Zimmerman, A. R., Ferriday, D., Davies, S. R., Martin, A. A., Rogers, P. J., Mason, A., & Brunstrom, J. M. (2017). "What time is my next meal?" delay-discounting individuals choose smaller portions under conditions of uncertainty. *Appetite*, *116*, 284-290. https://doi.org/10.1016/j.appet.2017.05.019

Peer reviewed version

License (if available):
CC BY-NC-ND

Link to published version (if available):
10.1016/j.appet.2017.05.019

Link to publication record in Explore Bristol Research
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via Elsevier at https://www.sciencedirect.com/science/article/pii/S0195666317306888?via%3Dihub . Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available: http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/

"What time is my next meal?" Delay-discounting individuals choose smaller portions under conditions of uncertainty

Annie R. Zimmerman, Danielle Ferriday, Sarah R. Davies, Ashley A. Martin, Peter J. Rogers, Alice Mason, and Jeffrey M. Brunstrom

Nutrition and Behaviour Unit, School of Experimental Psychology, University of Bristol, UK

Corresponding author:

Annie Zimmerman

Telephone +44 (0) 117 33 46621

E-mail annie.zimmerman@bristol.ac.uk

Abstract

'Dietary' delay discounting is typically framed as a trade-off between immediate rewards and long-term health concerns. Our contention is that prospective thinking also occurs over shorter periods, and is engaged to select portion sizes based on the interval between meals (inter-meal interval; IMI). We sought to assess the extent to which the length of an IMI influences portion-size selection. We predicted that delay discounters would show 'IMI insensitivity' (relative lack of concern about hunger or fullness between meals). In particular, we were interested in participants' sensitivity to an uncertain IMI. We hypothesized that when meal times were uncertain, delay discounters would be less responsive and select smaller portion sizes. Participants (N= 90) selected portion sizes for lunch. In different trials, they were told to expect dinner at 5pm, 9pm, and either 5pm or 9pm (uncertain IMI). Individual differences in future-orientation were measured using a monetary delay-discounting task. Participants chose larger portions when the IMI was longer ($p < .001$). When the IMI was uncertain, delay-discounting participants chose smaller portions than the average portion chosen in the certain IMIs ($p < .05$). Furthermore, monetary discounting mediated a relationship between BMI and smaller portion selection in uncertainty ($p < .05$). This is the first study to report an association between delay discounting and IMI insensitivity. We reason that delay discounters selected smaller portions because they were less sensitive to the uncertain IMI, and overlooked concerns about potential future hunger. These findings are important because they illustrate that differences in discounting are expressed in short-term portion-size decisions and suggest that IMI insensitivity increases when meal timings are uncertain. Further research is needed to confirm whether these findings generalise to other populations.

Keywords: Chaotic eating, Impulsivity, Delay discounting, Meal planning, Portion size

Introduction

Impulsivity is a multidimensional construct that can be measured in various ways (Evenden, 1999; Whiteside & Lynam, 2016). Delay discounting is a facet of impulsivity, referring to the tendency to respond to the immediate rather than the long-term consequences of a decision (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). It is considered a behavioural-economic index of impulsive decision-making (MacKillop et al., 2011). A non-future oriented individual who discounts delayed rewards is often described as a 'steep' delay discounter. Steep temporal discounting has been related to an unhealthy diet, overeating, and obesity (Barlow, Reeves, McKee, Galea, & Stuckler, 2016; Kulendran et al., 2014; Manwaring, Green, Myerson, Strube, & Wilfley, 2011; Rollins, Dearing, & Epstein, 2010). Nevertheless, associations are often weak and unreliable (Appelhans et al., 2011; Eisenstein et al., 2015; Hendrickson, Rasmussen, & Lawyer, 2015; Leitch, Morgan, & Yeomans, 2013; Rasmussen, Lawyer, & Reilly, 2010; Stoeckel, 2013; Stojek, Fischer, Murphy, & MacKillop, 2014; Weller, Cook, Avsar, & Cox, 2008).

One explanation for these inconsistencies is that delay discounting can have multiple effects on food decisions. By contrast, the role of temporal discounting is often framed around a single proposition; that impulsive people overeat because they discount long-term health consequences (Zhang & Rashad, 2008). For example, associations between discounting and overconsumption are often attributed to a lack of concern for future weight gain (Barlow, et al., 2016). This perspective stands at odds with research in both humans (Gregorios-Pippas, Tobler, & Schultz, 2009; Mcclure, Ericson, Laibson, Loewenstein, & Cohen, 2008; Tanaka et al., 2004) and non-human animals (Mazur, 2001; Shelley, 1993), which shows that temporal discounting operates over much shorter delays of seconds and minutes. Recent studies have found that humans also discount the value of food and drink at intervals as short as thirty seconds (Hendrickson & Rasmussen, 2013; Lumley, 2016;

Rasmussen, et al., 2010). This indicates that people also discount short-term consequences of dietary decisions, rather than just long-term concerns about health or weight gain. In the present study we considered the prospect that dietary discounting occurs over an intermediate time frame (hours rather than years) and is evident in the selection of portion sizes from one meal to the next.

The majority of meals are planned in advance – people tend to select a portion to eat and then clean their plate (Fay et al., 2011; Wilkinson et al., 2012). Portion size is often governed by the 'expected satiety' of a food – a concern to select an amount that is sufficient to stave off hunger (the desire to eat) in the interval between meals (Brunstrom & Rogers, 2009; Brunstrom, Shakeshaft, & Scott-Samuel, 2008). Anticipated meals timings probably influence these decisions. However, no studies have systematically explored this phenomenon and it remains unclear how monetary delay discounting relates to meal planning in this context. To address these questions we explored the extent to which the length of an inter-meal interval (IMI) influences lunchtime portion-size selection.

One possibility is that meal planning might be less evident in steeper discounters. People plan their behaviours by evaluating the future consequences of a decision (da Matta, Gonçalves, & Bizarro, 2012). However, impulsive decision-makers may fail to consider all relevant information before making a choices (Verplanken & Sato, 2011). Given this logic, we anticipated that steep delay discounters would be less concerned with the relative consequences of a long or short IMI when making in-the-moment portion-size judgements. Therefore, we reasoned that steep discounters would show 'IMI insensitivity', (a relative lack of concern for potential hunger or fullness during the IMI) and have a smaller difference between portion sizes chosen at a short and long IMI.

In addition, we are interested in the effects of an uncertain IMI. Traditionally, a Westernised meal pattern comprises three primary meals; breakfast, lunch, and dinner.

However, sometimes the IMI is uncertain. Recently, there has been an increase in ‘chaotic eating’ - snacking and eating meals at different times on different days (Samuelson, 2000; Warde & Yates, 2016). Irregular eating is associated with having a higher BMI (Sierra-Johnson et al., 2008) and is thought to be a contributing factor to high-energy intake and weight gain (Berg & Forslund, 2015; Murata, 2000). Unsurprisingly, various dimensions of impulsivity have been associated with chaotic eating behaviours, including opportunistic snacking and a preference for snack foods (Fay, White, Finlayson, & King, 2015; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010).

One possibility is that irregular meal times encourage impulsive behaviours because they generate uncertainty. Uncertainty has been shown to increase delay discounting; individuals discount future rewards more steeply when the delayed event is perceived to be more risky or less certain (Baumann & Odum, 2012; Green & Myerson, 2010; Patak & Reynolds, 2007). It is important to mention that these studies manipulated the likelihood of an event occurring, rather than uncertainty around the exact timing of an event. We propose that uncertainty about the timing of an event may also increase discounting. When IMIs are certain, individuals can make predictions about future hunger or satiety. However, when event timings are variable, it is harder to plan for the future (Greville & Buehner, 2010). On this basis, uncertainty may increase discounting of information about future meal timings. To protect against the potential for hunger, individuals who are sensitive to the future might select larger portions when the IMI is uncertain. Conversely, steep discounters may be less responsive. Hence, we hypothesized that when meal timings were uncertain, steep delay discounters would select portion sizes that are smaller the average of those chosen when meal times were certain. We considered evidence for this hypothesis by systematically manipulating the certainty of an IMI.

In the present study we measured portion selection in response to information about the IMI. Participants chose lunch portions in three different conditions; two where the IMI was ‘certain’ (dinnertime at 5pm and 9pm), and one where the IMI was ‘uncertain’ (dinnertime at either 5pm or 9pm). To measure individual differences in future-oriented decision-making we used a standard monetary delay-discounting task. Our primary hypothesis was that information about future meal timings would influence portion selection at lunchtime. Specifically, we predicted that portion sizes would differ in each of the three conditions and that participants would select smaller portions with a certain short IMI, compared to a certain long IMI. Second, we proposed that steep money discounting would be associated with IMI insensitivity in both certain and uncertain conditions. When the IMI was certain, we hypothesized that steep discounters would show a smaller difference between portions chosen at 5pm and 9pm. When the IMI was uncertain, we expected steep discounters to select smaller portion sizes than the average of those chosen when meal times were certain. Finally, to explore how BMI relates to future-oriented decision-making, we assessed relationships between BMI, portion size, and monetary delay discounting.

Method

Participants: Participants (*N*= 90; 61 females, 29 males) had a mean age of 21.2y (*SD* = 4.7) and were healthy staff or undergraduate and postgraduate students at the University of Bristol, recruited through our laboratory volunteer database or as part of a course requirement. They received either £5 (Sterling) or course credits in remuneration for their assistance. The protocol was approved by the local Faculty of Science Human Research Ethics Committee. *A priori*, we thought it was crucial that participants were familiar with the foods we were including in the experiment. Therefore, we excluded fifteen participants who indicated eating either of the test foods either *'never'*, or *'less than once a year'*. A further five participants were excluded for selecting the minimum portion of chow mein (20 kcal) for lunch, in every condition. We suspect this reflects a technical error or otherwise a problem in understanding the requirements of the tasks. Six participants had missing data for the delay-discounting task due to a technical error. In these cases, values were entered as missing data. The final dataset comprised 70 participants (46 females, 24 males), with a mean age of 21.0 years (*SD* = 4.2), and a mean BMI = 21.68 kg/m^2 (*SD* = 2.6; range = 16.6 - 27.1). In total, 7 participants were underweight, 55 participants were lean and 8 were overweight.

Food images: Based on previous research (Brunstrom, Collingwood, & Rogers, 2010) we selected two different dishes that are commonly consumed as main meals in the UK: chicken chow mein and chicken tikka masala with rice. 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 images were taken using a high-resolution digital camera under identical lighting conditions. The meals were photographed on the same white plate (255-mm diameter).

Measures

Liking: Participants were shown a 400-kcal portion of the two test foods in a random order. In each trial they responded on a 7-point scale with end anchor points labelled ‘extremely dislike’ and ‘extremely like.’

Familiarity: Familiarity was assessed using a food-frequency questionnaire. Again, participants were shown a 400-kcal portion of each food. In turn, they responded to the question ‘How often do you eat this meal?’ by selecting one of the following options; ‘never,’ ‘less that once a year,’ ’yearly,’ ‘every 2-3 months,’ ‘monthly,’ ‘weekly,’ or ‘daily.’ These were coded 1-7 (least to most familiar).

Appetite: Measures of hunger and fullness were obtained using a 100-mm visual-analogue rating scale headed ‘How [hungry/full/thirsty] do you feel right now?’, with end anchor points ‘not at all’ and ‘extremely.’ All ratings were elicited on a computer.

TFEQ: Dietary behaviour was assessed using a computerised version of the 51-item Three Factor Eating Questionnaire (TFEQ; (Stunkard & Messick, 1985). The instrument contains 36 items with a yes/no response format, 14 items on a 1-4 response scale and one vertical rating. The relevant items were scored and aggregated into two scales. We were interested in the Restraint and Disinhibition subscales. ‘Cognitive restraint’ (conscious control of food intake to control body weight) and ‘disinhibition’ (loss of control over intake). Respectively, higher scores indicate greater cognitive restraint and disinhibition. Internal-consistency reliability coefficients (Cronbach’s α) were found to be above 0.70 and below 0.90 (de Lauzon et al., 2004). The internal-consistency coefficient of the restraint and disinhibition scales in the current study was 0.89.

BMI: To assess Body Mass Index (BMI), we measured participant’s height and weight at the end of the experiment. BMI was calculated from measured weight/height^2.

IMI portion task: Two food images were presented on a VDU. We chose to use photographic images as similar computer-based tasks have been shown to predict real food selection (Pouyet, Cuvelier, Benattar, & Giboreau, 2015; Taylor, Yon, & Johnson, 2014). A fixed portion (400 kcal) of chicken tikka masala was presented on the right and labelled ‘This meal for dinner.’ A portion of chow mein was presented on the left and labelled ‘This meal for lunch.’ The chow mein lunch portion could be increased or decreased by depressing the right or left arrow-keys, respectively. In each trial the participants responded 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 at…[time inserted].’ In two of the trials the IMI was ‘certain.’ In one certain trial they were told to expect their evening meal at 5pm. In the other they were told to expect it at 9pm. In a third trial the IMI was ‘uncertain’ - they were told to expect the meal at either 5pm or 9pm. Participants completed a total of three trials. The order of the trials was randomised across participants and each trial started with a randomly selected portion of chow mein.

To assess whether participants were more responsive to the uncertain future meal times, we compared portions selected in the certain and uncertain conditions. The uncertain IMI is framed around the same time points as the two certain IMIs (5pm and 9pm). Therefore, the effect of uncertainty can be established by comparing portions chosen in the uncertain condition with average of the portions chosen in the two certain condition. Specifically, we used the three selected portion sizes (2 certain trials and 1 uncertain trial) and computed a value (IMI index score) based on the following calculation: uncertain 5pm or 9pm - (certain 5pm + certain 9pm)/2). This provides a measure of the effect of uncertainty (relative to certainty) on portion selection. We calculated a separate IMI index score for each participant. A positive IMI index score indicates that larger portions were chosen in the uncertain condition than in the average of the two portions selected in the certain conditions.

Delay-discounting task: Delay discounting was measured using a computerised forced-choice task. The task was an adapted version of one previously introduced by Du and colleagues (Du, Green, & Muerson, 2016). In a series of trials participants indicated whether they preferred to receive a hypothetical delayed reward of £100 after a fixed interval (*e.g.*, 1 year) or a smaller monetary amount immediately. Participants completed several blocks of 10 trials. In every trial the delayed reward was always £100. In the first trial of each block the immediate reward was half the delayed value (£50). 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 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. Each presented a scenario 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 and responses were used to calculate a measure of delay discounting. The delay-discounting task and the IMI portion task were implemented using custom software (available on request) written in Visual Basic (Microsoft version 6.0).

Following Myerson et al. (Myerson, Green, & Warusawitharana, 2001), for each participant, a measure of delay discounting was obtained from area under the curve (AUC) values derived from the delay-discounting task. AUC values were calculated using the trapezoid method. Smaller AUC values indicate steeper discounting.

Procedure: Participants completed one 45-minute session between 12pm and 2pm. On arrival they reported how long ago they last ate and then rated their appetite and thirst. They then completed the IMI portion task, followed by liking and familiarity ratings, and then the delay-discounting task. Finally, participants completed the TFEQ and we measured their BMI. At the end of the study the participants were debriefed and thanked for their assistance.

Data analysis: First, to determine whether portion-size selection was influenced by information about the IMI, we conducted a one-way, repeated-measures ANCOVA with three conditions (portion size when the IMI was short, long and uncertain). We included gender as a between-subjects factor and BMI and age as covariates. A paired *t*-test was used to evaluate specific differences across participants between portion sizes chosen in the long and short certain conditions. Second, to measure sensitivity to change in length of the certain IMI, we assessed the difference between portions chosen in the two certain conditions. This allowed us to calculate a Pearson's correlation to explore how certain IMI sensitivity related to monetary delay discounting. Similarly, we calculated the correlation between delay discounting and sensitivity to the uncertain IMI, relative to the certain IMIs (IMI index score). In addition, we assessed correlations between BMI and both IMI index score and delay discounting.

Post-hoc analyses were conducted to investigate whether individual differences in delay discounting mediated the relationship between BMI and portion-size selection in uncertain IMIs. For a mediating relationship to be confirmed, four key criteria must be met. Criterion 1, the independent variable (IV) and the dependent variable (DV) must be significantly associated (Baron & Kenny, 1986). Criterion 2, the IV and the mediator must be significantly associated; Criterion 3, the mediator and the DV must be significantly associated; Criterion 4, when the mediator is controlled for in a regression of the IV on the DV, the β-value relating the IV to the DV becomes insignificant. In our post-hoc analysis, we entered the IMI index scores as the IV, BMI as the DV, and impulsivity as the mediator.

All four criterion were explored using multiple regression analysis. The unstandardized regression coefficients and standard errors of the relationship between the IV and the mediator, and between the DV and the mediator, are used to calculate the path coefficient ($b_a b_b$) and its standard error ($^s b_a b_b$). The path coefficient is divided by the standard error to give a *t*-ratio. If the *t*-ratio exceeds ±1.96, then the indirect path is significant and a mediating relationship is confirmed. All data were analysed using IBM SPSS statistics version 21 (IBM, New York, USA).

Results

Participant characteristics: Table 1 shows mean scores for liking, appetite, TFEQ, and familiarity, as well as participant characteristics. Both BMI and Delay discounting AUC scores were not related to liking, hunger, fullness, familiarity restraint or disinhibition (See Table 2). Mean TFEQ-restraint score (M = 6.7, SD = 3.6) and mean TFEQ-disinhibition score (M = 6.3, SD = 2.6) were all in the low range (Lesdema et al., 2012; Stunkard & Messick, 1985).

Table 1. Means and standard deviations (SD) for participant characteristics, questionnaires, ratings and delay discounting AUC

Measure (units/range)	Mean (*SD*)	Range (min-max)
Age (y)	21.0 (4.2)	18.0 – 43.0
BMI (kg/m^2)	21.7 (2.6)	16.7 – 27.1

TFEQ-restraint (0 - 21)	6.7 (3.6)	1.0 – 17.0
TFEQ-disinhibition (0 - 16)	6.3 (2.6)	1.0 – 13.0
Delay discounting (AUC)	0.6 (0.2)	0.0 – 1.0
Appetite (1-7)	5.0 (1.73)	1.0 – 7.0
Familiarity (chicken tikka and chow mein; (2-14)	9.8 (1.33)	2.0 – 14.0

(*N* = 70; 46 female, 24 male)

Table 2. Relationships (Pearson's correlations) between inter-meal interval (IMI) index score, delay discounting area under the curve (DD AUC), TFEQ, BMI, liking, hunger, and fullness.

	1	2	3	4	5	6	7	8
1. IMI index								
2. DD AUC	.29*							
3. TFEQ-Disinhibition	.18	.17						
4. TFEQ-Restraint	-.01	-.03	.13					
5. BMI	-.27*	-.40**	-.16	.29*				
6. Liking	-.20	-.13	-.09	-.11	.04			
7. Fullness	.16	.11	.02	.03	.14	-.07		
8. Hunger	-.139	.051	-.03	-.12	-.08	.11	-.74**	

* $p < .05$

** $p < .01$

IMI portion task: Our analysis revealed a main effect of IMI on portion selection after controlling for age, gender and BMI, $F (2,132) = 4.53$, $p = .012$, $\eta^2 = .06$. Specifically, participants chose larger portions with a certain long IMI (dinner at 9pm; M = 549.1 kcal, *SD*, 205.3) than a short certain IMI (dinner at 5pm; M = 423.4 kcal, *SD* = 217.1), t (69) = 6.02, p =.00. Covariates, age, gender and BMI did not predict variance in portion selection (all $p >$ .05). Correlations between IMI index score and liking, fullness, TFEQ-restraint and TFEQ-disinhibition failed to reach significance (see Table 2).

Relationship between discounting and IMI sensitivity: There was a medium sized, but non-statistically significant, correlation between delay discounting AUC and the difference between portion size at long and short certain IMIs, r (62) = .18, p = .15[1]. Consistent with our hypothesis, we found a significant positive correlation between delay discounting AUC and IMI index score, r (62) = .29, $p < .05$[1]. Participants who exhibited steeper discounting (lower AUC) chose smaller portions when the IMI was uncertain than when it was certain (See Supplemental Material for visual representation of relationship between IMI index and delay discounting).

Relationship between BMI with discounting and portion size selection at the uncertain IMI: There was a significant negative correlation between BMI and IMI index score r (69) = -.27, $p < .05$. Individuals with a high BMI chose smaller portions when the IMI was uncertain, compared to when it was certain. There was also a significant negative correlation between BMI and delay discounting AUC r (62) = -.40, $p <.001$. Participants who showed steeper discounting had a higher BMI than those with shallower discounting. Relationship between

[1] Degrees of freedom differ due to missing data

BMI and inter-meal-interval (IMI) index score. (See Supplemental Material for visual representation of relationship between IMI index and BMI).

Post-hoc mediation analysis: Significant relationships were confirmed between IMI index score and BMI (criterion 1), between delay discounting AUC and IMI index score (criterion 2) and between delay discounting AUC and BMI (criterion 3). When delay discounting AUC was controlled for in a regression of IMI index score on BMI, IMI index score no longer predicted BMI (criterion 4). Figure 1 shows the regression coefficients associated with tests of each relationship. Subsequently, the Sobel test (Sobel, 1982) confirmed that the two-tailed mediator was significant, *t (62)* = -2.59, *p* = .012. As all criteria for mediation were met and the Sobel test was significant, this suggests that delay discounting mediates the relationship between BMI and smaller portion size selection at the uncertain, relative to certain, IMI

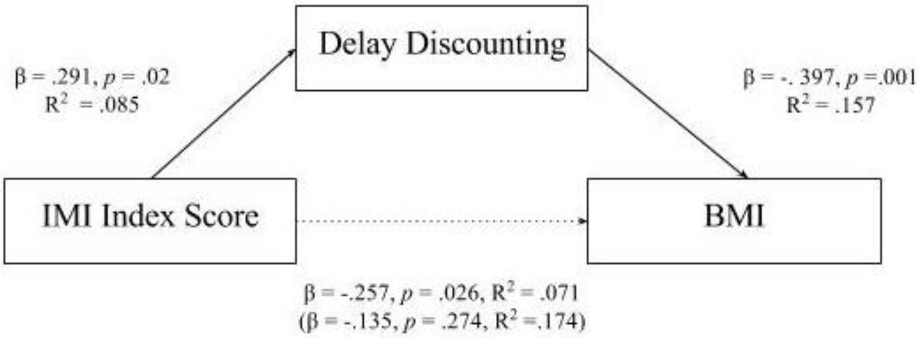

Figure 1. Delay discounting as a mediator of the relationship between selection of smaller portion sizes at the uncertain inter-meal interval (IMI index score) and BMI. Unstandardized β, *p* and R^2 values are shown for each relationship. Regression coefficients associated with Criterion 4 (when the mediator is controlled for in a regression of IMI index score on delay discounting) are shown in brackets.

Post-hoc power calculation: To assess satisfactory statistical power, we conducted a post hoc power analysis. The medium effect size states that we were underpowered to detect an association between delay discounting and the difference between portion sizes selected at the certain IMIs. The calculation revealed a sample size of 240 would be required to detect this effect with an α of 0.05 and a 1-β of 0.80.

Discussion

This study assessed how information about IMIs influences portion size decisions and whether steep delay discounters respond differently to the predictability of an IMI. Our primary hypothesis was that information about future IMIs would influence portion size decisions. Secondly, we hypothesised that steep monetary delay discounters would be less sensitive to information about the duration of the certain IMIs, and show a small differences between portions selected in the long and short IMIs. In particular, we predicted steep discounters would show even greater disregard for future meal times in the uncertain IMI.

Consistent with our first hypothesis, participants chose larger portions in response to the certain long IMI than in response to the certain short IMI. This is the first demonstration that people use information about future meal timings to make in-the-moment decisions about how much to eat. Greater monetary delay discounting was associated with smaller portion selection in response to the uncertain IMI, compared to the average of those chosen in the certain IMIs. We suggest that shallow discounters selected larger portions to protect against possible hunger during the IMI. Consistent with our hypothesis, steep delay discounters appeared to show a disregard for the uncertain IMI, possibly due to a lack of concern for potential hunger between meals. However, steep and shallow discounters selected similar portion sizes when the IMI was certain, suggesting that delay discounting is less relevant when an IMI is known. Consistent with this idea, individuals show greater discounting of a future reward when the occurrence of a delayed event is less certain (Baumann & Odum, 2012; Green & Myerson, 2010; Patak & Reynolds, 2007). Our results suggest that variability in the timing of the event also increases discounting. In the future, researchers should differentiate between irregular eating in the presence or absence of uncertainty. These observations suggest that dietary discounting is more likely to be expressed when meal times are uncertain. Hence, a distinction between certain and uncertain meal timings might be helpful, especially in studies seeking to understand relationships between chaotic eating, discounting, and BMI.

We also predicted that steep discounters would be less likely to plan their meals based on the duration of the certain IMI. In line with this, delay discounting was associated with a smaller difference between portions selected at the long and short certain IMIs. This suggests that steep discounters were less sensitive to information about future meal timings, whereas future-oriented individuals were more likely to plan for the IMI. Although this relationship failed to reach statistical significance, the effect sizes indicate a small-to-medium sized association, suggesting that the current study was potentially underpowered (a sample size of 240 would be required to detect this effect, with an α of 0.05 and a 1-β of 0.80).

Temporal discounting is generally regarded as a trait that promotes overconsumption. Our data show that delay discounting might actually reduce self-selected portion size. Specifically, the expression and downstream effects of discounting might depend upon whether a meal is planned and whether an IMI is certain or uncertain. These findings could help to explain previous inconsistent associations between delay discounting and eating behaviour. Dietary discounting is typically conceptualised as a trade-off between immediate food reward and long-term future health costs. Our data suggests that discounting is also expressed in shorter-term delays from one meal to the next. These distinctions are subtle yet potentially essential, and are generally overlooked in studies exploring the acute effects of temporal discounting on food intake. A more nuanced understanding of how meal timings influence future-oriented decisions will contribute to the development of an evidence base, which can inform guidelines around structured eating and meal planning.

Our post-hoc analysis suggests that delay discounting mediated a relationship between having a higher BMI and selecting *smaller* portions with an uncertain IMI. This appears counterintuitive; steep discounters had higher BMIs, yet chose smaller portions. One possibility is that a lack of concern for future hunger promotes various compensatory behaviours, such as the selection of energy-dense snacks between meals. In line with this, both chaotic eating and impulsivity have been associated with a greater tendency to snack between meals (Fay, et al., 2015) and also greater consumption of palatable foods (Lumley, 2016). Further research is required to determine whether snacking behaviour is more prevalent in individuals who less sensitive to information about IMIs.

The study may be limited by using computer-based judgements of food decisions. Nevertheless, our focus was to understand relationships between discounting and meal planning. Although computer-based portion judgments are shown to be predictive of real food intake (Pouyet, et al., 2015; Taylor, et al., 2014), it remains to be determined whether the same relationships might be observed in a study of food intake. This was beyond the scope of the present study but might be considered in future research. Additionally, as participants were university students with a relatively narrow range of BMIs, the generalizability of our findings remains unclear. The generalisability of our conclusions that delay discounters are less sensitive to information about future meal timings are somewhat limited by the lack of statistical power limited our conclusions; subsequent research is required to explore these relationships in a larger and more representative sample. Finally, as mood is shown to influence delay discounting (Koff & Lucas, 2011), subsequent studies could assess how mood influences decision-making regarding discounting of meal timings.

Concluding remarks

In summary, steep delay discounters selected smaller portions in response to an uncertain IMI, compared to the certain IMIs. We reasoned that in conditions of uncertainty, non-future oriented individuals were less concerned with potential hunger or fullness between meals and selected how much they would like in the moment. These results suggest that delay discounting is more likely to be expressed in a 'chaotic' eating environment. Future studies are required to assess these relationships in a wider sample and with real food intake to improve generalizability of our conclusions. Our findings merit consideration because they demonstrate how short-term discounting can influence portion-size decisions.

Acknowledgments

Work conducted at the University of Bristol was supported by the Biotechnology and Biological Sciences Research Council (BBSRC, grant references BB/ I012370/1 and BB/J00562/1). The research of Brunstrom, Rogers, and Zimmerman is currently supported by the European Union Seventh Framework Programme (FP7/2007-2013 under Grant Agreement 607310 [Nudge-it]).

Conflict of interest.

The authors declare no conflict of interest.

References

Appelhans, B. M., Woolf, K., Pagoto, S. L., Schneider, K. L., Whited, M. C., & Liebman, R. (2011). Inhibiting food reward: delay discounting, food reward sensitivity, and palatable food intake in overweight and obese women. *Obesity, 19*(11), 2175-2182. doi: 10.1038/oby.2011.57

Barlow, P., Reeves, A., McKee, M., Galea, G., & Stuckler, D. (2016). Unhealthy diets, obesity and time discounting: a systematic literature review and network analysis. *Obesity Reviews, 17*(9), 810-819. doi: 10.1111/obr.12431

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173. doi: 10.1037/0022-3514.51.6.1173

Baumann, A. A., & Odum, A. L. (2012). Impulsivity, Risk Taking, and Timing. *Behavioural Processes, 90*(3), 408-414. doi: 10.1016/j.beproc.2012.04.005

Berg, C., & Forslund, H. B. (2015). The Influence of Portion Size and Timing of Meals on Weight Balance and Obesity. *Current Obesity Reports, 4*(1), 11-18. doi: 10.1007/s13679-015-0138-y

Brunstrom, J. M., Collingwood, J., & Rogers, P. J. (2010). Perceived volume, expected satiation, and the energy content of self-selected meals. *Appetite, 55*(1), 25-29. doi: http://dx.doi.org/10.1016/j.appet.2010.03.005

Brunstrom , J. M., & Rogers, P. J. (2009). How many calories are on our plate? Expected fullness, not liking, determines meal-size selection. *Obesity (Silver Spring), 17*(10), 1884-1890. doi: 10.1038/oby.2009.201

Brunstrom, J. M., Shakeshaft, N. G., & Scott-Samuel, N. E. (2008). Measuring 'expected satiety' in a range of common foods using a method of constant stimuli. *Appetite, 51*(3), 604-614. doi: http://dx.doi.org/10.1016/j.appet.2008.04.017

da Matta, A., Gonçalves, F. L., & Bizarro, L. (2012). Delay discounting: Concepts and measures. *Psychology & Neuroscience, 5*(2), 135-146. doi: 10.3922/j.psns.2012.2.03

de Lauzon, B., Romon, M., Deschamps, V., Lafay, L., Borys, J. M., Karlsson, J., . . . Charles, M. A. (2004). The Three-Factor Eating Questionnaire-R18 is able to distinguish among different eating patterns in a general population. *The Journal of Nutrition, 134*(9), 2372-2380.

Du, W., Green, L., & Muerson, J. (2016). Cross-cultural comparisons of discounting delayed and probabilistic rewards. *The Psychological Record, 52*(4), 479-493.

Eisenstein, S. A., Gredysa, D. M., Antenor-Dorsey, J. A., Green, L., Arbelaez, A. M., Koller, J. M., . . . Hershey, T. (2015). Insulin, Central Dopamine D2 Receptors, and Monetary Reward Discounting in Obesity. *PLoS One, 10*(7), e0133621. doi: 10.1371/journal.pone.0133621

Evenden, J. L. (1999). Varieties of impulsivity. *Psychopharmacology (Berl), 146*(4), 348-361.

Fay, S. H., Ferriday, D., Hinton, E. C., Shakeshaft, N. G., Rogers, P. J., & Brunstrom, J. M. (2011). What determines real-world meal size? Evidence for pre-meal planning. *Appetite, 56*(2), 284-289. doi: http://dx.doi.org/10.1016/j.appet.2011.01.006

Fay, S. H., White, M. J., Finlayson, G., & King, N. A. (2015). Psychological predictors of opportunistic snacking in the absence of hunger. *Eating Behaviors, 18*, 156-159. doi: 10.1016/j.eatbeh.2015.05.014

Green, L., & Myerson, J. (2010). Experimental and correlational analyses of delay and probability discounting. In: Madden GJ, Bickel WK (eds) Impulsivity: the behavioral and neurological science of discounting. *American Psychological Association*, 67-92. doi: 10.1037/12069-003

Gregorios-Pippas, L., Tobler, P. N., & Schultz, W. (2009). Short-term temporal discounting of reward value in human ventral striatum. *Journal of Neurophysiology, 101*(3), 1507-1523. doi: 10.1152/jn.90730.2008

Greville, W. J., & Buehner, M. J. (2010). Temporal predictability facilitates causal learning. *Journal of Experimental Psychology: General, 139*(4), 756. doi: 10.1037/a0020976

Hendrickson, K. L., & Rasmussen, E. B. (2013). Effects of mindful eating training on delay and probability discounting for food and money in obese and healthy-weight individuals. *Behaviour Research and Therapy, 51*(7), 399-409. doi: 10.1016/j.brat.2013.04.002

Hendrickson, K. L., Rasmussen, E. B., & Lawyer, S. R. (2015). Measurement and validation of measures for impulsive food choice across obese and healthy-weight individuals. *Appetite, 90*, 254-263. doi: 10.1016/j.appet.2015.03.015

Koff, E., & Lucas, M. (2011). Mood moderates the relationship between impulsiveness and delay discounting. *Personality and Individual Differences, 50*(7). doi: 10.1016/j.paid.2011.01.016

Kulendran, M., Vlaev, I., Sugden, C., King, D., Ashrafian, H., Gately, P., & Darzi, A. (2014). Neuropsychological assessment as a predictor of weight loss in obese adolescents. *International Journal of Obesity, 38*(4), 507-512. doi: 10.1038/ijo.2013.198

Leitch, M. A., Morgan, M. J., & Yeomans, M. R. (2013). Different subtypes of impulsivity differentiate uncontrolled eating and dietary restraint. *Appetite, 69*, 54-63. doi: 10.1016/j.appet.2013.05.007

Lesdema, A., Fromentin, G., Daudin, J. J., Arlotti, A., Vinoy, S., Tome, D., & Marsset-Baglieri, A. (2012). Characterization of the Three-Factor Eating Questionnaire scores of a young French cohort. *Appetite, 59*(2), 385-390. doi: 10.1016/j.appet.2012.05.027

Lumley, J., Stevenson, RJ , Oaten, MJ, Mahmut, M, Yeomans, MR. (2016). Individual differences in impulsivity and their relationship to a Western-style diet. *Personality and Individual Differences, 97*, 178–185. doi: 10.1016/j.paid.2016.03.055

MacKillop, J., Amlung, M. T., Few, L. R., Ray, L. A., Sweet, L. H., & Munafò, M. R. (2011). Delayed reward discounting and addictive behavior: a meta-analysis. *Psychopharmacology (Berl), 216*(3), 305-321. doi: 10.1007/s00213-011-2229-0

Manwaring, J. L., Green, L., Myerson, J., Strube, M. J., & Wilfley, D. E. (2011). Discounting of various types of rewards by women with and without binge eating disorder: Evidence for general rather than specific differences. *The Psychological Record, 61*(4), 561-582.

Mazur, J. E. (2001). Hyperbolic value addition and general models of animal choice. *Psychological Review, 108*(1), 96-112.

Mcclure, S. M., Ericson, K. M., Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2008). Time Discounting for Primary Rewards. *The Journal of Neuroscience, 27*(21), 5796-5804. doi: 10.1523/jneurosci.4246-06.2007

Moeller, F. G., Barratt, E. S., Dougherty, D. M., Schmitz, J. M., & Swann, A. C. (2001). Psychiatric aspects of impulsivity. *American Journal of Psychiatry, 158*(11), 1783-1793. doi: 10.1176/appi.ajp.158.11.1783

Murata, M. (2000). Secular trends in growth and changes in eating patterns of Japanese children. *American Journal of Clinical Nutrition, 72*(5), 1379-1383.

Myerson, J., Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior, 76*(2), 235-243. doi: 10.1901/jeab.2001.76-235

Nederkoorn, C., Houben, K., Hofmann, W., Roefs, A., & Jansen, A. (2010). Control yourself or just eat what you like? Weight gain over a year is predicted by an interactive effect of response inhibition and implicit preference for snack foods. *Health Psychology, 29*(4), 389-393. doi: 10.1037/a0019921

Patak, M., & Reynolds, B. (2007). Question-based assessments of delay discounting: do respondents spontaneously incorporate uncertainty into their valuations for delayed rewards? *Addictive behaviors, 32*(2), 351-357. doi: 10.1016/j.addbeh.2006.03.034

Pouyet, V., Cuvelier, G., Benattar, L., & Giboreau, A. (2015). A photographic method to measure food item intake. Validation in geriatric institutions. *Appetite, 84*, 11-19. doi: 10.1016/j.appet.2014.09.012

Rasmussen, E. B., Lawyer, S. R., & Reilly, W. (2010). Percent body fat is related to delay and probability discounting for food in humans. *Behavioural Processes, 83*(1), 23-30. doi: 10.1016/j.beproc.2009.09.001

Rollins, B. Y., Dearing, K. K., & Epstein, L. H. (2010). Delay discounting moderates the effect of food reinforcement on energy intake among non-obese women. *Appetite, 55*(3), 420-425. doi: 10.1016/j.appet.2010.07.014

Samuelson, G. (2000). Dietary habits and nutritional status in adolescents over Europe. An overview of current studies in the Nordic countries. *European Journal of Clinical Nutrition, 54*(3), S21-28. doi: http://dx.doi.org/10.1038/sj.ejcn.1600980

Shelley, M. K. (1993). Outcome Signs, Question Frames and Discount Rates. *Management Science. Jul1993, 39*(7), 806. doi: http://dx.doi.org/10.1287/mnsc.39.7.806

Sierra-Johnson, J., Unden, A. L., Linestrand, M., Rosell, M., Sjogren, P., Kolak, M., . . . Hellenius, M. L. (2008). Eating meals irregularly: a novel environmental risk factor for the metabolic syndrome. *Obesity (Silver Spring), 16*(6), 1302-1307. doi: 10.1038/oby.2008.203

Sobel, M. (1982). Asymptotic confidence intervals for indirect effects in strucutural equation models. *Sociological Methodology, 13*, 290-312.

Stoeckel, L. E., Murdaugh, D.L.,Cox, J.E., Cook, E.W., Weller, R.E. (2013). Greater impulsivity is associated with decreased brain activation in obese women during a delay discounting task. *Brain Imaging and Behavior, 7*(2), 116-128.

Stojek, M. M., Fischer, S., Murphy, C. M., & MacKillop, J. (2014). The role of impulsivity traits and delayed reward discounting in dysregulated eating and drinking among heavy drinkers. *Appetite, 80*, 81-88. doi: 10.1016/j.appet.2014.05.004

Stunkard, A. J., & Messick, S. (1985). The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. *Journal of Psychosomatic Research, 29*(1), 71-83. doi: http://dx.doi.org/10.1016/0022-3999(85)90010-8

Tanaka, S. C., Doya, K., Okada, G., Ueda, K., Okamoto, Y., & Yamawaki, S. (2004). Prediction of immediate and future rewards differentially recruits cortico-basal ganglia loops. *Nature Neuroscience, 7*(8), 887-893. doi: doi:10.1038/nn1279

Taylor, J. C., Yon, B. A., & Johnson, R. K. (2014). Reliability and validity of digital imaging as a measure of schoolchildren's fruit and vegetable consumption. *Journal of the Academy of Nutrition and Dietetics, 114*(9), 1359-1366. doi: 10.1016/j.jand.2014.02.029

Verplanken, B., & Sato, A. (2011). The Psychology of Impulse Buying: An Integrative Self-Regulation Approach. [article]. *Journal of Consumer Policy, 34*(2), 197-120. doi: http://dx.doi.org/10.1007%2Fs10603-011-9158-5

Warde, A., & Yates, L. (2016). Understanding Eating Events: Snacks and Meal Patterns in Great Britain. *Food, Culture and Society*, 1-22. doi: 1243763

Weller, R. E., Cook, E. W., Avsar, K. B., & Cox, J. E. (2008). Obese women show greater delay discounting than healthy-weight women. *Appetite, 51*(3), 563-569. doi: http://dx.doi.org/10.1016/j.appet.2008.04.010

Whiteside, S. P., & Lynam, D. R. (2016). The Five Factor Model and impulsivity: using a structural model of personality to understand impulsivity. *Personality and Individual Differences, 30*(4), 669-689. doi: 10.1016/S0191-8869(00)00064-7

Wilkinson, L. L., Hinton, E. C., Fay, S. H., Ferriday, D., Rogers, P. J., & Brunstrom, J. M. (2012). Computer-based assessments of expected satiety predict behavioural measures of portion-size selection and food intake. *Appetite, 59*(3), 933-938. doi: 10.1016/j.appet.2012.09.007

Zhang, L., & Rashad, I. (2008). Obesity and time preference: the health consequences of discounting the future. *Journal of Biosocial Science, 40*(1), 97-113. doi: 10.1017/s0021932007002039