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Obese and overweight individuals are less sensitive to information about meal times in
portion size judgements

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Abstract

Background: Obesity is related to a tendency to discount the future. Information regarding inter-meal interval (IMI) allows meal planning. We sought to assess how obese, overweight, and lean people select portion sizes based on the length of an IMI. We hypothesised that individuals with a high BMI would discount information about the IMI. In addition, we investigated how **reduced sensitivity to IMIs** relates to monetary temporal discounting.

Methods: Participants (lean, $n = 35$; overweight, $n = 31$; obese, $n = 22$), selected lunchtime portion sizes in response to information about the timings of their next meal. In seven trials, the time of the IMI was systematically manipulated, ranging from 'right now' to '8 hours'. Participants then completed a monetary temporal discounting task. BMI was included as a continuous measure. For each participant, we conducted a linear regression of portion size on IMI to yield a gradient that reflected reduced sensitivity to future meal timings.

Results: As expected, participants selected larger portion sizes in response to a long IMI. Consistent with our hypothesis, individuals with a high BMI discounted information about the IMI ($\beta = -3.49, p = .015$; confidence interval (CI) **6.29 to -.70**). Monetary discounting also negatively predicted BMI ($\beta = -8.1, p = .003$; CI = **-13.43 to -2.77**), but did not correlate with IMI sensitivity ($p > .05$).

Conclusions: These results are the first to demonstrate that temporal discounting operates in planning from one meal to the next, and is more prevalent in obese and overweight, relative to lean individuals. Participants with a high BMI discounted concerns about potential future fullness and hunger in the IMI. Our observations might begin to explain associations between obesity and irregular meal timings or help to form the basis for a targeted intervention that promotes future thinking in meal planning.

Introduction

Temporal discounting is a facet of impulsivity that is frequently studied in relation to eating behaviour and obesity. It refers to the tendency to respond to immediate rewards rather than the long-term consequences of a decision¹. Monetary temporal discounting is associated with the selection of larger portion sizes in normal-weight women², individuals with obesity³⁻⁵ and binge eating disorder^{6,7}. Although the relationship between obesity and monetary discounting has been widely researched, the findings have been variable, with the observed associations being weak or present only in women^{5,8-13}.

One explanation for these inconsistencies is that monetary discounting is a poor proxy for the tendency to discount the future consequences of consuming food^{14,15}. Evidence suggests that money and food are discounted differently; food tends to be valued as more rewarding, and discounted at a higher rate than money¹⁶⁻¹⁸. Furthermore, dietary discounting appears to be a more consistent predictor of BMI than discounting of money^{8,19}; studies have found discounting of food, but not money, to be associated with body fat percentage and impulsive eating behaviours^{8,20}. Therefore, food-based discounting tasks may be more relevant to eating behaviour and obesity²¹.

Monetary discounting is often considered over long periods. Typically, dietary discounting is conceptualised as a tendency to discount long-term future health consequences of eating²¹. However, obese individuals discount food rewards at much shorter intervals (hours rather than years^{6,8,11}). This indicates that people also discount the shorter-term consequences of dietary decisions, rather than only long-term concerns about health or weight gain. It is important to note that, unlike money, the future value of food is not stable and may depend on the timing of a person's next meal. For example, a large portion might be less desirable if a person plans to eat again in thirty minutes. As such, the value of food, and therefore the rate of discounting, may be dependent on short-term future meal planning. Until

now, studies have not assessed how short-term temporal dietary discounting is influenced by information about future meal timings.

In this study, we considered the novel prospect that shorter-term discounting is evident in the selection of portion sizes from one meal to the next. When people make dietary decisions, information about future meal timings allows them to plan for the interval between meals (inter-meal interval, IMI²²). Indeed, meal planning has been established as a successful weight loss tool²³. One critical aspect of meal planning is portion size; people tend to select a portion size before the meal and then clean their plate²⁴⁻²⁶. The ‘expected satiety’ of food plays a key role in portion-size decisions^{27, 28}. Specifically, people consider the future when selecting portions and choose an amount that they expect to stave off hunger (desire to eat) in the IMI. Our study explored how information about future meals influences portion size decisions by systematically manipulating the length of an IMI. We predicted that future meal timings would influence in-the-moment portion-size decisions.

Of interest is how individuals differ in their sensitivity to information about the duration of an IMI. People plan their behaviours by evaluating the future consequences of a decision²⁹. However, impulsive decision-makers may fail to consider all relevant information before making a choice³⁰. One possibility is that non-future-oriented individuals are less sensitive to information about the length of an IMI when selecting portion sizes. In a previous study²², monetary discounting and BMI were associated with reduced sensitivity to an uncertain IMI when making portion selections. We suggested that high monetary discounters were less sensitive to information about the IMI. Furthermore, monetary discounting mediated the relationship between high BMI and reduced IMI sensitivity. However, participants had a narrow BMI range and only two IMIs were compared, limiting the opportunity to draw conclusions about obesity and sensitivity to meal timings.

The present study investigated how the length of an inter-meal interval (IMI) influenced lunchtime portion-size selection decisions in obese, overweight, and lean participants. As in previous studies¹⁹, we included BMI as a continuous measure in our analysis. To assess the extent to which participants discount future meal times, we measured lunchtime portion-size selection using a computerized task and systematically manipulated the timing of the following meal. From this, we derived a measure of IMI sensitivity that reflects the tendency to discount information about IMI when selecting portion-sizes. To evaluate decisions across a range of foods, we measured portion-size judgements of high and low-calorie foods in response to a future savoury and sweet meal. In addition, to assess whether reduced IMI sensitivity reflected a conscious lack of concern about fullness or hunger, we asked participants to report whether they considered hunger and fullness in making the decisions.

First, we predicted that participants would choose larger portion sizes when confronted with a longer IMI. To assess whether energy density influenced IMI sensitivity, we compared differences in sensitivity to meal timings when selecting low and high-energy portions. Second, based on previous findings²² we hypothesized that both reduced IMI sensitivity and monetary discounting would predict BMI. We hypothesized that individuals with a high BMI would discount the length of an IMI when making portion selections. Third, we assessed whether the inverse relationship between IMI sensitivity and BMI was mediated by monetary discounting. Given previous research²², where monetary discounting mediated a relationship between reduced IMI sensitivity and BMI, we expected to see an inverse relationship between IMI sensitivity and monetary discounting.

Method

Participants: Participants ($N= 88$; 52 females, 34 males, 1 transgender) had a mean age of 32.4 years ($SD = 11.1$) and a mean BMI of 27.7 kg/m² ($SD = 6.7$). All participants were members of

the public, recruited through our laboratory volunteer database. To reduce demand awareness, participants were told that the purpose of the study was to explore ‘decision making and food preferences’. Participants were excluded if they were vegetarian or vegan, not fluent in English, taking any medication that might influence appetite or metabolism (with the exception of oral contraceptive pills), or allergic or intolerant to any foods. Participants completed an initial pre-screening questionnaire where they reported their height, weight, age, and gender. We calculated self-reported BMI and selected participants on this basis to achieve an equal distribution of lean ($\text{BMI} < 25\text{kg/m}^2$), overweight ($\text{BMI} = 25\pm 30\text{ kg/m}^2$) and obese ($\text{BMI} > 30\text{kg/m}^2$) participants. The sample comprised 35 lean, 31 overweight, and 22 obese participants. Once recruited, BMIs were re-classified based height and weight measured in the laboratory. All participants gave informed consent. All received £30 (sterling) in remuneration for their assistance. The protocol was approved by the local Faculty of Science Human Research Ethics Committee.

Food images: Based on previous research³¹, and to represent a range of energy densities, we selected four foods that are commonly consumed in the UK: McDonald’s fries (3.0 kcal/g), four bean salad (1.1 kcal/g), chicken tikka (1.6kcal/g), and apple pie (2.9kcal/g). For each dish, we photographed a series of 50 images with portion sizes ranging from 20 kcal to 1000 kcal, in equal 20-kcal steps. The name of the food was included in the top-right corner of each photograph. All meals were photographed on an identical white plate (255-mm diameter). All images were taken using a high-resolution digital camera under the same lighting conditions.

Measures

IMI sensitivity task: Two food images were presented on a VDU. One portion was presented on the left and labelled ‘This meal for lunch’. A different plate of food was presented on the right and labelled ‘This later meal’. Lunch was either a high energy–dense meal (McDonald’s fries; MF) or a low energy–dense meal (four bean salad; FBS). The ‘later meal’ was either a fixed 400-kcal portion of chicken tikka masala with rice (CT) or apple pie (AP). Participants were asked to respond to the question ‘How much would you eat for lunch RIGHT NOW if you had to eat all of the food on the right for dinner ...[in time inserted].’ There were seven IMIs: right now, 15 mins, 30 mins, 1 hour, 2 hours, 4 hours, or 8 hours. They were instructed that they would not be eating anything else in between the meals. Participants were instructed to use the arrow keys to adjust the size of the lunchtime portion and press the ‘Enter’ key when they had made their portion selection. Each participant completed a total of twenty-eight randomised trials; seven different IMIs repeated with four food combinations (MF&CT and FBS&CT; MF&AP and FBS&AP). **This resulted in twenty-eight scores for each participant, reflecting the portion size chosen at each of the seven IMIs for the four food combinations.** The orders of the meal timings and foods were randomised for each participant. Every trial started with a randomly selected portion size of the lunchtime food.

Post-task Questions: After completing the IMI sensitivity task, participants were asked about the strategies used to make portion decisions. In two separate questions, participants were asked to rate ‘the extent to which they considered potential future hunger/fullness in deciding how much food to select’ on a 100-mm visual-analogue scale.

Temporal monetary discounting-task: Monetary discounting was measured using a computerised forced-choice task. The task was an adapted version of a procedure introduced by Du and colleagues³² and followed the same modifications as Zimmerman et al.²². In a

series of trials, participants indicated whether they preferred to receive a hypothetical delayed reward of £100 (sterling) after a fixed interval (*e.g.*, 1 year) or a smaller amount immediately. Participants completed nine blocks of ten trials. In the first trial of each block, the immediate reward was half the delayed value (£50). **Given that small delayed amounts are discounted more steeply** ³², we chose to use an initial relatively small delayed reward of £100. If the participant selected the immediate reward it was adjusted down to £16.66 (33.3% of its original value) in the second trial. If the participant selected the delayed reward then it was adjusted up to £83.33 (the same difference = £33.33). The same rationale was applied in subsequent trials (trials 3-10). However, in each trial the adjustment amount decreased by 33.3% (*i.e.*, from £33.33 in trial 2 to £22.22 in trial 3, from £22.21 in trial 3 to £14.81 trial 4, and so on). This single 'staircase' approach progressively converged around a point of indifference in which the delayed and immediate amounts are equally likely to be selected.

Initially, three practice blocks were presented. In order, the hypothetical delays were 2 years, 1 year, and 6 months. This was followed by six further blocks. In each block, a scenario was presented with one of the following delays; 2 days, 7 days, 30 days, 6 months, 1 year, 2 years. The order of these blocks was randomised across participants. For each participant, a measure of temporal discounting was obtained from area under the curve (AUC) values using the trapezoid method ³³. Participants' indifference points were plotted at each delay interval and AUC was calculated. Smaller AUC values indicate greater discounting and a tendency to discount future events. The monetary discounting task and the **IMI insensitivity task** were implemented using custom software (available on request) written in Visual Basic (Microsoft version 6.0).

TFEQ: Dietary behaviour was assessed using a computerised version of the

Three Factor Eating Questionnaire (TFEQ³⁴). This instrument contains 36 items with a yes/no response format, 14 items on a 1-4 response scale and one vertical rating. All items are scored and aggregated on three sub-scales. Cognitive restraint (conscious control of food intake to control body weight), disinhibition (loss of control over intake) and hunger (subjective cravings and feelings of hunger).

Ratings: To assess participants' food preferences, liking and familiarity were measured.

Liking: Participants were shown a 400-kcal portion of the foods in a random order. In each trial, they responded on a 100-mm visual-analogue scale with end anchor points labelled 'extremely dislike' and 'extremely like.'

Familiarity: *A priori* we decided to only include participants who were familiar with the test foods. Participants were shown a 400-kcal portion of each food. In turn, they responded to the question 'Have you ever eaten this meal?' by selecting one of the following options; 'yes,' or 'no'.

Appetite: Measures of momentary hunger and fullness were obtained using 100-mm visual-analogue rating scales headed 'How [hungry/full] do you feel right now?' with end anchor points 'not at all' and 'extremely.'

Procedure: Participants completed a lunchtime session between 11:00 and 14:00. On arrival, they reported how long ago they last ate and rated their appetite. They completed the IMI sensitivity task, followed by liking and familiarity ratings, and the monetary discounting task. Finally, participants completed the TFEQ and we measured their height and weight. Participants were debriefed and thanked for their assistance. Participants were tested for approximately two hours as this experiment was run alongside other measures that addressed unrelated questions associated with food choice.

Data analysis strategy: Due to a technical issue, liking and familiarity scores were not recorded for the apple pie. Therefore, we chose to exclude all sweet trials from the analysis.

To assess the extent to which participants discounted future meal times, we derived a measure of IMI sensitivity. To calculate the gradient of change in portion size selection across time, we conducted two separate linear regression for each participant with portion sizes selected in the low and high calorie trials as the dependent variable and meal time (IMI in minutes) as the independent variable³⁵. The regression equation was: Portion size (kcal) = $\beta * \text{IMI (minutes)} + \alpha$. For each participant, this yielded two gradients and intercepts that relate portion selection to IMI (IMI sensitivity score). Large, positive slopes were taken as evidence for greater sensitivity to information about the IMI. Additionally, intercepts were used to determine the unique explanatory power of the slope term in later analysis.

Initially, using a two-sided, paired samples t-test, we assessed whether IMI sensitivity differed between the high and low energy portion decisions. If we saw no difference in IMI sensitivity, we planned to use the composite intercepts and slopes in subsequent analysis. The composite IMI sensitivity scores were calculated by averaging the high and low calories IMI sensitivity scores (Composite IMI sensitivity = (high calorie IMI sensitivity + low calorie IMI sensitivity)/2).

To explore our primary hypothesis, that progressively longer IMIs would result in larger portion selections, we performed a planned *t*-test to determine whether **IMI sensitivity** scores deviated significantly from zero. Subsequently, we evaluated whether BMI is predicted by **IMI sensitivity**, monetary discounting, and the interaction between **IMI sensitivity** and monetary discounting. Using multiple regression, we entered **composite IMI sensitivity** scores and monetary discounting scores simultaneously as independent predictors of BMI. In addition, to assess whether the effect of **IMI sensitivity** on BMI changes with monetary discounting, we entered the interaction between monetary discounting and IMI sensitivity (**IMI sensitivity scores * monetary discounting AUC**) as independent variables. Age, gender and TFEQ scores were also included in the regression analysis. **To identify whether IMI sensitivity predicts variance in BMI independently of the average immediate portion size, we included each participant's intercept score in the regression analysis. The overall regression equation was:**

$$\text{BMI} = \beta_0 + \beta_1 * \text{IMI Sensitivity} + \beta_2 * \text{Intercept} + \beta_3 * \text{Delay Discounting} + \beta_4 * (\text{Delay Discounting} * \text{IMI sensitivity}) + \beta_5 * \text{Age} + \beta_6 * \text{Gender} + \beta_7 * \text{TFEQ-hunger} + \beta_8 * \text{TFEQ disinhibition}$$

Results

Participant characteristics: Table 1 shows participant characteristics. A small proportion of participants expressed unfamiliarity with the test foods. We excluded six who were unfamiliar with one food and two who were unfamiliar with two foods. The final sample (47 females and 32 males and 1 transgender) comprised 31 lean, 29 overweight, and 20 obese participants. Hunger and fullness did not correlate with **IMI sensitivity** (see Table 2). **As there were no significant correlations between IMI sensitivity scores and liking of each test food (all $p > .05$), we chose not to include liking as a covariate in the regression analysis.** As TFEQ-disinhibition

and TFEQ-hunger correlated with BMI, these variables were also included in the regression analysis. Pearson's correlations are reported in Table 2. A post-hoc power calculation based on the effect sizes in our previous study²² showed a minimum 45 participants would be required to detect a relationship between BMI, IMI sensitivity and monetary discounting with 95% power and $\alpha = 0.05$; thus the current study was powered to detect an effect.

Difference between high and low-energy density IMI sensitivity: There was no significant difference between IMI sensitivity in the high ($M = .32, SD = .25$) and low energy density trials ($M = .33, SD = .28; t(79) = -1.1, p < .27$). IMI sensitivity was comparable in the high and low energy density trials. As such, we used the composite IMI sensitivity scores and intercept scores in subsequent analyses. Composite IMI scores were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$) and there were no outliers in the data, as assessed by inspection of a boxplot.

Portion size across IMI: IMI sensitivity scores ($M = .76, SD = .53$) were significantly different from zero ($t(79) = 12.77, p < .001$). This demonstrates that portion selection was influenced by IMI.

IMI sensitivity and monetary discounting as predictors of BMI: IMI sensitivity negatively predicted variance in BMI ($\beta = -3.49, p = .015; 95\% CI = 6.29 \text{ to } -.70$), indicating that those with a high BMI were less sensitive to information about IMIs (Figure 1). Intercept scores did not significantly predict BMI, suggesting IMI sensitivity accounts for variance in BMI beyond the average immediate portion size ($p > .05$). Monetary discounting predicted variance in BMI ($\beta = -8.1, p = .003; CI = -13.43 \text{ to } -2.77$). Those with a high BMI showed a greater tendency to discount monetary rewards. The interaction between IMI sensitivity and

monetary discounting did not significantly predict variance in BMI ($\beta = 2.9, p = .46; 95\% \text{ CI} = -4.87 \text{ to } 10.69$). This suggests monetary discounting and IMI sensitivity are separate constructs, which both predict BMI independently. Age, gender, TFEQ-hunger did not predict BMI (all $p > .05$). TFEQ-disinhibition significantly predicted BMI ($\beta = .89, p < .001; 95\% \text{ CI} = .35 \text{ to } 1.43$). Separate regression coefficients with R^2 values derived from multiple regression analysis are provided in Table 3.

Self-reported concerns about fullness and hunger: Concerns about hunger or fullness did not correlate with IMI sensitivity (hunger concern: $r = .07, p = .54$, fullness concern: $r = .13, p = .25$).

Discussion

To our knowledge, this is the first study to show that information about future meal timings influences portion-size selection in participants with a wide-range of BMI. Consistent with our primary hypothesis, we found that participants selected larger portion sizes in response to a longer IMI. This confirms previous results²², suggesting that people use information about future meal timings to make decisions about portion size. In addition, our findings demonstrate that participants were equally sensitive to the length of an IMI when making portion-decisions about the high-energy dense food compared to the low-energy dense food.

These findings have implications for the assessment of temporal discounting in eating behaviour. Dietary discounting tasks neglect to assess how future meal planning might influence discounting. In these tasks, the timings of subsequent meals are not controlled for^{4, 6, 8, 36}. Our results suggest that dietary decisions are influenced by the length of an IMI. It is important that dietary discounting studies account for the fact that the value of food is not

stable, and is influenced by future meal planning. This distinction is subtle, yet potentially essential, and is generally overlooked in studies exploring the acute effects of discounting on eating behaviour.

In line with our second hypotheses, and consistent with previous findings²², BMI was associated with **reduced sensitivity to the length of an IMI**. Our findings indicate that people differ in their capacity to consider the future when making dietary decisions. Specifically, individuals with a high BMI discounted information about the length of the IMI.

Furthermore, those with a high BMI showed reduced IMI sensitivity in portion decisions about both high and low-energy dense foods. We propose that they are more concerned with how much they want to eat in the moment and **discount information about future meal timings**. Indeed, obesity has been related to poor future episodic thinking about food³⁷. In contrast, lean individuals were more sensitive to information about the length of the IMI. This suggests they are more future-oriented and plan for potential meals. However, the tendency to discount hunger and fullness was not evident in self-report. This suggests that participants were unaware they discounted information about the IMI length.

One possibility is that obese and overweight individuals discounted the length of an IMI because they have a higher tolerance for hunger and fullness. Previous studies have shown that BMI is related to poor interoceptive awareness³⁸. This refers to the ability to perceive one's internal state. Specifically, body weight has been associated with insensitivity to visceral cues of hunger and satiety^{39, 40}. It is possible that bodily signals are not important drivers of portion size decisions in obese individuals. Participants with a high BMI may not have imagined they would feel hungry when the prospective IMIs were longer, and selected smaller portions accordingly. However, contrasting findings show that obese and lean people do not differ in their sensitivity to gastric filling⁴¹. At present, though we are unable to rule

out this alternative account; research is required to assess whether IMI sensitivity is associated with individual differences in interoception.

The current results may help to inform our understanding of meal patterns and the development of interventions for obesity. Structured meal timings are regarded as an effective tool for weight loss^{23,42}. However, patients with a high BMI often struggle to adhere to diets and meal plans⁴³⁻⁴⁵. Our findings suggest that overweight individuals may be less responsive to meal plans because they are less sensitive to meal timings. Indeed, greater monetary discounting in obese participants predicts reduced success at following weight-loss interventions⁴⁶. This supports the notion that an individual's reduced sensitivity to meal timings might affect their ability to follow and maintain a structured eating routine. One possibility is that individuals attempting meal-planning interventions might benefit from training in their ability to forward think. For example, studies have employed episodic future thinking tasks to reduce discounting and, consequentially, reduce food intake and snacking in obese individuals^{37,47}. Our findings might contribute to a novel intervention that promotes future-thinking about meal timings, to help patients successfully adhere to structured meal patterns.

Contrary to our hypothesis, there was no association between monetary discounting and **reduced IMI sensitivity**, yet both significantly predicted BMI. This suggests that monetary discounting and IMI discounting have independent effects on eating behaviour, and consequential weight gain. We propose that the monetary task reflects a tendency to discount long-term events. Our results suggest that long-term discounting should be considered separate from shorter-term discounting between meals. This is a critical distinction for future research, reinforcing the notion that there is no single underlying temporal-discounting process⁴⁸. It is important that future studies consider this division and begin to move away

from a solely long-term discounting model to understand the role of dietary discounting in eating behaviours related to obesity.

Although computer-based portion judgments are predictive of real food intake^{49, 50}, it could be instructive to explore how temporal discounting moderates real food intake in at varying IMI lengths. One possible issue is that obese and overweight individuals are shown to under-report portion sizes^{51, 52}. However, our data should not be affected by underreporting as they reflect the rate of change in portion size across time. Future research could explore differences in discounting of sweet and savoury foods.

Conclusion: Our findings indicate that information about the length of an IMI influences portion size judgements and that individuals with a high BMI are less sensitive this information. Our observations might help to explain associations between obesity and irregular meal timings and/or snacking behaviour, which in turn might form the basis for a targeted intervention that promotes future thinking in meal planning. Future research is required to confirm whether these findings generalise to actual food intake.

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Conflict of interest.

The authors declare no conflict of interest.

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Figure and Table Legends

Table 1. Means for age, BMI, IMI sensitivity (slope and intercept), monetary delay discounting AUC, TFEQ, liking and appetite.

Table 2. Pearson's correlations between IMI sensitivity (slope and intercept), monetary delay discounting AUC, BMI, TFEQ (three subscales), hunger, fullness and liking.

Table 3. Regression coefficients with r-squared values derived from the multiple regression analysis.

Figure 1. Mean high and low energy density portion size (kcal) selected in response to increasing IMIs in lean (n = 31), overweight (n = 29) and obese (n = 20) participants. Participants were split into weight groups for visual depiction of the data only. Shallow slopes represent reduced sensitivity to IMIs. Curves were fitted to the mean composite portion sizes selected in response to inter-meal intervals; right now, thirty minutes, one hour, two hours, four hours and eight hours.