunger and response inhibition explaining slightly more variance of total purchased calories and calories from snack food ($\Delta R^2 = 0.08$, $P < 0.01$ and $\Delta R^2 = 0.13$, $P < 0.001$), but not the purchase of calories from non-snack foods).

BMI and response inhibition were not significantly correlated ($r = 0.01$, NS). However, when comparing a subgroup of overweight participants (BMI $\geqslant 25$, mean BMI 26.9, $n = 14$) with the remaining lean participants (BMI < 25, mean BMI $= 21.1$, $n = 80$), the overweight participants tended to be less effective at response inhibition (SSRT overweight: 220.8, lean: 196.1, $t(93) = 1.9$, $P = 0.061$).

Discussion study 2

The results of study 2 replicated the findings of study 1, in that again the interaction between response inhibition and hunger influenced food purchase behaviour. Participants who were both hungrier and more impulsive bought more calories. When looking at the specific type of food that was bought, it appears that the effect can be attributed to particularly the purchase of high caloric snack foods. In other words, hungry impulsive participants are especially vulnerable to buying snack calories. This effect exists in addition to the effects of gender, BMI and restraint. Further, in line with previous research,[12,17] the present overweight participants tended to be less effective in response inhibition than the lean participants, which suggests an association between overweight and impulsivity.

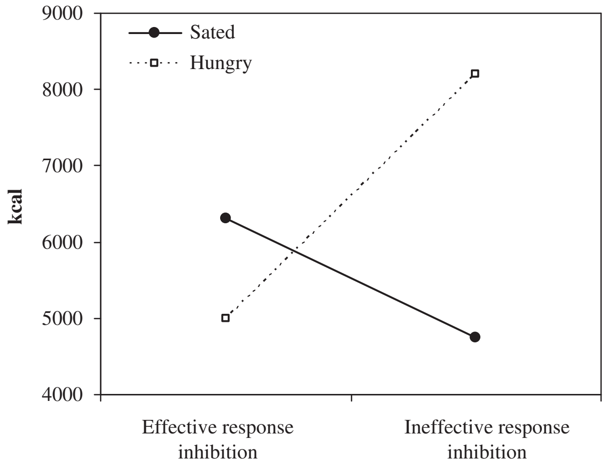

Figure 2 Purchase of calories from snack food in participants with effective or ineffective response inhibition (1 s.d. below or above the mean SSRT), who are currently sated or hungry (1 s.d. below or above the mean of self-reported hunger), controlled for gender, BMI and restraint. Study 2.

General discussion

We hypothesized that highly impulsive persons are more likely to overeat (study 1) and to buy excess calories from particularly high caloric foods (study 2), and that this relation between impulsivity and food consumption is moderated by momentary hunger. The present results confirm these hypotheses. To our knowledge, these are the first investigations demonstrating that hunger moderates the influence of response inhibition on both food intake and the purchase of food; participants with ineffective response inhibition consumed more food, but only when hungry at that moment. This is a substantial effect as the hunger × response inhibition interaction predicted 8% of food intake during a taste test (study 1) and even 11% of the purchase of snack calories (study 2).

One might argue that the moderating effect of hunger is somewhat artificial as it was manipulated in study 1. Indeed, in study 1, participants in the hunger condition were asked to refrain from eating for 4 h. This period of not being able to eat, however, does not necessarily extend an individual's normal interval between meals. Moreover, we did not manipulate momentary hunger at all in study 2, but instead measured state hunger levels prior to the supermarket task. One may further conclude then that in daily life highly impulsive people are more likely to experience temptations to eat than less impulsive people are, especially between meals when hunger levels are higher. A moderate feeling of hunger clearly is enough for the more impulsive person to buy snack foods and to increase food intake substantially.

It is commonly known that the longer-term effectiveness of behavioural treatments of obesity is poor. Although reasonable short-term weight reduction (about 5–15% reduction of BMI) can be achieved, most people having participated in such treatment programs fail to maintain their weight loss. Reviews show that 1–5 years after treatment, the majority of obese individuals who successfully lost weight returned to or even exceeded their initial BMI.[32,33] The present results may help explain these poor outcomes. Obese participants are in general less effective in response inhibition[12,17] and a diet (eating less than they are used to) makes them feel hungry. The present results show that this is an unfortunate combination when attempting to lose weight. Indeed, we previously showed that within an obese sample especially those participants with less effective response inhibition did not lose as much weight in treatment.[12,34] Presumably, this subgroup is not able to endure feelings of hunger and therefore break their diet rules. It seems that these people might benefit from a treatment that focuses on hunger reduction and impulsivity reduction. In treatment, psychopharmacological products are sometimes used to reduce hunger, like sibutramine. The addition of sibutramine to behaviour therapy has been found to be more effective than adding a placebo.[35] It might be hypothesized from the present data that sibutramine is more effective in people with less effective response inhibition. To reduce impulsivity an effective treatment strategy might be to train response inhibition. If people can learn to overrule their impulses, that is, their impulses to overeat when hungry, adhering to a weight loss diet might become less difficult. Research into the training of improved response inhibition and its effect on food intake and weight loss might prove fruitful.

An interesting hypothesis for future research that follows from the present data is that less effective response inhibition predicts weight gain in a normal weight sample. This study shows that in a moderately hungry state, after being abstinent for only a few hours, impulsive participants (scoring 1 s.d. above the mean SSRT on the stop signal task) consumed a surplus of 166 kcal, compared with non-impulsive participants (scoring 1 s.d. above the mean SSRT, study 1). In study 2, hungry impulsive participants (scoring 1 s.d. above the mean SSRT) even bought 3200 kcal more in a virtual supermarket than hungry non-impulsive participants (scoring 1 s.d. below the mean SSRT). If this is not an occurrence confined to a lab environment, but a regular phenomenon in daily life, it indicates that less effective response inhibition easily leads to frequent overeating and hence weight gain when people are hungry. The interaction between state hunger and impulsivity therefore might be considered a strong determinant of overweight and obesity.

In this study, participants with ineffective response inhibition were found to eat more when feeling hungry. However, in the literature eating in absence of hunger is considered impulsive eating.[36] In the measure of this eating style, children are typically asked to eat until feeling sated during a meal, and shortly afterwards they are offered a taste test with palatable foods. Children who ate most during this second taste test were more likely to be overweight[37] and to gain weight and become overweight in the future.[38] The offered explanation is that these children are less sensitive to their internal state and eat more in response to external cues, like palatability, portion size, variation in food, etc. However, increased responsiveness to external food cues does not need to imply decreased responsiveness to internal cues. In the studies on absence of hunger the influence of hunger was not measured, but held constant and it is conceivable that the same children who overeat when sated, eat even more disproportioned when hungry. Internal and external cues could both act as disinhibiting cues, without excluding each other. Are individuals with poor response inhibition also more responsive to external cues, as they are to hunger? Theoretically, this would make sense, since rewarding, appetitive stimuli inevitably trigger prepotent approach responses,[39] and food exposure has been found to induce craving, a wide range of physiological responding and increased food intake.[40,41] To overrule the first automatic intention to approach the stimuli, operations must be stopped and in some cases reorganised to fit the new intention, which appeals for response inhibition.[39,42] However, the relation between response inhibition and reactivity to food cues has hardly been tested yet. In one study, Guerrieri *et al.*[21] found that response inhibition and variety of food was not related in children, although reward sensitivity as measured with a gambling task was. Further research is required to understand the relation between food cue reactivity and response inhibition.

In brief, the present research shows that participants with less effective response inhibition who are feeling hungry, eat more in a taste test and purchase more high caloric food in a virtual supermarket, compared to participants with effective response inhibition and participants with inefficient response inhibition who are not feeling hungry. This might explain why especially impulsive obese persons are less adept at weight loss, by assuming that a diet makes them feel more hungry more often. Research should be aimed at ameliorating obesity treatment by focusing on impulsivity and resisting the urge to overeat, especially when feeling hungry.

Conflict of interest

The authors declare no conflict of interest.

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