



O Shahrokni, R., Ferriday, D., Miguel, S., Laurent, A. L., & Brunstrom, J. M. (2022). "This snack is too small - I'll take a different one": Quantifying 'norm' and 'choice' boundaries to inform effective portion-reduction strategies. *Appetite*, 171, 105886. [105886].
<https://doi.org/10.1016/j.appet.2021.105886>,
<https://doi.org/10.1016/j.appet.2021.105886>

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“This snack is too small - I’ll take a different one”: Quantifying ‘norm’ and ‘choice’ boundaries to inform effective portion-reduction strategies

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ARTICLE INFO

Keywords:

Portion size
Food choice
Reformulation
Energy intake
Desire to eat

ABSTRACT

Previous research suggests that portion sizes can be categorised as ‘normal’ or ‘abnormal’ and that reduced portions which are still categorised as normal do not promote compensatory responses in intake. However, a critical question remains – will consumers choose a reduced portion product from among standard portion competitors? For the first time, we explore the effects of portion reduction on food choice. Participants (N = 45) categorised 20 different portions (range 40–420 kcal) of five snacks as normal or abnormal (to quantify individual ‘norm boundaries’ for each food) and rated their desire to eat each snack. Using a 2-alternative forced choice hypothetical task, we then calculated a ‘choice boundary’ by offering smaller portions of their most-desired snack (range 40–240 kcal) alongside standardised portions (240 kcal) of the less-desired foods. Boundaries were derived using probit analysis (choice boundary mean = 185.8 kcal, SD = 54, norm boundary mean = 127.3 kcal, SD = 49.5) and these deviated significantly ($p < .01$, $d = 0.98$, mean difference = 58.0 kcal, SD = 59.1). Critically, this shows that only a small reduction – where the product is still considered normal - can nudge a consumer to select an alternative. Choice boundaries were also affected by differences in desire to eat; when two foods were desired to a similar degree, only minor reductions in the size of the favourite food elicited a switch in choice. Together, these findings indicate that portion reduction can also influence food choice, highlighting the importance of measuring choice boundaries before reformulating commercial products.

1. Introduction

The portion size effect has been researched extensively (Ello-martin, Ledikwe, & Rolls, 2005; Ledikwe et al., 2005; Marchiori et al., 2014; Rolls, Roe, & Meengs, 2006a; Rolls et al., 2007); it describes a phenomenon where large serving sizes promote increased intake. Since the 1970’s, portion sizes in the U.S. have increased considerably (Nielsen & Popkin, 2003) and this has been shown to correspond with concurrent increases in obesity rates (Young & Nestle, 2002). Accordingly, some suggest that portion size plays a causal role in the development of obesity (Ledikwe et al., 2005), and, on this basis, researchers have advocated for portion-reduction strategies (Hollands et al., 2014; Marteau et al., 2015). In comparison to the abundance of research into the portion size effect, relatively few studies have explored the converse - the effects of portion size reduction. Of these studies, some find that

serving smaller portions promotes a short-term reduction in body weight (Hannum et al., 2004), however subsequent weight gain has also been reported (Rolls et al., 2017).

Recently, Haynes, Hardman, Halford, et al. (2019), Haynes, Hardman, Makin, et al. (2019), Haynes et al. (2020) have theorised that consumers classify portion sizes into discrete categories (i.e., abnormally small, normal or abnormally large). They suggest that these classifications may impact consumers’ decisions regarding intake, potentially undermining portion reduction interventions (Haynes et al., 2020, Haynes, Hardman, Makin, et al. 2019). To test this theory, Haynes, Hardman, Makin, et al. (2019) measured three portion size categories (i.e., abnormally small, normal, and abnormally large) and explored associated consumption plans. Participants categorised a series of portions as either ‘normal’ or ‘not normal’. For this task in Study 1, five different foods were assessed and, in each case, the smallest portion size

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<https://doi.org/10.1016/j.appet.2021.105886>

Received 22 April 2021; Received in revised form 17 December 2021; Accepted 20 December 2021

Available online 22 December 2021

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judged to be 'normal' by at least 60% of participants was defined as the 'lower boundary' (i.e., the perceptual boundary between normal and abnormally small portions). The same approach was used to measure the 'upper boundary' (i.e., the perceptual boundary between normal and abnormally large portions). Together, the upper and lower boundary frame a 'norm range' (see Fig. 1). Based on this range, participants were presented with images of abnormally small, normal, and abnormally large portions of the test foods and, using a Likert scale, indicated how much of each of the portions they would consume. Results suggested that participants intended to consume additional food if the portion size was abnormally small, consume only part of the portion when it was abnormally large, and would consume the full portion with no additional food when it was within the norm range. These findings were interpreted as being indicative of a causal relationship between the categorisation of these portion sizes and planned intake. However, we note a recent study by the same authors (Haynes et al., 2020) in which 24-h energy intake was measured for three separate five-day periods. In each testing period, participants were presented with one of three portions for lunch and dinner - either large-normal (within the norm range), small-normal (within the norm range) or smaller-than-normal (outside of the norm range). Washout time between each five-day period lasted between 1 and 6 weeks. The findings suggested a linear reduction in daily energy intake from large-normal to smaller-than-normal portions, regardless of portion size normality.

While this novel research provides valuable insight in an under-researched area, we note two limitations. First, in Study 1 of Haynes, Hardman, Makin, et al.'s (2019) initial work on norm boundaries, boundaries were calculated by averaging responses across individuals - such an approach does not account for differences between participants. In Study 2 of the same paper, this approach was modified by calculating individual norm boundaries - participants completed the 'norm boundary' task, described above, ten times. Boundaries were calculated as the smallest (lower boundary) and largest (upper boundary) portion size considered 'normal' in $\geq 60\%$ of trials. While it is commendable that the authors calculated norm boundaries for individual participants, the choice of threshold is somewhat arbitrary. Second, the authors considered only one consequence of portion reduction - the effect on intended intake. This focus overlooks a critical moment of decision making prior to consumption - whether the reduced-portion product will be selected from among a range of competitors. Consumers are often confronted with a range of options at the point of purchase. For example, at the time of writing, a search for 'pepperoni pizza' on a leading UK supermarket website (ASDA) displays 23 varieties of this product, in sizes ranging from 250 to 953 g. We argue that, to develop successful portion reduction interventions, the consumer must both select the reduced portion from among competitors and consume the reduced portion without fully compensating for the 'missing' calories. However, to date,

there has been a paucity of research into the effects of portion reduction on food choice. To begin to address these limitations, we employed a method to quantify both 'norm boundaries' (equivalent to the lower boundary as described by Haynes, Hardman, Makin, et al. (2019)) and 'choice boundaries' (the portion size boundary at which a reduced portion of a favourite food is rejected in favour of a standard portion of an otherwise less desired food) in individual participants. We used this approach to assess snack foods; snacks were selected as these products have been found to contribute around 24% of total energy intake in adults in the United States (Pernas & Popkin, 2010). For many snacks, there are often alternative products available which are designed to target a similar consumer base (e.g., chocolate) - in an attempt to capture the effects of portion reduction in such markets, we used only chocolate snacks as the test food.

The primary aim of this experiment was to determine the impact of portion size reduction on food choice. To do this, participants completed three main tasks. First, they categorised portions of chocolate snacks as abnormally small, normal or abnormally large - similar to the approach taken by Haynes, Hardman, Makin, et al. (2019). Individual norm boundaries (the perceptual boundary between abnormally small and normal portions) were calculated from this data. Since the experiment was focussed on the effects of smaller portions on choice behaviour, as opposed to larger portions, data surrounding the 'upper norm boundary' was discarded. Second, participants rated their desire to eat a single portion of each test food. With these data, we were able to identify each participant's most desired snack (their 'favourite'), as well as the difference in desire to eat between their favourite food and the other chocolates. Finally, they completed a 2-Alternative Forced Choice (2AFC) hypothetical task. For this, they chose between images of one of 11 portion sizes of their favourite food and a single standardised portion of each of their less desired foods. This enabled us to calculate the 'choice boundary', which we define as the portion size at which a preferred food is rejected in favour of a larger portion of an otherwise less desired food (see Fig. 2). To assess the primary aim, we identified the position of the choice boundary in relation to the norm boundary - i.e., if it is smaller or larger (see Fig. 2). We reasoned that if the choice boundary is smaller than the norm boundary (i.e., Option 1), this would imply that consumers will choose an alternative product only after they consider the reduced-portion snack to be abnormally small. On the other hand, if the choice boundary is larger than the norm boundary (i.e., Option 3), this would imply that consumers will choose an alternative product despite still considering the reduced-portion snack to be normal. For the potential benefits of portion reduction strategies to be realised, consumers must be willing to select a reduced-portion product over standard-portion competitors. Therefore, the location of this boundary could be critical in determining the success of a commercial portion-reduction intervention.

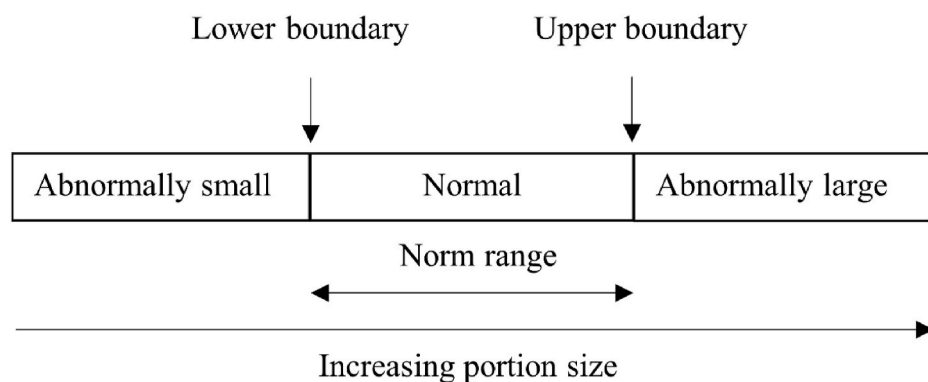


Fig. 1. Graphical depiction of the perceptual boundaries and norm range as defined by Haynes, Hardman, Makin, et al. (2019). The lower boundary identifies the conceptual boundary between normal and abnormally small portion sizes. The upper boundary identifies the conceptual boundary between normal and abnormally large portion sizes. Between these two boundaries is the norm range - this is the range of portion sizes considered to be normal. Commercially available portions are normally within this range.

Haynes, Hardman, Makin, et al. (2019) identified distinct consumption plans for portion sizes below the lower boundary, above the upper boundary and within the norm range. Specifically, portions which were below the lower boundary resulted in planned compensatory, or additional, eating. Portions above the upper boundary were not planned to be

consumed in their entirety. Finally, portions which were within the norm range were planned to be consumed in their entirety, with no additional intake.

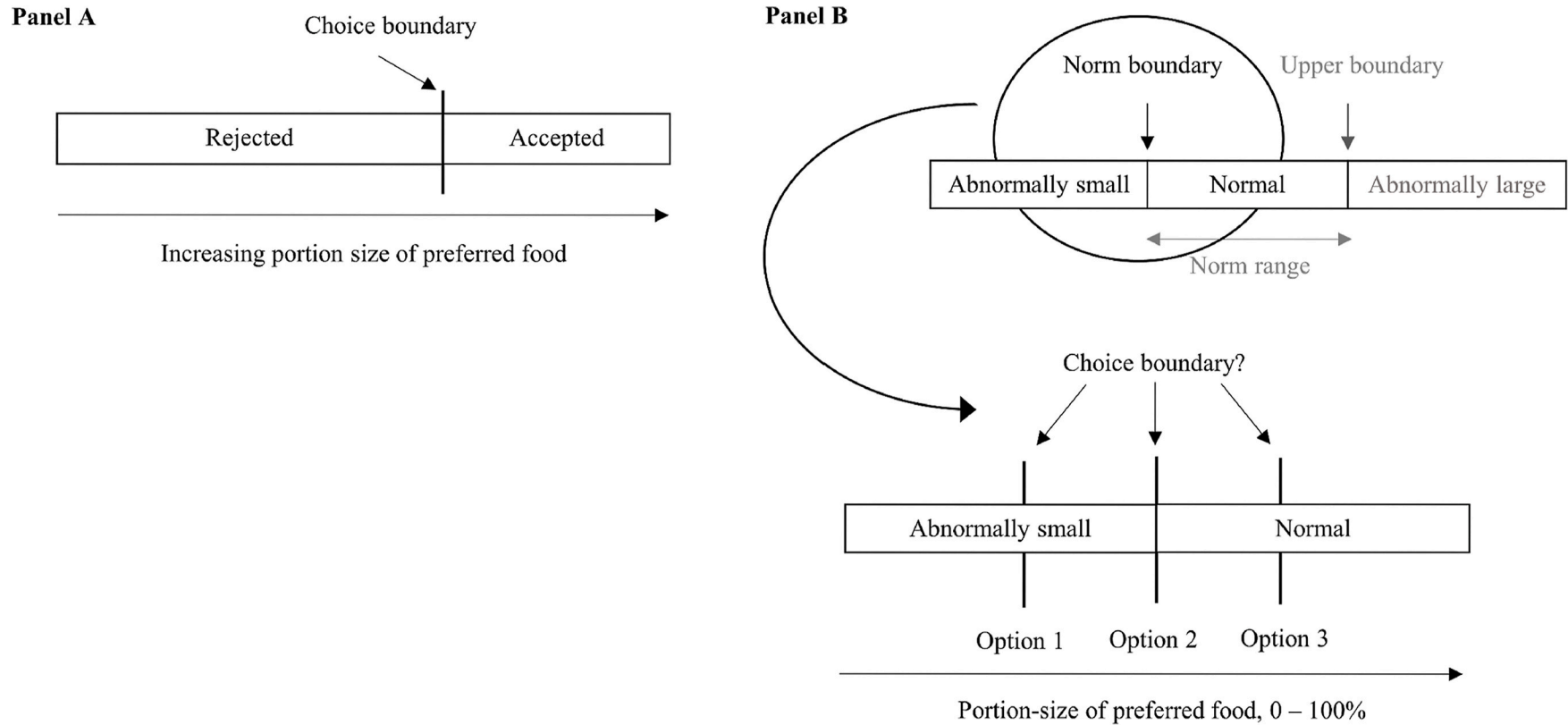


Fig. 2. Panel A. A separate conceptual boundary we intend to consider is the choice boundary. Portion sizes above this boundary will be accepted by the consumer. Portion sizes below this boundary will be rejected in favour of an alternative, standard-portion product.

Panel B. The three potential locations of the choice boundary. *Option 1* is that the choice boundary is located below the norm boundary (*i.e.*, it is a smaller portion size) – in this case consumers will continue to choose the abnormally small portion of their favourite food over standard-portion alternatives. *Option 2* is that the choice boundary sits on the norm boundary (*i.e.*, they are the same portion size) – in this case, consumers will choose a standard-portion alternative as soon as the portion size of their favourite food is considered abnormally small. *Option 3* is that the choice boundary is located above the norm boundary (*i.e.*, it is a larger portion size) – in this case, consumers will choose a standard-portion alternative product despite still considering the portion size of their favourite food to be normal.

The secondary aim of this experiment was to assess whether the choice boundary is affected by differences in desire to eat. As we have noted, snacks are often sold alongside a range of similar, competitor products. We suggest that when a snack is desired to a much greater degree than a competitor, there may be more scope to reduce its size (*i.e.*, it may take a relatively substantial reduction before the competitor is chosen). Similarly, when the difference in desirability is small, we would expect that only a minor reduction in portion size might lead to the selection of the alternative. To test this idea, we compared differences in desire to eat with choice boundary portion sizes. When the difference in desire to eat between the favourite snack and a competitor is large, we expected to see a smaller choice boundary portion size (see Fig. 3).

2. Methods

2.1. Participants

To calculate the minimum required sample size for this experiment, the work by Haynes, Hardman, Makin, et al. (2019) was utilised as a foundation. In their paper, Haynes et al. measured the effects of portion size norm boundaries on intended eating behaviour and, in Study 1, identified a medium effect size ($\eta p^2 = 0.16$). Within the same paper, for Study 2, the authors used this effect size to calculate how many participants would be required to replicate the experiment to, once again, observe the effects of portion size norm boundaries on intended eating behaviour. To achieve 80% power with an alpha of 0.05, the authors estimated that a minimum sample size of 34 participants would be required. We acknowledge that the aims of the experiment in our paper, namely, to observe the difference between norm and choice boundaries (aim one) and to identify a potential negative correlation between difference in desire to eat and the choice boundary portion size (aim two), are not the same as those described by Haynes, Hardman, Makin, et al. (2019). However, the work conducted by Haynes, Hardman, Halford, et al. (2019), Haynes, Hardman, Makin, et al. (2019), Haynes et al. (2020) is, to date, the only other published work which explored the effects of portion size boundaries on participant behaviour. Therefore, in line with their calculations, we chose to use an equivalent minimum sample size of 34 participants, though over-recruited to allow for potential data loss during analysis.

The total recruited sample comprised 44 participants (37 female), with a mean age of 26.3 years ($SD = 7.6$, range = 18–52) and a mean Body Mass Index (BMI) of 22.6 kg/m² ($SD = 3.9$, range = 15.9–35.3). Analysis of the Dutch Eating Behaviour Questionnaire (DEBQ) restrained eating subscale revealed average scores of 2.5 ($SD = 0.8$). At the point of recruitment, inclusion criteria included no history of an eating disorder, no food allergies or intolerances, no vegetarians or vegans, and to not be taking medication which could affect appetite. Participants were recruited from the general population of Bristol using

the Nutrition and Behaviour Unit’s database of approximately 1250 volunteers. The experiment was advertised under the title ‘Snacking and cognition’ and the specific aims of the experiment were concealed until the participant was debriefed, prior to providing final consent. The self-selected participants were each reimbursed £10 for their time. Ethical approval was granted by the University of Bristol Faculty of Life Sciences Human Research Ethics Committee (ID: 27061989707).

2.2. Stimuli

The test foods were: After Eight Bites (Nestlé), Chocolate M&Ms (Mars), Maltesers (Mars), Milkybar Giant Buttons (Nestlé), and Snickers Bites (Mars) (for nutritional information, see Table 1). Each test food was photographed in portions ranging from 40 to 420 kcal in 20 kcal steps (see supplementary materials). This wide range (20 images) was chosen to minimise the likelihood that the smallest portion (40 kcal) might be judged as ‘normal’ or that the largest portion (420 kcal) might be judged as ‘abnormally small’. To ensure that our stimuli were of an appropriate range for our individual participants, we calculated the percentage of trials that our smallest and largest portions (40 kcal and 420 kcal) were marked as either smaller than normal (40 kcal) or normal/larger than normal (420 kcal). Reassuringly, in 93.3% of trials, the 40-kcal portion was marked as ‘smaller than normal’ (5% marked as ‘normal’) and in 99.2% of trials, the 420-kcal portion was marked as ‘normal’ or ‘larger than normal’. The images were captured at a 45° angle on a standard-sized white dinner plate (255 mm diameter), without packaging, using a high-resolution digital camera. They were presented with their name and brand information at 620 x 620 pixels on a 22” TN LED display using the online experiment builder Gorilla (www.gorilla.sc) (Anwyl-Irvine, Massonnié, Flitton, Kirkham, & Evershed, 2020).

Table 1
Nutritional information for test foods. Values are provided per serving.

	After Eight Bites (Nestlé)	Chocolate M&Ms (Mars)	Maltesers (Mars)	Milkybar Giant Buttons (Nestlé)	Snickers Bites (Mars)
Recommended serving size (g)	31.0	44.3	46.5	20.1	39.6
Unit size (g)	~5.0	~1.0	~2.0	~2.5	~5.5
Energy (kcal)	144	213	234	109	192
Fat (g)	6.0	8.5	11.4	6.4	9.1
Carbohydrate (g)	20.9	31.1	28.6	10.7	24.0
Protein (g)	1.0	2.3	3.8	2.1	3.2
Salt (g)	0.01	0.06	0.21	0.07	0.23

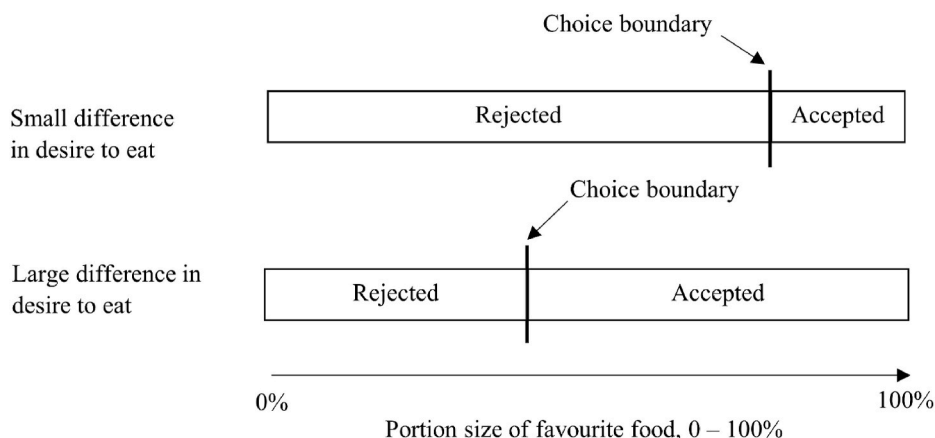


Fig. 3. Diagram of the effects of differences in desire to eat on the choice boundary portion size. Small differences in desire to eat between two foods (*i.e.*, two foods are desired to a similar degree) will result in little tolerance for reductions in portion size of the favourite food. This will be demonstrated with a larger choice boundary portion size. Large differences in desire to eat between two foods (*i.e.*, the favourite food is desired much more than the second-favourite) will result in much greater tolerance for portion size reductions of the favourite food. This will be demonstrated with a smaller choice boundary portion size.

All foods were purchased in large ‘share bag’ style packets. The manufacturers recommended portions from these bags ranged from 109 kcal (Milkybar Giant Buttons) to 234 kcal (Maltesers) – calorie density ranged from 4.6 kcal/g (After Eight bites) to 5.4 kcal/g (Maltesers). Due to the variations in unit size and calorie content, the number of additional units required for each 20-kcal step varied across the test foods – from ~0.8 units (Snickers bites) to ~4.5 units (Chocolate M&Ms). Care was taken to select whole pieces which matched the desired step size. However, when this was not possible, larger pieces were cut to ensure accurate calorie steps and the cut side of the piece was hidden (e.g., turned to face away from the camera) where possible.

2.3. Measures

2.3.1. Norm boundary

To obtain a measure of an individual’s norm boundary, participants were asked to indicate whether each of the 20 portion size images of the five test foods were ‘smaller than normal’, ‘normal’ or ‘larger than normal’. To maximise the precision of the boundary estimates, they repeated this process 10 times, resulting in 1000 trials per participant (5 snacks x 20 portions x 10 repetitions) which were presented in a random order.

Participants were instructed to; “Imagine you have some chocolate to consume in one sitting for an afternoon snack with no additional food. For each of the following images, you will be asked to decide if the portion size of the food being presented is ‘Smaller than normal’, ‘Normal’ or ‘Larger than normal’ by pressing the corresponding buttons. Try to answer as quickly as possible.” A prompt was shown in each trial: “Is this portion size normal or abnormal for you to consume in one sitting (with no additional food)?”

Since we were only interested in the boundary between normal and abnormally small portions, trials where the portion size was considered ‘larger than normal’ were removed from the dataset. For each participant’s favourite food, a probit analysis was then conducted to fit a

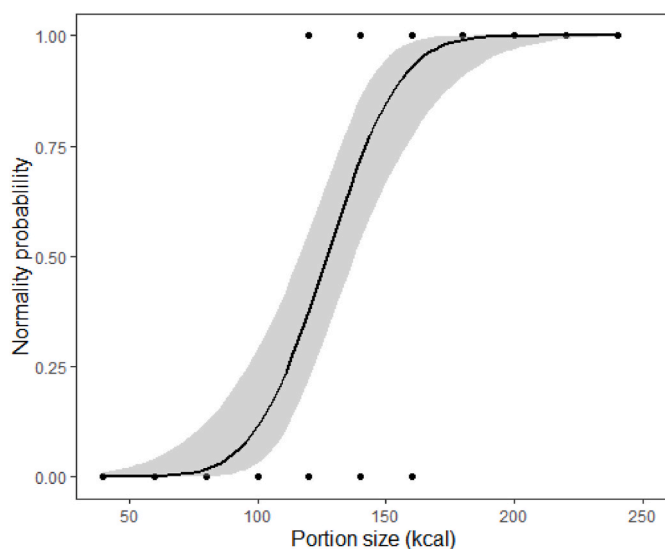


Fig. 4. Example probit analysis for the norm boundary. X-axis indicates portion size in kcal, Y-axis indicates probability of perception of normality. A score of 0 for perceived normality demonstrates a 0% likelihood this portion will be categorised as ‘normal’. A score of 1 for perceived normality demonstrates a 100% likelihood this portion will be categorised as ‘normal’. The portion size which was categorised as normal in 50% of trials was identified as the norm boundary.

A near identical process occurred for the identification of the choice boundary. Here, the X-axis indicated portion size in kcal, as above, and the Y-axis indicated probability of acceptance. The portion size which was accepted in 50% of trials was identified as the choice boundary.

sigmoid function relating portion size to the probability of being categorised as either normal or abnormal (see Fig. 4). From this, the portion size estimate that had an equal likelihood of being categorised as either ‘normal’ or ‘smaller than normal’ (i.e., the point of subjective equality) was considered the norm boundary.

For each norm boundary estimate to be accepted, the following criteria had to be met; a) there was a good fit of the sigmoid function (i.e., the Pearson goodness-of-fit Chi-Squared test returned a p -value of $< .05$, indicating the fit does not differ from the theoretical distribution) and b) the estimate was within the range presented to participants (i.e., between 40 and 420 kcal). If one or more of these criteria were unfulfilled, the norm boundary was treated as missing for this participant.

2.3.2. Desire to eat

Participants were told to “Imagine you are choosing a chocolate to consume in one sitting as an afternoon snack with no additional food. For the following task you will be presented with five chocolates; for each, please indicate how much you would like to eat the presented portion of each chocolate in this context.” As this question assesses a person’s motivation to consume a snack, we refer to this as a rating of ‘desire to eat’. In each trial, one 240-kcal portion of one of the five test foods was presented above a Visual Analogue Scale (VAS) headed “How much would you like to eat this portion of this chocolate as an afternoon snack (with no additional food)?”, with anchor points “Not at all” and “Extremely”. This was repeated for each test food, resulting in 5 trials. The 240-kcal portion was used as the standardised portion in both this task and the choice boundary task (described in detail in 2.3.3). As we were interested in exploring the difference between norm and choice boundary portion sizes, it was necessary to use a standardised portion which was larger than the norm boundary portion size. Using a standardised portion which was ‘abnormally small’, we argue, would artificially inflate the difference between the two boundaries. Therefore, the standardised portion was selected as the closest 20-kcal step to the largest manufacturer recommended portion size, that being 234 kcal (Maltesers).

Using these ratings (scored 0–100), each participant’s highest rated snack was identified as their ‘favourite’ food. Ratings were also used to calculate a set of four difference scores - for each participant, the difference in desire to eat between the favourite food and the second, third, fourth, and fifth most desired foods. The second, third, fourth and fifth most desired foods are referred to as ‘desire rank 2’, ‘desire rank 3’, ‘desire rank 4’ and ‘desire rank 5’, or, collectively, the ‘less-desired’ foods.

2.3.3. Choice boundary

In a 2AFC task each participant was presented with images of two different test foods side-by-side. The first image was one of 11 portion sizes of their favourite food, ranging from 40 to 240 kcal in 20-kcal steps. The second image was a standard 240-kcal portion of one of the four less-desired foods - the 240-kcal portion was chosen to match that used in the desire to eat task. Participants were instructed to “Imagine you are choosing a chocolate to consume in one sitting as an afternoon snack with no additional food. For each of the following trials, you will be shown two images of two different chocolates. For each, please select the chocolate which you would choose in this context by clicking the image. Please answer as quickly as possible.” To prompt this scenario, at each trial participants were asked “Which of these would you choose as an afternoon snack?”. Participants did not expect to receive a chocolate bar based upon their results and the food choices were therefore hypothetical.

To maximise the precision of the boundary estimates, each trial was repeated 10 times (in a random order), rendering 440 trials per participant (4 snacks x 11 portions x 10 repetitions).

With these data, separate choice boundaries were calculated for the four less-desired foods. As with norm boundaries, for each of the less-desired foods, probit analysis was used to determine by how much the

favourite food needs to be reduced in size before it is selected 50% of the time – the point of subjective equality. This portion was considered the choice boundary. The criteria for rejecting a choice boundary estimate were identical to those for a norm boundary.

2.4. Procedure

Participants attended a single 60-min test session at the Nutrition and Behaviour Unit (University of Bristol) between 09:00 and 17:15. Upon arrival, they read an information sheet and signed a consent form. They then rated their hunger, thirst, and lethargy [“How HUNGRY/THIRSTY/(SLUGGISH/SLEEPY/LETHARGIC) do you feel right now?”] on VAS scales using the anchor points “Not at all” and “Extremely”. Participants then completed the norm boundary task and the desire to eat task. They were then given a 4-min distraction task (word-search using neutral words). This distraction task was included to provide time for the experimenter to analyse the results from the desire to eat task, determine the participants’ favourite food, and prepare the choice boundary task. Next, participants completed the choice boundary task. Finally, they completed the restraint section of the DEBQ. A small area of the test room was set-up with a stadiometer and a digital weight scale, both with a precision of 0.1 cm/kg. Following completion of the DEBQ, height and weight were recorded by the experimenter to calculate the participants’ BMI. At the end of the test session, the participants were asked to report their beliefs about the aim of the experiment and were then debriefed and reimbursed for their time.

2.5. Data analysis

2.5.1. Identification of boundaries

In July 2019, we obtained data from 37 participants (30 female). However, using the criteria for the identification of boundaries (originally outlined in section 2.3.1), choice boundaries from 9 participants were rejected. On this basis, an additional seven were recruited in October 2019 – choice boundaries were identified for four of these participants.

Probit estimates and all other statistical analyses (elsewhere) were conducted using RStudio version 3.5.1 (RStudio Team, 2020). When calculating the choice boundary, we failed to fit a sigmoid curve to the data for desire rank 2 on 27.3% of occasions. Visual inspection of the data revealed that participants often rejected the favourite food even when it was presented in a large portion (e.g., 220–240 kcal); this tended to occur when ratings for the favourite and the second most desired chocolate were similar (typically less than 10 points). In these cases, the choice boundary appeared to occur close to the maximum portion (240 kcal, i.e., the largest presented portion). For such boundaries to be detected, step sizes between boundaries would need to be smaller than that used within this experiment (that being 20 kcal). Accordingly, in cases where the Pearson Chi-Squared test returned a p value of $\geq .05$ and the difference in desire to eat was between 0 and 10 points, we implemented additional criteria for the identification of the choice boundary. The boundary was therefore extracted as the portion which met the following conditions: 1) the portion was chosen for 5 trials (i.e., 50% of the time) and 2) all subsequent larger portions were selected for 5 or more trials (i.e., larger portions were also selected $\geq 50\%$ of the time). If either one of these conditions was not met, this indicated that the participant was not willing to accept any portion size smaller than the standardised portion and 240 kcal was consequently extracted as the choice boundary. Figures supporting the additional criteria for the identification of the choice boundary can be found in the supplementary materials (Supplementary Figs. 1–12).

Norm boundary portion sizes were identified for the favourite food in 43 participants using the inclusion criteria outlined in 2.3.1. These boundaries ranged from 60 to 277.7 kcal ($M = 127.3$ kcal, $SD = 49.5$). For desire rank 2, choice boundaries were identified for 32 participants ($M = 185.8$ kcal, $SD = 54.0$). For desire ranks 3, 4 and 5, choice

boundaries were identified for 33 ($M = 150.3$ kcal, $SD = 50.0$), 28 ($M = 130.9$, $SD = 50.4$) and 25 ($M = 119.5$, $SD = 45.7$) participants, respectively.

2.5.2. Relationship between norm boundaries and choice boundaries

In relation to the primary aim, we sought to determine whether a reduction in portion size causes people to switch to an alternative, less desired food (choice boundary) and to do so even with small reductions that do not transgress a norm boundary (boundary between a portion being regarded as normal or abnormally small). To answer this question, norm and choice boundaries must be compared. For each participant, we calculated the difference between the desire rank 2 choice boundary (choice boundary for second-most desired food) and the norm boundary for the favourite food. In cases where one of these boundaries was not available, the difference score was classed as ‘missing data’. Despite norm boundaries being calculated for 43 participants, choice boundaries for desire rank 2 could only be calculated for 32 participants. Therefore, only data from those 32 participants were used for this analysis. A one-sample t -test was then used to determine whether these difference scores deviated from zero. Positive difference scores would indicate that the portion size for the norm boundary is smaller than the portion size for the choice boundary. In turn, this would suggest that reducing the portion size of the favourite food past the choice boundary would cause participants to switch to their second most desired food and that this would occur even when the size of the reduced favourite is still categorised as ‘normal.’

2.5.3. Effect of desirability on choice boundary

The secondary aim was to explore the effect of differences in desirability on choice boundaries. For each participant we calculated the difference in desire to eat between the favourite snack and desire rank 2, desire rank 3, desire rank 4, and desire rank 5 (four sets of desire to eat difference scores). We hypothesised that with small differences in desire to eat, the choice boundary would be larger. In other words, when a competitor food is desired almost as much as a favourite food, then only a small reduction in the size of the favourite will lead to the selection of the alternative. Because we calculated a choice boundary for desire ranks 2, 3, 4, and 5, we were able to test this hypothesis by exploring evidence for a negative correlation between each set of choice boundaries and its corresponding set of desire to eat difference scores (desire ranks 2–5).

3. Results

3.1. Relationship between norm boundaries and choice boundaries

For each participant, difference scores were calculated by subtracting the norm boundary portion size for the favourite food from the choice boundary portion size for desire rank 2. A one-sample t -test demonstrated that they deviated significantly from 0 ($t(31) = 5.6$, $p < .001$, 95% CIs [36.7, 79.3], $d = 0.98$). The mean difference for this measure was greater than 0 ($M = 58$ kcal, $SD = 59.1$), indicating that the choice boundary portion size is larger (i.e., higher in calories) than the norm boundary portion size. Based on a standardised portion size of 240-kcal, reduced portions were considered abnormal after a reduction of 46.7%, however, a reduction of only 22.6% led to the selection of an alternative product.

3.2. Effect of desirability on choice boundary

The difference in desire to eat was calculated by subtracting desire to eat ratings of each of the four less-desired foods from the desire to eat rating of the favourite food for each participant (for means and standard deviations, see Table 2). Pearson correlations were conducted on the results of these calculations and the corresponding choice boundaries (see Fig. 5). Significant negative correlations were found between

Table 2

For each participant, we calculated the difference in desire to eat between the favourite food and the second, third, fourth, and fifth most desired food. Respectively, these difference scores are referred to as desire rank 2, 3, 4 and 5. Means and standard deviations of the choice boundary portion sizes (kcal) and differences in desire to eat are displayed for each desire rank separately.

Desire rank	Choice boundary (kcal)		Difference in desire to eat (0–100)	
	Mean	SD	Mean	SD
2	185.8	54.0	9.4	9.0
3	150.3	50.0	17.7	13.5
4	130.9	50.4	33.1	16.3
5	119.5	45.8	46.8	21.2

difference in desire to eat and choice boundaries for desire ranks 2 and 3 (desire rank 2: $r(30) = -0.5, p < .01$; desire rank 3: $r(31) = -0.5, p < .01$). A negative correlation was also found for desire ranks 4 and 5, however these were not significant (desire rank 4: $r(26) = -0.4, p = .06$; desire rank 5: $r(23) = -0.3, p = .13$). Based on Cohen (1988), medium effect sizes were observed for all four correlations. Here, negative correlations indicate that while the difference in desire to eat between two foods increases, the choice boundary portion size for the favourite food decreases.

4. Discussion

The primary aim of this experiment was to explore the impact of portion reduction on food choice. The results suggest that, based on a standardised portion of 240-kcal, a reduction of 46.7% was needed for a snack to be considered abnormally small. However, an alternative product was selected after a reduction of only 22.6%. This disparity suggests that participants rejected a reduced portion of their favourite food for an alternative, despite perceiving the reduced portion to be a normal size. The second aim of the experiment was to explore the effect of differences in desire to eat the favourite brand of chocolate and the alternative chocolate brands on food choice. As predicted, we observed negative correlations between differences in desire to eat and choice boundaries. Specifically, when two foods were desired to a similar degree, only minor reductions in portion size were tolerated before an alternative product was selected. By contrast, when the favourite food was desired to a greater extent than the second option, larger reductions

in the favourite food were accepted before consumers switched to the second option.

Together, these findings have an important implication. Previous research has explored the impact of reducing portion size on meal size (Haynes et al., 2020; Rolls, Roe, & Meengs, 2006b) and subsequent intake (Haynes et al., 2020; Lewis, Ahern, et al., 2015) under tightly controlled conditions. These studies have concluded that reductions in portion size are accepted by consumers and lead to sustained reductions in intake. However, our results suggest that for these findings to be translated for real-world application, choice boundaries should also be measured. For a product that has little ‘competition’ at the point of purchase (e.g., popcorn at a cinema), larger reductions in portion size might be achievable and acceptable to the consumer. On the other hand, our results indicate that when competitor products (e.g., alternative types of chocolate bar) are available, such as at vending machines and supermarkets, a reduction to the preferred option might prompt consumers to select a second-favourite offering. Furthermore, this switch can occur with even very small reductions, and this is especially the case when the second-favourite option is desired almost as much as the favourite. Accordingly, the focus solely on intake in previous research may have led to an overestimation of the potential success of portion-reduction interventions – if consumers are unwilling to accept a reduced-portion product and choose an alternative, no energy reduction can take place. Indeed, such resistance to reduced portion sizes could be linked to a general tendency to procure and consume calories when they are available – a strategy that evolved to protect our ancestors from famine, but now causes unhealthy overconsumption in environments where food is energy rich and abundant (Cordain et al., 2005; Leonard & Robertson, 1994; Neel, 1962).

In 2016, Public Health England announced a sugar-reduction programme in which manufacturers were challenged to reduce the sugar content of many snack foods by reducing energy density (kcal/g) and/or portion size. A related challenge, however, is ‘first mover disadvantage’ (see Marteau et al., 2015) – the food manufacturer that reduces their portion size first is likely to give their competitors an advantage. As outlined by Marteau and colleagues (2015), a radical solution would be a synchronised reduction in portion size across an entire food group (e.g., chocolate bars). However, such an approach is likely to meet strong resistance (see Diepeveen, Ling, Suhrcke, Roland, & Marteau, 2013).

One way to mitigate the effects of first-mover disadvantage might be

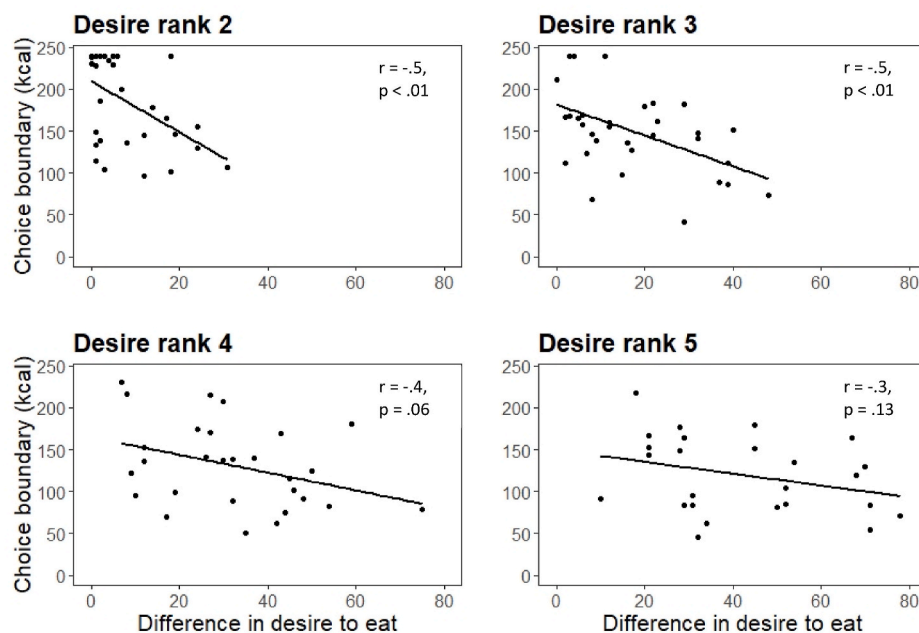


Fig. 5. Multiplot of correlation analyses. X-axis indicates difference in desire to eat, Y-axis indicates choice boundary portion size. The difference in desire to eat was calculated by subtracting the desire to eat score (out of 100) for the four less desired foods from the desire to eat score of the favourite food. All plots show evidence of a negative correlation – i.e., when the difference in desire to eat is small, the choice boundary portion size is large. These results suggest that when two foods are desired to a similar degree, consumers are less tolerant of a reduction in portion size.

to enhance the overall appeal of a snack, thereby creating greater 'hedonic distance' between the reformulated snack and its competitors. Indeed, previous research has suggested that interventions that draw attention to the hedonic characteristics of a food cause an increase in desire to eat, and that participants are even willing to pay the same amount (or slightly more) for a smaller portion (Cornil & Chandon, 2016). In this context, other ways to increase enjoyment and satisfaction have also been suggested, such as incorporating greater variety, increasing flavour intensity, and the use of hedonic labelling (Rogers et al., 2016). One additional method to modify choice behaviour might be manipulation of unit size or unit number. Previous research has suggested that both the number of units and the size of the units of the food affects perceptions of portion size as well as consumption (Almiron-Roig, Solis-Trapala, Dodd, & Jebb, 2013; Vandebroele, Van Kerckhove, & Zlatevska, 2019). This study used foods for which a range of unit sizes and numbers were presented. While the experiment was not powered to accurately analyse the effects of unit size on either choice or norm boundaries, we ran an exploratory post-hoc analysis to determine if there was a pattern indicating an effect of unit size. According to our analyses, the effect of unit size on either norm boundaries ($f(1,209) = 2.7, p = .1$) or choice boundaries ($f(1,30) 3.6, p = .07$) was not statistically reliable. To analyse this in more detail, potential future studies could examine whether foods with a distinctly larger number of units are selected over foods with a smaller number of units.

With regards to the foods used within this study, the authors note that the standardised portion of 240-kcal was larger than the manufacturer recommended portions for all foods (which ranged from 109 kcal (Milkybar Giant Buttons) to 234 kcal (Maltesers)). As described in the methodology, the standardised portion was calculated as the closest 20-kcal step to the largest recommended portion size to minimise the likelihood that the standardised portion would be considered abnormally small (7.24% of trials with this portion were considered abnormally small). We acknowledge that the use of portions which are larger than the recommended portion size resulted in the standard portion being considered abnormally large for a number of trials (33.6%). However, using a standardised portion which was generally considered abnormally small would artificially inflate the difference between the two boundaries, which was of greater concern. As such, we argue that the use of this standardised portion of 240-kcal was appropriate within this context. It is important to note, however, that the use of a standardised portion in commercial contexts is unrealistic and future experiments should use portions which are tailored to typical consumer intakes.

One note worth mentioning is that the sample used for this study was primarily female with an average, relatively 'healthy' BMI of 21.7 kg/m². Statistically, this study was not powered to determine any individual difference, such as how sex and BMI might affect either norm or choice boundary portion size. However, it is important to note that the somewhat homogenous sample might have influenced results. Indeed, previous research has suggested that females have greater understanding of nutrition than men (Kiefer, Rathmanner, & Kunze, 2005). One interesting area for future research would be to explore how individual differences affect the choice boundary portion size. For example, our sample had an average DEBQ-restraint score of 2.49 – according to Wardle (1986) the average DEBQ-restraint score for men in the UK is 1.9, while that for women in the UK is 2.7. It seems plausible, however, that highly restrained eaters may have different boundary portion sizes than unrestrained eaters. Specifically, highly restrained eaters are likely to have greater tolerance for smaller portion sizes than unrestrained eaters, resulting in both smaller norm and choice boundaries. Indeed, from a public health perspective, unrestrained eaters seem a more important target for portion-reduction strategies. In addition, previous research has found that men, those with a higher BMI, and those with lower dietary restraint, self-report larger portion-size norms (Lewis, Forwood, et al., 2015) – it would be interesting to explore whether these individual differences affect choice boundaries.

Furthermore, decisions made during the choice boundary task did not directly impact outcomes for the participant – no matter what answers they gave, they would receive the reimbursement of £10 and nothing else. By adding real-world consequences to participants' decisions, and therefore increasing their investment in the outcome, it may be possible to more accurately measure how a participant would respond to reductions in portions of foods they intend to consume. One method by which this could be conducted could be through the provision of the participants' favourite chocolate bar as a part of the compensation, with the portion size received being directly related to the responses they provide. Indeed, a future study could be conducted to compare results from a purely hypothetical exploration of choice boundaries, as was conducted here, with one which involves more real-world implications for the participants.

More generally, our methodology demonstrates a novel approach to quantifying individual norm and choice boundaries in portion size research. Indeed, while our approach requires refining, to our knowledge, this was the first study to demonstrate that choice boundaries can be measured alongside norm boundaries. Furthermore, to date, such individual analysis has seen limited use in this area, which tends to take a group-wise approach. Unfortunately, there are statistical limitations in such group-based approaches. For example, the previous method to derive norm boundaries used by Haynes, Hardman, Makin, et al. (2019) in Study 1 relied upon an arbitrary limit of $\geq 60\%$ of participants to choose the same portion size as a boundary for it to be identified as such. In Study 2 of the same paper, they modified this by calculating individual norm boundaries, though using the same limit of $\geq 60\%$, with boundaries selected as the smallest (lower boundary) or largest (upper boundary) portion size considered normal in $\geq 60\%$ of trials. By contrast, our psychophysical approach measures the point of subjective equality – that is, statistically, the perceptual boundary at which a portion is equally likely to be judged as normal or abnormal. With this approach we can also track differences in sub-groups based on age, location, socioeconomic status, and so on.

However, as with many novel approaches, we see areas for improvement. In particular, we had to exclude many data points when calculating choice boundaries. We suspect that in many cases this occurred because the reduction in portion size that participants were willing to accept was smaller than expected, and, for this reason, the step size in our stimuli was too large (20 kcal) to detect small changes of this kind. An obvious solution might be to decrease this step size; however, this is burdensome for participants because it dramatically increases the number of trials. Previously, researchers (Brunstrom & Shakeshaft, 2009) have addressed this problem by using an Adaptive Probit Estimation (APE) algorithm (Watt & Andrews, 1981). Rather than using a brute-force approach (all stimuli presented on multiple occasions), the algorithm uses a recursive approach in real time – during the test session, previous responses are used to calculate a probable portion size estimate, and this is then used to select stimuli that are likely to be most helpful in refining this estimate.

Finally, the research conducted within this experiment focussed on the effects of portion reduction on food choice, and therefore compared the choice boundary with the lower-norm boundary. In doing so, we discarded data related to the upper-norm boundary. While outside the scope of the research discussed here, participant behaviour around abnormally large portions, both eating and choice behaviour, is an area of scientific interest. For example, consumers who present with higher restrained eating scores might reject seemingly larger, more voluminous portions of food (*i.e.*, those deemed 'abnormally large') for acceptably smaller portions, resulting in an 'upper-choice boundary'.

In summary, previous work by Haynes, Hardman, Halford, et al. (2019), Haynes, Hardman, Makin, et al. (2019), Haynes et al. (2020), explored the role of norm boundary portion sizes on additional intake. These authors took a first step to investigate the potential impact of portion size reductions on aspects of eating behaviour, and our work extends and builds on this. We have introduced a novel methodology to

assess the effects of portion size reduction on food choice for the first time. Our research suggests that, when competitor products are available, a reduced-portion food is likely to be rejected in favour of a standard-portion competitor, even though the smaller portion is perceived to be normal. Moreover, our results indicate that there is a negative correlation between the choice boundary size and difference in desire to eat which, in turn, suggests that should two products be desired a similar amount, consumers will be less tolerant of portion size reductions. Moving forward, we see opportunities to refine the methodology (see above) and explore the reliability of this choice boundary (over weeks or months) and how it changes when a food is available in different formats (e.g., chocolate bars vs separate chocolate pieces).

Ethical statement

Ethical approval for this experiment was granted by the University of Bristol Faculty of Life Sciences Human Research Ethics Committee (ethical approval ID: 27061989707). All participants provided informed consent before taking part in the experiment as well as informed final consent after being debriefed.

Funding

This work was supported by a Biotechnology and Biological Sciences Research Council Doctoral Training Partnership with Mondelēz International Limited awarded to ROS (BB/S506850/1). The ideas relating to portion size breakpoints were developed in part during the preparation of a grant funded by BBSRC DRINC (BB/L02554X/1). JMB is supported by the NIHR Biomedical Research Centre at University Hospitals Bristol and Weston NHS Foundation Trust and the University of Bristol. The views expressed in this publication are those of the author and not necessarily those of the NHS, NIHR, or the Department of Health and Social Care.

Declaration of competing interest

Sonia Miguel and Aurelie Lesdema-Laurant are employed by Mondelēz International. Mondelēz International imposed no restrictions on the design, implementation, analysis, or interpretation of the data. All other co-authors declare no conflicts of interest.

Acknowledgements

We would like to thank Sophie Vinoy for her contributions to this project.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.appet.2021.105886>.

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