British Journal of Nutrition (2016), **116**, 935–943 doi:10.1017/S0007114516002750

British Journal of Nutrition

Test-meal palatability is associated with overconsumption but better represents preceding changes in appetite in non-obese males

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(Submitted 7 March 2016 – Final revision received 13 May 2016 – Accepted 23 June 2016 – First published online 1 August 2016)

Abstract

Single-course, *ad libitum* meals are recommended for the assessment of energy intake within appetite research. This study represents the first investigation of the comparative sensitivity of two single-course, *ad libitum* meals designed to differ in palatability. We conducted two experiments using a preload study design. All protocols were identical except for the energy content of the preloads (Expt 1: 579 and 1776 kJ; Expt 2: 828 and 4188 kJ). During each experiment, ten healthy men completed four experimental trials constituting a low- or high-energy preload beverage, a 60-min intermeal interval and consumption of a pasta-based or a porridge-based, *ad libitum* meal. Appetite ratings were measured throughout each trial, and palatability was assessed after food consumption. Preload manipulation did not influence appetite ($P=0.791$) or energy intake ($P=0.561$) in Expt 1. Palatability and energy intake were higher for the pasta meal than for the porridge meal in both experiments (palatability $P \leq 0.002$; energy intake $P \leq 0.001$). In Expt 2, consumption of the high-energy preload decreased appetite ($P=0.051$) and energy intake ($P=0.002$). Energy compensation was not significantly different between pasta and porridge meals ($P=0.172$), but was more strongly correlated with preceding changes in appetite at the pasta meal (r –0·758; $P=0.011$) than the porridge meal (r –0·498; $P=0.143$). The provision of a highly palatable, pasta-based meal produced energy intakes that were more representative of preceding appetite ratings, but the moderately palatable, porridge-based meal produced more ecologically valid energy intakes. *Ad libitum* meal selection and design may require a compromise between sensitivity and ecological validity.

Key words: Energy intake: Preloads: Energy compensation: Sensitivity

The increase in obesity prevalence during recent decades has stimulated an abundance of research into the regulation of appetite and energy balance in humans. This research frequently includes the objective measurement of energy intake during *ad libitum* meals in response to nutritional[1,2], pharmaceutical[3,4] and exercise interventions[5,6]. Such monitoring of energy intakes under laboratory conditions is recommended because of the dubious accuracy of self-reported measures[7,8], and a range of *ad libitum* meals have demonstrated high levels of repeatability in quantifying energy intakes[9–13]. However, despite the prevalent use of *ad libitum* feeding, there has been little investigation into the sensitivity of these meals to reflect changes in appetite, and only one study to date has compared the sensitivity of commonly used *ad libitum* meals. In this regard, Wiessing *et al.*[14] recently demonstrated a similar energy compensation of approximately 28 % in response to a high-energy *v.* low-energy preload when assessing energy intake via an *ad libitum* buffet meal and single-course, pasta-based meal. However, both meals promoted overconsumption with mean intakes >4500 kJ at each meal after the low-energy preload.

Single-course meals are recommended for the assessment of *ad libitum* energy intake because of concerns that buffet meals delay satiation and promote overconsumption, thereby not reflecting the habitual intakes of participants[7]. However, overconsumption during single-course, pasta-based meals is commonly reported in the literature, with mean intakes ranging from approximately 3200 to 6400 kJ in a range of participant populations[1,14–20]. Such large intakes are likely to be due to the high palatability of pasta-based *ad libitum* meals[14,21]. It has previously been demonstrated that increasing the palatability of *ad libitum* meals can enhance appetite during feeding, induce overconsumption and reduce the sensitivity of the meal to detect previous changes in appetite[22]. Subsequently, it seems plausible that overconsumption during pasta-based meals may contribute to the dissociations observed between appetite ratings and food intake responses in previous studies[1,15,18].

Recent studies by Corney *et al.*[23,24] have used an *ad libitum* porridge meal to assess energy intake and have reported mean intakes of approximately 2500 kJ after an overnight fast in healthy, young men. These intakes are substantially lower than those reported from pasta meals within similar populations[15–18], are more representative of expected habitual intakes (increasing external validity) and may produce greater sensitivity to previous changes in appetite by reducing overconsumption (enhancing precision). However, because of large individual differences in

Abbreviations: HE, high energy; LE, low energy.

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energy intake during *ad libitum* feeding combined with the subjectivity of appetite perceptions, direct comparisons within subjects are essential for appropriate assessment of appetite and energy intake responses to an intervention[7].

Thus, the purpose of this study was to compare the sensitivity of a pasta-based *v.* a porridge-based *ad libitum* meal for the assessment of energy intake. This represents the first comparison of two commonly used single-course, *ad libitum* meals and provides guidance on the selection of *ad libitum* meals for future research studies. We hypothesised that *ad libitum* energy intake at the porridge-based meal would be more ecologically valid and more representative of preceding appetite ratings than energy intake at the pasta-based meal.

Methods

Study design

This investigation included two experiments, which were conducted according to the guidelines laid down in the Declaration of Helsinki. Both experiments involved a preload study design to investigate the influence of *ad libitum* meal composition on the compensatory energy intake response to different energy preloads. The experimental protocols were identical, except for the energy content of the preloads. Expt 1 was conducted at the University of Bath and it compared the effects of a 579 and 1776 kJ preload. Expt 2 was conducted at Leeds Beckett University and it compared the effects of an 828 and 4188 kJ preload. The use of different preloads in each experiment enabled comparisons to be made regarding the effects of moderate and large differences in preload energy content. Each experiment was approved by the Institutional Ethics Advisory Committee for the university at which the experimental testing was performed, and written informed consent was obtained from all participants.

Participants and standardisation

Study participants were non-smokers, not taking any medication, weight stable for at least 6 months before participation and were not dieting. Participants had no known history of CVD/metabolic disease, were classified as unrestrained eaters[25] and were recreationally active.

In both experiments, participants completed a food diary detailing all foods and drinks consumed in the 24 h before their first experimental trial and repeated this before each subsequent trial. Alcohol, caffeine and strenuous physical activity were not permitted during this period. All trials commenced between 08.00 and 09.00 hours after an overnight fast of at least 10 h, and participants exerted themselves minimally when travelling to the laboratory, using motorised transport when possible. Verbal confirmation of dietary and exercise standardisation was obtained at the beginning of each experimental trial.

Experimental protocol

For each experiment, ten healthy men participated in four experimental trials separated by a minimum of 72 h in a randomised, semi-double blind (blinded to the preload composition but not the test meal), cross-over design. The four trials constituted a low-energy (LE) or high-energy (HE) preload, followed by an *ad libitum* test meal that was either pasta based or porridge based. Anthropometric measurements, screening for eating behaviours[25], habitual physical activity levels and verbal confirmation of the acceptability of the foods to be provided during the study were obtained immediately before the first experimental trial. Habitual consumption of pasta-based and porridge-based meals was assessed using an eight-point scale ranging from ‘almost never’ to ‘>2 meals/d’.

Upon arrival to the laboratory for each experimental trial, participants completed a baseline appetite visual analogue scale before consuming a low- or high-energy preload beverage. Participants were instructed to consume the beverage within 5 min, and a 60-min intermeal interval commenced upon the first mouthful of the beverage in accordance with Almiron-Roig *et al.*[26]. Participants rested within the laboratory (sitting, reading or listening to music) throughout the intermeal interval, and were provided with an *ad libitum* pasta-based or porridge-based meal at 60 min.

Preloads

The preload beverages were matched for macronutrient composition and were designed to closely align with the UK dietary guidelines for macronutrient proportions (58 % carbohydrate, 26 % fat, 16 % protein). The preloads consisted of water, single cream (Tesco), maltodextrin (MyProtein), whey protein isolate (MyProtein) and vanilla flavouring (MyProtein). These beverages were comparable with those used in previous studies[19]. The energy content of the preload beverages was 579 and 1776 kJ in Expt 1 and 828 and 4188 kJ in Expt 2. All preload beverages weighed 550 g and were distributed evenly between two 568-ml glasses in order to disguise any subtle differences in volume. All beverages were consumed by participants in isolation. The preloads were prepared by a third party external to the study, and both the researcher and participant were asked to identify which beverage they thought had been consumed at the end of each trial. All participants were fully unblinded upon completion of the experiment.

Appetite and palatability assessment

Appetite perceptions (hunger, satisfaction, fullness and prospective food consumption (PFC)) were assessed at baseline and every 15 min during both experiments using 100-mm visual analogue scales with descriptors anchored at each end describing the extremes (e.g. ‘I am not hungry at all’/‘I have never been more hungry’)[27]. Participants rated their appetite perceptions by placing a mark across each line on paper, and participants were not able to refer to their previous ratings when completing the appetite scales. The scales were analysed by measuring the horizontal distance from the left-hand side of the continuum to the point on the line indicated by the participant. Each visual analogue scale was measured twice to ensure accuracy. A composite appetite score was calculated for each time point as the mean value of the four appetite perceptions after inverting the values for satisfaction and fullness[28]. Palatability ratings (visual appeal, smell, taste, aftertaste and pleasantness) were obtained for the preloads and *ad libitum* meals immediately after consumption[27]. A composite palatability score was calculated as the mean value of the palatability subscales.

Ad libitum *meals*

The *ad libitum* meals were matched for macronutrient content and were designed to closely align with the UK dietary guidelines for macronutrient proportions (52 % carbohydrate, 34 % fat and 14 % protein). The meals were also matched for energy density (8·45 kJ/g). The pasta-based meal consisted of penne pasta (Tesco), Cheddar cheese (Tesco), tomato sauce (Tesco) and olive oil (Tesco) in accordance with previous research[15,16]. Pasta was cooked for 15 min in unsalted water at 700 W before being mixed with the remaining ingredients and re-heated for 2 min at 700 W. The porridge-based meal consisted of rolled oats (Tesco), whole milk (Tesco), double cream (Tesco), maltodextrin (MyProtein) and whey protein isolate (MyProtein). The oats were cooked in the microwave with milk and double cream for 2 min at 700 W before being mixed with the remaining ingredients.

Participants consumed the *ad libitum* meals in isolation in order to prevent any social influence affecting food intake. Participants were provided with a bowl of the respective meal, and this was replaced by an investigator before the participant had emptied it and with minimal interaction. Each portion of the porridge-based meal weighed 300 g, and each portion of the pasta-based meal weighed 430 g before consumption; three bowls of the respective meal were prepared for each trial in accordance with previous research[15], which met the requirements of all participants during the trials. No time limit was set for eating, and participants were instructed to eat until 'comfortably full'. Subsequently, participants determined the point of meal termination and were asked to leave the feeding area and to inform the researcher once they felt 'comfortably full'. Food intake was determined as the weighted difference in food before and after eating. Water was available *ad libitum* during the participants' first trial and standardised for each subsequent trial. Energy compensation was calculated using the following equation:

$$\text{Energy compensation (\%)} = ((\text{energy intake}_{\text{low energy preload}} - \text{energy intake}_{\text{high energy preload}}) / \text{energy difference between preloads}) \times 100.$$

Statistical analysis

Data for each experiment were analysed separately using IBM SPSS statistics version 19 for Windows. Total AUC values were calculated for appetite perceptions using the trapezoidal method. Repeated measures, two-way ANOVA (preload × meal) was used to assess differences in energy intake, composite palatability scores and AUC values for composite appetite scores between the trials. Pearson's product-moment correlation coefficient was used to examine the relationship between energy intake and preceding appetite ratings. This included correlations between the change in appetite scores and the percentage energy compensation in response to the high-energy preload compared with the low-energy preload in order to determine the utility of the test meals to reflect changes in appetite. Wilcoxon's signed-rank was used to assess differences between the habitual consumption of pasta-based and porridge-based meals. Statistical significance for this study was accepted at $P \leq 0{\cdot}05$. Participant characteristics and data in the text are presented as mean values and standard deviations. All other results are presented as mean values and 95 % CI. A sample size of ten participants was determined to be sufficient to detect an energy compensation of 40 % in Expt 1 and 15 % in Expt 2, based on previous data from Corney *et al.*[23]. This calculation was performed using G* power with an α value of 5 % and a power of 80 %[29]. Individual compensatory responses are plotted within the figures to allow further examination of the findings, and the results of each experiment are presented separately to ensure clarity.

Results

Expt 1

Participant characteristics. Participant characteristics were as follows: age 22 (SD 1) years, height 1·80 (SD 0·06) m, body mass 81·1 (SD 7·9) kg and BMI 24·8 (SD 1·6) kg/m^2. There was no significant difference in the habitual consumption of pasta-based and porridge-based meals ($P = 0{\cdot}917$) with the same median intake of 1 meal/week. Habitual consumption of pasta-based meals ranged from 'almost never consumed' to '5–6 meals/week', whereas habitual consumption of porridge-based meals ranged from 'almost never consumed' to '1 meal/d'.

Energy intake. Two-way ANOVA revealed higher *ad libitum* energy intake during the pasta meal compared with the porridge meal ($P < 0{\cdot}0005$) but no difference between the 579 and 1776 kJ preloads ($P = 0{\cdot}561$) (Fig. 1(a)). There was no significant difference in energy compensation between test meals ($P = 0{\cdot}922$) (Fig. 1(b)).

Appetite and palatability ratings. Two-way ANOVA demonstrated similar results for each appetite perception with no significant differences between preloads and test meals for hunger (preload: $P = 0{\cdot}694$; meal: $P = 0{\cdot}928$), satisfaction (preload: $P = 0{\cdot}420$; meal: $P = 0{\cdot}239$), fullness (preload: $P = 0{\cdot}338$; meal: $P = 0{\cdot}233$) or PFC (preload: $P = 0{\cdot}241$; meal: $P = 0{\cdot}862$). Subsequently, composite appetite scores are presented for clarity.

Composite appetite scores did not differ between trials at baseline ($P = 0{\cdot}421$). Two-way ANOVA revealed no significant difference in composite appetite AUC between the 579 and the 1776 kJ preload trials ($P = 0{\cdot}791$). Similarly, there was no difference in appetite scores between the pasta and the porridge trials ($P = 0{\cdot}523$; LE porridge 70 (SD 10), LE pasta 64 (SD 9), HE porridge 65 (SD 14), HE pasta 68 (SD 14)) (Fig. 2).

British Journal of Nutrition

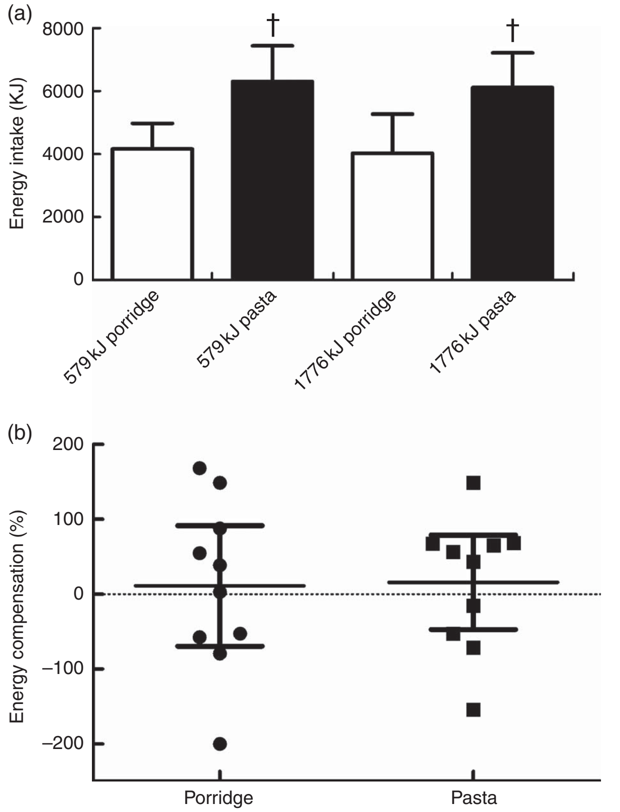

Fig. 1. Energy intake (a) and energy compensation (b) for Expt 1. † Significantly different between test meals. Values are means (n 10) and 95 % CI.

Two-way ANOVA demonstrated no significant differences in composite palatability scores for the high-energy preload compared with the low-energy preload ($P=0·136$). The palatability response to preloads was not different during the pasta and porridge trials ($P=0·218$). Composite palatability scores for the test meals were significantly higher for the pasta meal compared with the porridge meal ($P=0·001$). The palatability response to the test meals was not different during the high- and low-energy preload trials ($P=0·431$) (Fig. 3).

The preload beverage was correctly identified by participants in twenty-one of the forty trials and by the researcher in five of the forty trials.

Correlations. Composite appetite AUC values were not significantly correlated with energy intake in any of the four trials (all $r<0·438$; $P>0·205$). Energy compensation at the *ad libitum* meals was not significantly correlated with the change in AUC or 60-min composite appetite scores between the 579 and the 1776 kJ preloads (pasta AUC: r 0·077, $P=0·832$; pasta 60 min: r –0·497, $P=0·143$; porridge AUC: r –0·452, $P=0·190$; porridge 60 min: r –0·385, $P=0·272$) (Fig. 2).

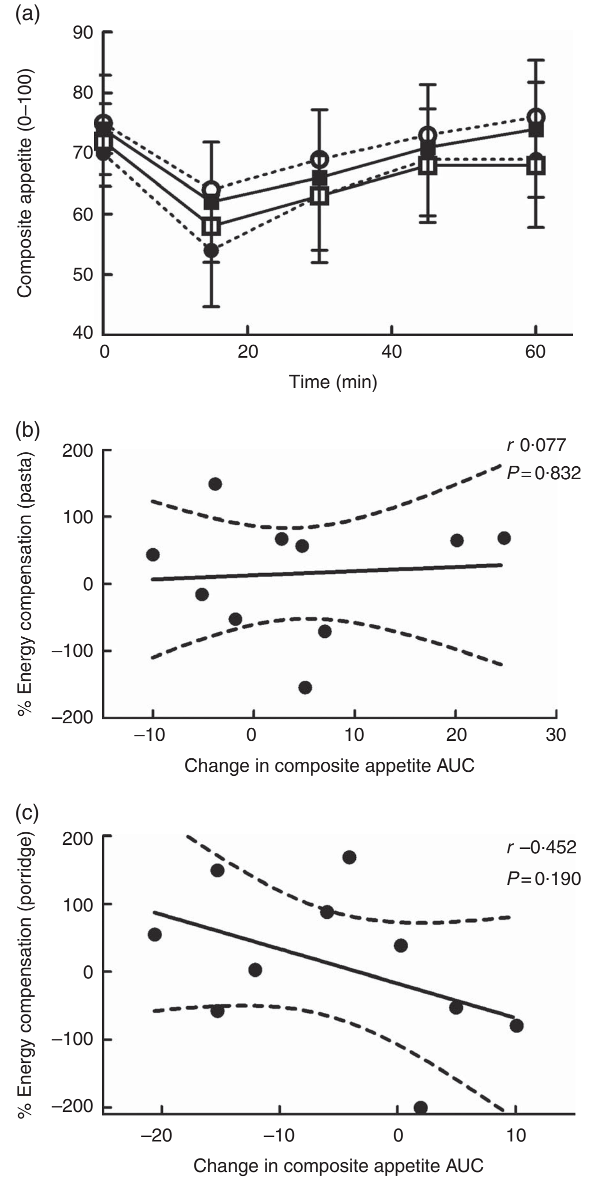

Fig. 2. Composite appetite scores (a) in the 579 kJ porridge (○), 579 kJ pasta (●), 1776 kJ porridge (□) and 1776 kJ pasta (■) trials for Expt 1. - - - - -, The low-energy preload trials. Values are means (n 10) and 95 % CI. Linear correlation with 95 % CI between the change in composite appetite AUC after the 1776 *v.* 579 kJ preload and energy compensation for the pasta meal (b) and porridge meal (c).

Expt 2

Participant characteristics. Participant characteristics were as follows: age 21 (SD 4) years, height 1·80 (SD 0·05) m, body mass 77·2 (SD 6·4) kg and BMI 24·2 (SD 2·3) kg/m^2. Habitual consumption of pasta-based meals was significantly higher than porridge-based meals ($P=0·014$) with median intakes of '2–4 meals/week' and '1 meal/week', respectively. Habitual consumption of pasta-based meals ranged from '1 meal/week' to '2–4 meals/week', whereas habitual consumption of porridge-based meals ranged from 'almost never consumed' to '2–4 meals/week'.

Energy intake. Two-way ANOVA demonstrated higher *ad libitum* energy intake after the 828 kJ preload compared

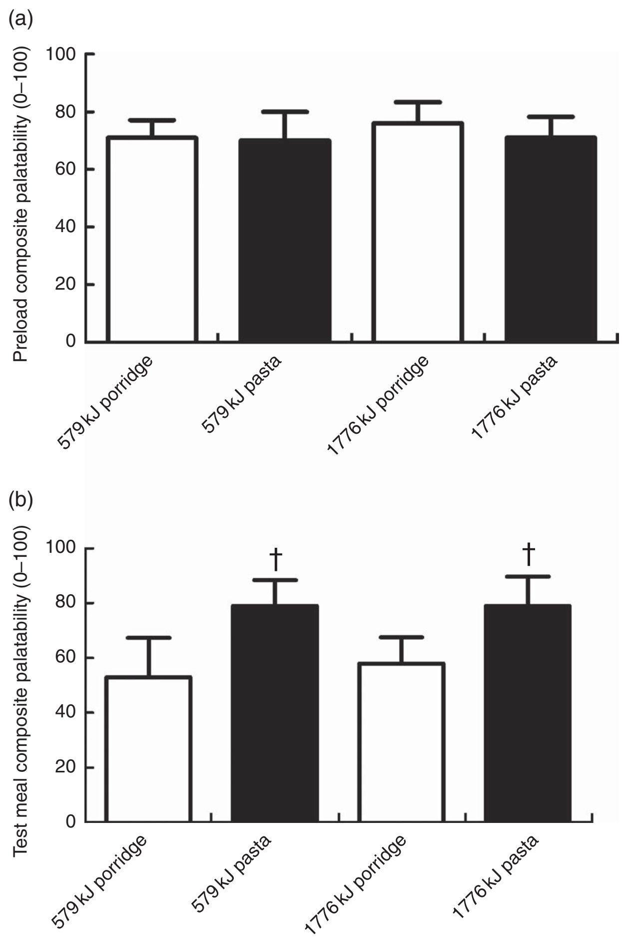

Fig. 3. Composite palatability scores for the preloads (a) and test meals (b) for Expt 1. † Significantly different between test meals. Values are means (*n* 10) and 95 % CI represented by vertical bars.

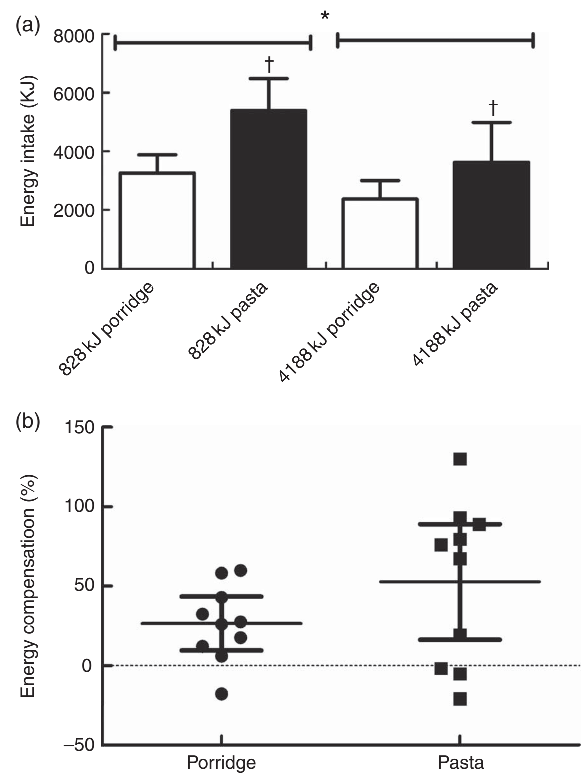

Fig. 4. Energy intake (a) and energy compensation (b) for Expt 2. * Significantly different between preloads, † significantly different between test meals. Values are means (*n* 10) and 95 % CI.

with the 4188 kJ preload ($P=0{\cdot}002$) and during the pasta meal compared with the porridge meal ($P=0{\cdot}001$) (Fig. 4(a)). However, there was no significant difference in energy compensation between test meals ($P=0{\cdot}172$) (Fig. 4(b)).

Appetite and palatability ratings. Two-way ANOVA demonstrated similar results for each appetite perception with higher hunger ($P=0{\cdot}066$), higher PFC ($P=0{\cdot}035$), lower fullness ($P=0{\cdot}062$) and lower satisfaction ($P=0{\cdot}077$) after consumption of the 828 kJ preload compared with the 4188 kJ preload. There were no significant differences for any of the appetite perceptions between the pasta and the porridge trials (hunger: $P=0{\cdot}531$; satisfaction: $P=0{\cdot}813$; fullness: $P=0{\cdot}654$; PFC: $P=0{\cdot}327$). Subsequently, composite appetite scores are presented for clarity.

Composite appetite scores did not differ between trials at baseline ($P=0{\cdot}642$). Two-way ANOVA revealed higher composite appetite AUC after consumption of the 828 kJ preload compared with the 4188 kJ preload ($P=0{\cdot}051$). Appetite AUC responses to the preloads did not differ between pasta and porridge trials ($P=0{\cdot}642$; LE porridge 69 (SD 9), LE pasta 66 (SD 13), HE porridge 57 (SD 18), HE pasta 58 (SD 20)) (Fig. 5).

Two-factor ANOVA demonstrated higher composite palatability scores for the 4188 kJ preload compared with the 828 kJ preload ($P=0{\cdot}001$). The palatability response to preloads was not different during the pasta and porridge trials ($P=0{\cdot}877$). Composite palatability scores for the test meals were significantly higher for the pasta meal compared with the porridge meal ($P=0{\cdot}002$). The palatability response to the test meals was not different during the low- and high-energy preload trials ($P=0{\cdot}888$) (Fig. 6).

The preload beverage was correctly identified by the participant in twenty-six of the forty trials and by the researcher in fifteen of the forty trials.

Correlations. Composite appetite AUC values were more strongly correlated with energy intake during the pasta trials than the porridge trials (LE porridge: r 0·165, $P=0{\cdot}649$; LE pasta: r 0·567, $P=0{\cdot}087$; HE porridge: r 0·565, $P=0{\cdot}089$; HE pasta: r 0·909, $P<0{\cdot}0005$). Energy compensation at the *ad libitum* meal was significantly correlated with the change in AUC and 60-min composite appetite scores between the 828 and the 4188 kJ preloads for the pasta meal (AUC: r −0·758, $P=0{\cdot}011$; 60 min: r −0·673, $P=0{\cdot}033$), demonstrating greater energy compensation in response to larger reductions in appetite. However, these correlations did not reach statistical significance

https://doi.org/10.1017/S0007114516002750 Published online by Cambridge University Press

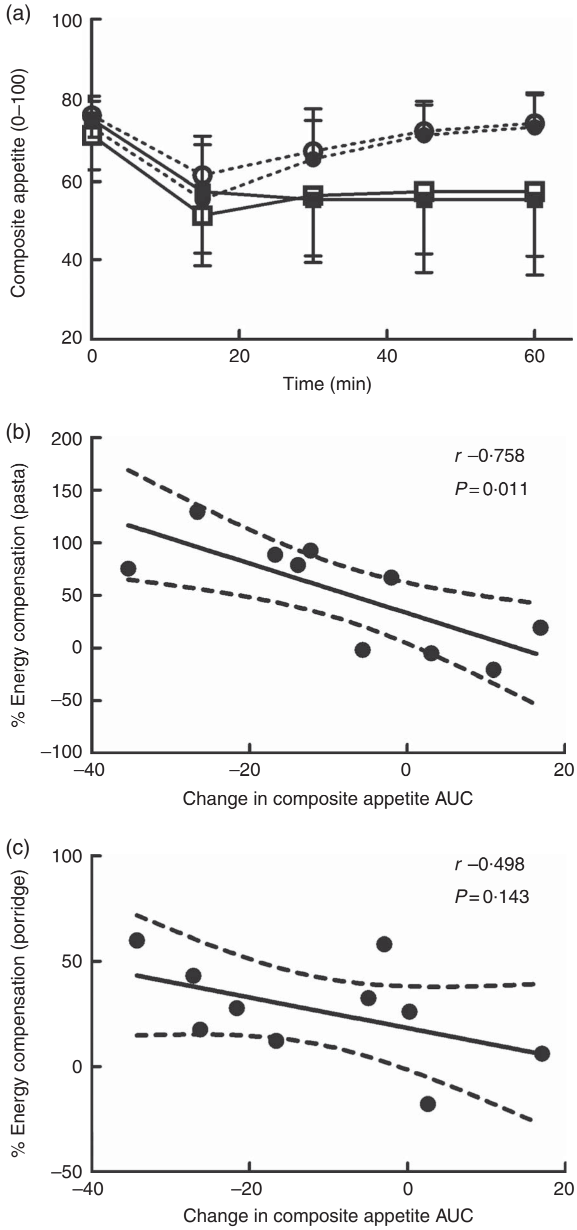

Fig. 5. Composite appetite scores (a) in the 828 kJ porridge (○), 828 kJ pasta (●), 4188 kJ porridge (□) and 4188 kJ pasta (■) trials for Expt 2. - - - - -, The low energy preload trials. Values are means (*n* 10) and 95 % CI. Linear correlation with 95 % CI between the change in composite appetite AUC after the 4188 *v.* 828 kJ preload and energy compensation for the pasta meal (b) and porridge meal (c).

for the porridge meal (AUC: *r* −0·498, *P*=0·143; 60 min: *r* −0·499; *P*=0·142) (Fig. 5).

Discussion

The use of *ad libitum* meals to quantify energy intake is a prominent methodology within appetite and energy balance research. This investigation represents the first comparison of the sensitivity of two commonly used single-course, *ad libitum* meals in response to appetite manipulation. These findings

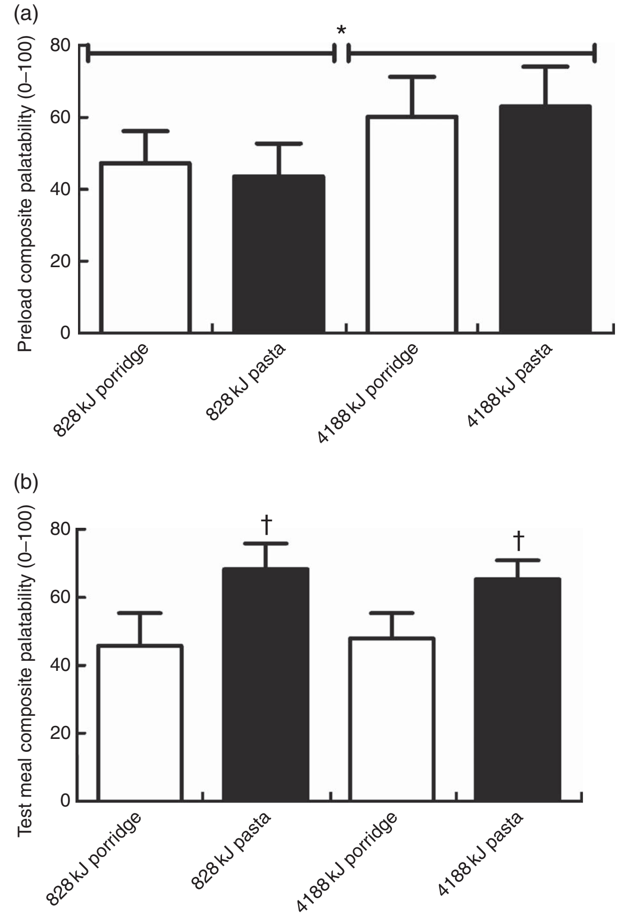

Fig. 6. Composite palatability scores for the preloads (a) and test meals (b) for Expt 2. * Significantly different between preloads, † significantly different between test meals. Values are means (*n* 10) and 95 % CI represented by vertical bars.

demonstrate that the provision of a moderately palatable porridge-based meal reduces overconsumption in comparison with a more highly palatable, pasta-based meal. However, energy compensation at the pasta meal was more strongly correlated with preceding appetite ratings, demonstrating greater sensitivity to appetite manipulation.

The incorporation of two experiments within this report enabled the sensitivity of the test meals to be investigated in response to a moderate and large manipulation of preload energy content. Surprisingly, the 1197 kJ difference in energy content between preloads in Expt 1 did not produce any discernible changes in appetite or energy intake. This finding contrasts with previous studies that have reported reductions in appetite and an energy intake compensation of 30–57 % in response to preload energy manipulations of approximately 1500 kJ[19,30]. The participants recruited for the present experiment were all young, healthy, recreationally active men, and an intermeal interval of 60 min was used based on evidence that this population and experimental design will maximise the compensatory response to preload manipulation[19,26,31,32]. Subsequently, it is not clear why the preload manipulation failed to alter appetite responses, but this may be related to the composition of the preload beverages. In this regard, although similar preload beverages have been found to influence appetite and energy intake through the manipulation of maltodextrin content[19,33], the increases in preload energy during the present study were primarily achieved via the addition of maltodextrin *and* single cream. Such sugar–fat combinations are frequently used in laboratory models to promote hyperphagia[34], and any appetite-stimulating properties of the higher energy preload may have compensated for the appetite-suppressing effects of the moderately increased energy content. This finding supports long-standing concerns regarding the weak satiating effects of high sugar- and fat dairy-based beverages and their likely contribution to a positive energy balance[35].

The increased manipulation of preload energy content in Expt 2 successfully generated divergent appetite and energy intake responses between the high- and low-energy preloads. Compensatory reductions in energy intake during both *ad libitum* meals after consumption of the high-energy preload in Expt 2 and the absence of change in energy intake during both meals in Expt 1 support the use of these meals to reflect preceding appetite ratings. However, the findings of the present study reveal important strengths and limitations for the use of these meals in future appetite studies.

In accordance with previous research, the pasta-based, *ad libitum* meal induced significant overconsumption in both experiments[1,14–20], which conflicts with current recommendations for *ad libitum* meals to reflect habitual energy intakes[7]. In this regard, energy intakes during the pasta meals were more than 50 % higher than the respective porridge meals and occurred despite the meals being matched for energy density. This difference appears to be due to the highly palatable nature of the pasta-based meal and is supported by previous studies demonstrating that highly palatable foods can stimulate appetite during *ad libitum* feeding, thereby overriding signals of satiation and increasing energy intakes[22,36]. The moderately palatable porridge meal produced energy intakes that were more representative of expected habitual intakes, which demonstrated the importance of considering and reporting the palatability ratings of *ad libitum* meals within research studies. In addition, such large differences in intakes occurred despite participants having higher habitual intakes of pasta-based meals, which would be expected to improve the environmental contingencies associated with this food and reduce intakes to more ecological levels. This further emphasises the importance of palatability as a determinant of energy intake during *ad libitum* feeding.

Although large inter-individual variation in short-term energy compensation has been previously documented[19,30,37], the findings of the present study suggest that this may be accentuated by the provision of a highly palatable *ad libitum* meal in response to appetite manipulation. In this regard, higher energy intakes during the pasta meal were associated with markedly greater heterogeneity in the compensatory response to preload manipulation in Expt 2. It seems likely that the higher energy intakes of the pasta meal provided opportunity for greater compensatory responses (i.e. larger changes in energy intake) to the observed decrease in appetite perceptions. Alternatively, the modest energy intakes observed during the porridge meal after consumption of the low-energy preload appear to have limited the potential range available for reductions in energy intake in response to the large manipulation of preload energy content in Expt 2 and produced a more homogenous response. In this regard, although participant blinding was unsuccessful, the participants were unaware of the energy content of the preloads, which maintained the impact of environmental contingencies on food intake and encouraged consumption during both meals[38]. Such unsuccessful blinding is an expected consequence of the experimental manipulation as the preload beverages were designed to produce contrasting appetite responses. Although subtle differences in preload appearance may have contributed to the observed appetite responses[39], the successful blinding of experimenters presenting the beverages suggests that post-ingestive consequences from preload consumption may have dominated.

Despite overconsumption and high levels of heterogeneity in compensatory energy intake responses, energy compensation during the pasta-based meal was strongly correlated with appetite changes in response to the high-energy *v.* low-energy preload (i.e. larger reductions in appetite were associated with greater energy compensation). Furthermore, this was superior to the correlations observed between changes in appetite and the more ecologically valid energy intakes achieved during the porridge meal. These findings suggest that the increased range available for compensatory feeding responses as a result of the overconsumption of a highly palatable meal may enhance the sensitivity to reflect preceding appetite ratings and improve alignment between these variables. Subsequently, despite current recommendations for *ad libitum* meals to reflect habitual energy intakes[7], the present study provides evidence that this may limit the sensitivity of the meal to reflect preceding changes in appetite. However, it must be acknowledged that mean energy compensation was not different between the test meals, which suggests that both meals are sufficiently sensitive to detect compensatory responses to appetite manipulation.

In conclusion, the experiments conducted within this investigation have demonstrated compensatory changes in energy intake in response to appetite manipulation when assessed using either a pasta-based or a porridge-based, *ad libitum* meal. The provision of a highly palatable, pasta-based meal induced significant overconsumption, but changes in energy intake were strongly correlated with preceding appetite ratings. Alternatively, the ecologically valid energy intakes achieved with the provision of a moderately palatable, porridge-based meal were less representative of changes in appetite perceptions. These findings support continuation in the use of a commonly used, pasta-based, *ad libitum* meal when the priority is to reflect preceding appetite ratings, and suggest that the large energy intakes observed during such feedings are unlikely to reduce the sensitivity of the measure to reflect preceding changes in appetite. Alternatively, it seems that meals producing moderate energy intakes during *ad libitum* feeding may limit the range of potential compensatory responses but could be suitable when energy intakes reflective of habitual diet are preferable. Subsequently, future *ad libitum* meal designs may require a compromise between sensitivity and ecological validity.

Acknowledgements

The authors thank all the volunteers for their participation in this study.

Data collection at Leeds Beckett University was supported internally by the Carnegie Research Fund. This research received no specific grant from any external funding agency or from commercial or not-for-profit sectors.

All authors contributed to the study design, data collection, data analysis and writing of the manuscript.

The authors declare that there are no conflicts of interest.

References

1. Chowdhury EA, Richardson JD, Tsintzas K, *et al.* (2016) Effect of extended morning fasting upon *ad libitum* lunch intake and associated metabolic and hormonal responses in obese adults. *Int J Obes* **40**, 305–311.
2. Sun FH, Li C, Zhang YJ, *et al.* (2016) Effect of glycemic index of breakfast on energy intake at subsequent meal among healthy people: a meta-analysis. *Nutrients* **8**, E37.
3. Batterham RL, Cowley MA, Small CJ, *et al.* (2002) Gut hormone PYY(3-36) physiologically inhibits food intake. *Nature* **418**, 650–654.
4. Lippl F, Erdmann J, Steiger A, *et al.* (2012) Low-dose ghrelin infusion – evidence against a hormonal role in food intake. *Regul Pept* **174**, 26–31.
5. Deighton K & Stensel DJ (2014) Creating an acute energy deficit without stimulating compensatory increases in appetite: is there an optimal exercise protocol? *Proc Nutr Soc* **73**, 352–358.
6. Schubert MM, Desbrow B, Sabapathy S, *et al.* (2013) Acute exercise and subsequent energy intake: a meta-analysis. *Appetite* **63**, 92–104.
7. Blundell J, de Graaf C, Hulshof T, *et al.* (2010) Appetite control: methodological aspects of the evaluation of foods. *Obes Rev* **11**, 251–270.
8. Dhurandhar NV, Schoeller D, Brown AW, *et al.* (2015) Energy balance measurement: when something is not better than nothing. *Int J Obes* **39**, 1109–1113.
9. Arvaniti K, Richard D & Tremblay A (2000) Reproducibility of energy and macronutrient intake and related substrate oxidation rates in a buffet-type meal. *Br J Nutr* **83**, 489–495.
10. Gregersen NT, Flint A, Bitz C, *et al.* (2008) Reproducibility and power of *ad libitum* energy intake assessed by repeated single meals. *Am J Clin Nutr* **87**, 1277–1281.
11. Horner KM, Byrne NM & King NA (2014) Reproducibility of subjective appetite ratings and *ad libitum* test meal energy intake in overweight and obese males. *Appetite* **81**, 116–122.
12. Lara J, Taylor MA & Macdonald IA (2010) Is *ad libitum* energy intake in overweight subjects reproducible in laboratory studies using the preload paradigm? *Eur J Clin Nutr* **64**, 1028–1031.
13. Tucker AJ, Heap S, Ingram J, *et al.* (2016) Postprandial appetite ratings are reproducible and moderately related to total day energy intakes, but not *ad libitum* lunch energy intakes, in healthy young women. *Appetite* **99**, 97–104.
14. Wiessing KR, Xin L, McGill AT, *et al.* (2012) Sensitivity of *ad libitum* meals to detect changes in hunger: restricted-item or multi-item testmeals in the design of preload appetite studies. *Appetite* **58**, 1076–1082.
15. Gonzalez JT, Veasey RC, Rumbold PL, *et al.* (2013) Breakfast and exercise contingently affect postprandial metabolism and energy balance in physically active males. *Br J Nutr* **110**, 721–732.
16. Clayton DJ, Stensel DJ, Watson P, *et al.* (2014) The effect of post-exercise drink macronutrient content on appetite and energy intake. *Appetite* **82**, 173–179.
17. Deighton K, Karra E, Batterham RL, *et al.* (2013) Appetite, energy intake, and PYY3-36 responses to energy-matched continuous exercise and submaximal high-intensity exercise. *Appl Physiol Nutr Metab* **38**, 947–952.
18. Deighton K, Batterham RL & Stensel DJ (2014) Appetite and gut peptide responses to exercise and calorie restriction: the effect of modest energy deficits. *Appetite* **81**, 52–59.
19. Appleton KM, Martins C & Morgan LM (2011) Age and experience predict accurate short-term energy compensation in adults. *Appetite* **56**, 602–606.
20. Chowdhury EA, Richardson JD, Tsintzas K, *et al.* (2015) Carbohydrate-rich breakfast attenuates glycaemic, insulinaemic and ghrelin response to *ad libitum* lunch relative to morning fasting in lean adults. *Br J Nutr* **114**, 98–107.
21. Roe LS, Kling SM & Rolls BJ (2016) What is eaten when all of the foods at a meal are served in large portions? *Appetite* **99**, 1–9.
22. Yeomans MR, Lee MD, Gray RW, *et al.* (2001) Effects of test-meal palatability on compensatory eating following disguised fat and carbohydrate preloads. *Int J Obes Relat Metab Disord* **25**, 1215–1224.
23. Corney RA, Sunderland C & James LJ (2016) Immediate pre-meal water ingestion decreases voluntary food intake in lean young males. *Eur J Nutr* **55**, 815–819.
24. Corney RA, Horina A, Sunderland C, *et al.* (2015) Effect of hydration status and fluid availability on *ad-libitum* energy intake of a semi-solid breakfast. *Appetite* **91**, 399–404.
25. de Lauzon B, Romon M, Deschamps V, *et al.* (2004) The three-factor eating questionnaire-R18 is able to distinguish among different eating patterns in a general population. *J Nutr* **134**, 2372–2380.
26. Almiron-Roig E, Palla L, Guest K, *et al.* (2013) Factors that determine energy compensation: a systematic review of preload studies. *Nutr Rev* **71**, 458–473.
27. Flint A, Raben A, Blundell JE, *et al.* (2000) Reproducibility, power and validity of visual analogue scales in assessment of appetite sensations in single test meal studies. *Int J Obes Relat Metab Disord* **24**, 38–48.
28. Stubbs RJ, Hughes DA, Johnstone AM, *et al.* (2000) The use of visual analogue scales to assess motivation to eat in human subjects: a review of their reliability and validity with an evaluation of new hand-held computerized systems for temporal tracking of appetite ratings. *Br J Nutr* **84**, 405–415.
29. Faul F, Erdfelder E, Lang AG, *et al.* (2007) G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* **39**, 175–191.
30. Soenen S & Westerterp-Plantenga MS (2007) No differences in satiety or energy intake after high-fructose corn syrup, sucrose, or milk preloads. *Am J Clin Nutr* **86**, 1586–1594.
31. Davy BM, Van Walleghen EL & Orr JS (2007) Sex differences in acute energy intake regulation. *Appetite* **49**, 141–147.
32. Martins C, Kulseng B, Rehfeld JF, *et al.* (2013) Effect of chronic exercise on appetite control in overweight and obese individuals. *Med Sci Sports Exerc* **45**, 805–812.
33. Long SJ, Hart K & Morgan LM (2002) The ability of habitual exercise to influence appetite and food intake in response to high- and low-energy preloads in man. *Br J Nutr* **87**, 517–523.

British Journal of Nutrition

34. Avena NM, Rada P & Hoebel BG (2009) Sugar and fat bingeing have notable differences in addictive-like behavior. *J Nutr* **139**, 623–628.
35. de Graaf C (2006) Effects of snacks on energy intake: an evolutionary perspective. *Appetite* **47**, 18–23.
36. Robinson TM, Gray RW, Yeomans MR, *et al.* (2005) Test-meal palatability alters the effects of intragastric fat but not carbohydrate preloads on intake and rated appetite in healthy volunteers. *Physiol Behav* **84**, 193–203.
37. Anderson GH, Catherine NL, Woodend DM, *et al.* (2002) Inverse association between the effect of carbohydrates on blood glucose and subsequent short-term food intake in young men. *Am J Clin Nutr* **76**, 1023–1030.
38. Blundell JE & King NA (1999) Physical activity and regulation of food intake: current evidence. *Med Sci Sports Exerc* **31**, S573–S583.
39. Chambers L, McCrickerd K & Yeomans MR (2015) Optimising foods for satiety. *Trends Food Sci Tech* **41**, 149–160.

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