Planned aerobic exercise increases energy intake at the preceding meal

Planned aerobic exercise increases energy intake at the preceding meal

Asya Barutcu[1], Shelley Taylor[1], Chris J. McLeod[1], Gemma L. Witcomb[1] and Lewis J. James[1]

[1]School of Sport, Exercise and Health Sciences, Loughborough University, Leicestershire, UK, LE11 3TU.

Corresponding author

Lewis J. James

L.James@lboro.ac.uk

School of Sport, Exercise and Health Sciences

Loughborough University

Abstract

Purpose: Effects of exercise on subsequent energy intake are well documented, but whether pre-exercise energy intake is affected by future planned exercise is unknown. This study investigated the effect of planned late-afternoon exercise on appetite and energy intake before (breakfast and lunch) and after (evening meal/snacks) exercise. **Methods:** Twenty healthy, active participants (10 male; age 23 ± 5 y, BMI 23.7 ± 3.2 kg/m^2, VO_2peak 44.1 ± 5.4 ml/kg/min) completed randomised, counterbalanced exercise (EX) and resting (REST) trials. After trial notification, participants were provided ad libitum breakfast (0800 h) and lunch (1200 h) in the laboratory, before completing 1-h exercise (30 min cycling, 30 min running) at 75-80% maximal HR (EX; 2661 ± 783 kJ) or 1-h supine rest (REST; 310 ± 58 kJ) 3-h post-lunch. Participants were provided a food pack (pasta meal/snacks) for consumption post-exercise (outside laboratory). Appetite was measured regularly and meal and 24-hour energy intake quantified. **Results:** *Ad-libitum* energy intake was greater during EX at lunch (EX 3450 ± 1049 kJ; REST 3103 ± 927 kJ; *P*=0.004), but similar between trials at breakfast (EX 2656 ± 1291 kJ; REST 2484 ± 1156 kJ; *P*=0.648) and dinner (EX 6249 ± 2216 kJ; REST 6240 ± 2585 kJ; *P*=0.784). Total 24-hour energy intake was similar between trials (*P*=0.388), meaning relative energy intake (24-h energy intake minus EX/REST energy expenditure), was reduced during EX (EX 9694 ± 3313 kJ; REST 11517 ± 4023 kJ; *P*=0.004). **Conclusion:** Energy intake appears to be increased in anticipation of, rather than in response to, aerobic exercise, but the increase was insufficient to compensate for energy expened during exercise, meaning aerobic exercise reduced energy balance relative to rest.

Key words: Appetite; energy intake; eating behavior; weight loss; exercise

Introduction

Obesity remains a major public health concern responsible for many deaths each year, with the prevalence of overweight and obesity continuing to rise both in the UK (1) and globally (2). Overweight and obesity develop due to an accumulation of body fat caused by a long-term positive energy balance (i.e. energy intake greater than energy expenditure; 3). Whilst conceptually simple, the mechanisms responsible for regulating energy balance are complex, making treatment of overweight/obesity extremely difficult (4). Whilst there is a clear need to identify strategies that help to facilitate weight loss, increases in overweight/obesity prevalence must, at least partially, be caused by previously lean individuals gaining weight (5). Therefore, whilst most research tends to focus on weight loss (i.e. treatment), far more research is warranted on how to maintain weight in lean individuals (i.e. prevention). Therefore, it is of interest to better understand the mechanisms by which energy balance is regulated, and affected by exercise, in lean individuals.

To effectively attenuate energy balance, strategies that decrease energy intake and/or increase energy expenditure, without compensatory alterations in the other components of energy balance are warranted. Regular exercise, which increases energy expenditure, has been identified as one such strategy that may assist in the battle against obesity (4). Aerobic exercise causes effects on gut-derived endocrine mediators of appetite/energy intake, producing reductions in the orexigenic hormone ghrelin and increases in the anorexigenic hormone peptide tyrosine tyrosine (PYY; 6,7). Presumably due to alterations in these homeostatic regulators of appetite, previous studies documenting the acute effects of exercise on appetite and energy intake have typically examined energy intake in response to, rather than in anticipation of, exercise. A meta-analysis of this now substantial body of evidence concluded that acute exercise training does not alter energy intake in the hours after exercise compared to a resting control condition (8). Consequently, relative energy intake (energy consumed minus energy expended through exercise/rest) is reduced, and an acute energy deficit is created (9). Whilst chronic aerobic exercise training facilitates weight loss, studies do not report the expected reduction in body mass/fat predicted from the acute responses (10–13). What accounts for this less than anticipated weight loss has not been elucidated, but compensatory increases in hunger and energy intake (13,14), and/or decreases in non-exercise physical activity (15) have been postulated. However, resting metabolic rate (13,16,17) and non-exercise physical activity energy expenditure appear to be unaffected by aerobic exercise training (13,18). Therefore, it seems likely that compensatory increases in energy intake are more likely to explain the less than expected weight loss observed with long-term aerobic exercise training (11,13,18). Indeed, a recent study (13) reported that 12 weeks aerobic exercise training (5 x 500 kcal exercise per week) produced a less than anticipated decrease in body mass/fat, which was accompanied by an increase in *ad-libitum* energy intake, but no change in resting metabolic rate or non-exercise physical activity.

Energy intake is regulated by a host of homeostatic and non-homeostatic mechanisms that ultimately drive behaviour (19). Whilst exercise induces acute changes in the endocrine regulators of appetite, these changes do not appear to manifest in differences in subsequent energy intake. Given exercise sessions are rarely spontaneous, there will usually be ample time for an exerciser to alter their energy/nutrient intake in anticipation of exercise. Energy/nutrient intake before exercise is commonly reported to increase exercise capabilities and thus exercisers may, over time, upregulate energy intake in the pre-exercise period to effectively prepare for the exercise session. Indeed, one recent study (20) reported that inactive overweight males who were restrained eaters chose more snack foods when they were served before exercise compared to a no exercise control trial. However, the extent to which these effects are apparent over longer periods of time, or at complete meals in proximity to exercise, is currently unknown.

Therefore, this study aimed to investigate the effect of a planned late afternoon exercise session on appetite and energy intake both before (at breakfast and lunch) and after (evening meal/snacks) exercise and to compare these responses to an identical resting control trial. It was hypothesised that energy intake at breakfast and lunch, but not in the evening after exercise, would be greater for exercise compared to rest.

Methods

Participants

Participants were twenty healthy, non-smoking, weight stable (self-reported), habitually active (<10 hours per week) males (n=10; age 23 ± 6 years; BMI 23.9 ± 3.3 kg/m^2; body fat 16.3 ± 4.2 %; VO_2max 47.7 ± 4.0 $ml/kg/min^{-1}$) and females (n=10; age 24 ± 4 years; BMI 23.5 ± 3.2 kg/m^2; body fat 28.6 ± 6.3 %; VO_2max 40.6 ± 4.3 $ml/kg/min^{-1}$). participants provided written consent before taking part in the study. Ethical approval was obtained from the Loughborough University Ethics Approvals (Human Participants) Sub Committee (reference number: R17-P024). Participants were not taking any medications known to affect appetite, and they were also not restricted, disinhibited, or hungry eaters, as determined by the Three-Factor Eating Questionnaire (21). Each participant completed two preliminary trials and two experimental trials in a randomised counterbalanced order and separated by 4-14 days. All females were using the combined oral contraceptive pill, with all trials taking place after at least 3 days of continuous contraceptive pill use. In the absence of any data to inform the size of the anticipated effect, the sample size used was in line with previous studies in this area using a similar cross-over design.

Pre-trial standardisation

In the 24 h preceding the first experimental trial, participants recorded their dietary intake and habitual physical activity. These diet and activity patterns were then replicated prior to the second experimental trial. Strenuous exercise and alcohol intake were not permitted during this 24 h pre-trial period and adherence to all pre-trial requirements were verbally checked before trials.

Preliminary trials

During the first preliminary trial, height (to nearest 0.1 cm; SECA stadiometer, Germany) and body mass (to nearest 0.01 kg; Adam Equipment, CFM-150 scales, UK) were measured, whilst body composition was estimated using skinfold thickness (Harpenden, UK) at four sites (biceps, triceps, sub-scapula, supra-iliac; 22). Participants then completed questionnaires to assess health status and eating patterns, before performing two submaximal exercise tests; one on a cycle ergometer (Lode Corival, Groningen, Holland) and one on a treadmill (h/p/cosmos sports & medical gmbh, Germany). These submaximal tests involved four incremental 4-min stages on both a cycle ergometer (at workloads between 80-280 W) and treadmill (at speeds between 6-13 km/h), with the specific intensities used dependent on each participant's fitness. Heart rate (Polar M400, Kempele, Finland) and rating of perceived exertion (RPE; 23) were recorded at the end of each 4-min stage.

After a short break, participants completed a maximal incremental exercise test on the treadmill to determine their peak oxygen uptake (VO_2peak). Exercise started at a gradient of 1% and at a speed estimated to elicit a heart rate of ~160 beats/min, with the gradient increasing by 1% every min until volitional exhaustion. Expired gas was collected during the final min of the maximal incremental exercise test, with heart rate and RPE recorded at the end of each 1-min increment. During the second preliminary trial, participants arrived at the laboratory at 0800 h in a fasted state and completed visual analogue scales to assess subjective appetite, consisting of ratings of hunger, fullness, desire to eat (DTE) and prospective food consumption (PFC). After 25 min supine rest, a 5-min expired gas sample was collected into a Douglas Bag to determine resting energy expenditure. Participants were then familiarized with experimental procedures by replicating procedures described below for the exercise trial, including appetite questionnaires, *ad-libitum* breakfast and lunch meals, the exercise session and the *ad-libitum* evening food intake.

Experimental trials

Participants completed two experimental trials; exercise (EX) and rest (REST) in a randomised counter-balanced order and separated by at least 4 days. Participants arrived at the laboratory at 0800 h in a fasted state and baseline measures of subjective appetite and post-void body mass in light clothing were made (0800 h). Participants were then informed if they were on the EX or REST trial that day, before subjective appetite was again measured 15 min later (0815 h). Participants were then given 30 min to consume breakfast, which consisted of a multi-item cold-food buffet, with subjective appetite measured again post-breakfast (0845 h). Before eating breakfast, participants were provided the following standard instructions *"You have 30 min to eat your breakfast. Remember that you are on the exercise/rest trial today, so please choose your food items accordingly. You are welcome to eat whatever and how much you want from the selection. If you want more of anything, please let us know and we will put out more food."* Participants left the laboratory after breakfast and continued with their daily activities (restricted to low-intensity activities), returning for lunch at 1200 h, which again consisted of a multi-item cold-food buffet for a period of 30 min. Before lunch, participants were given the same trial-specific instructions as before breakfast. Subjective appetite was measured before (1200 h) and after (1230 h) lunch. Participants then rested quietly in the laboratory for the next 3 h, with subjective appetite measured every hour (1330 h, 1430 h, 1530 h), before they completed the exercise/rest session. In the EX trial, exercise consisted of 30 min of steady state cycling at 75% heart rate-max, followed by 30 min of steady state running at 80% heart rate-max. Heart rate and RPE were recorded every 5 min throughout exercise. Expired gas samples were collected between 14-15 min and 29-30 min during cycling and running. In the REST trial, participants completed the equivalent duration of supine rest, with expired gas samples collected between 25-30 min and 55-60 min. Subjective appetite was measured at 30 min (1600 h) and upon completion (1630 h) of the exercise/rest period. Participants were then provided a food pack (main meal and snack options) to eat from over the evening and were free to leave the laboratory. Participants were also given appetite questionnaires to complete at certain times outside the laboratory (pre-evening meal, post-evening meal, before bed, morning).

Study Foods

Participants were only permitted to eat foods provided to them during experimental trials but were free to drink water *ad-libitum* throughout trials (including during the exercise/rest periods). For all meals, food was provided in excess of expected consumption. For breakfast and lunch meals only, additional food was available on request. Foods provided at breakfast, lunch and evening are presented in Table 1. For breakfast and lunch meals, foods were presented in a research kitchen, where participants were able to serve and/or make food items, before moving to a separate dining room to eat. For these meals, participants ate in isolation and there was no interaction between researcher and participants, with participants free to select foods they wanted. For the evening food pack, participants were provided with a main meal (cheese and tomato pasta), along with a standard bowl, and a variety of snacks. Participants were instructed to bring back any leftover items (including wrapping and fruit skins) for accurate measurements of energy intake and told that they were free to keep any food items after the food pack was re-measured. The pasta meal was prepared on the day of the experimental trial using standard cooking and cooling procedures and was given to participants cold. The cheese and tomato pasta provided 6.63 (± 0.03 SD) $kJ \cdot g^{-1}$ (with 14%, 60%, 25% and 1% of the energy provided by protein, carbohydrate, fat and fibre, respectively).

Participants completed questionnaires related to liking of study foods to ensure the available foods were adequately palatable. For each meal, food consumed was quantified by weighing foods before and after consumption and taking into account any leftovers. Energy and macronutrient content of foods was ascertained from manufacturer values. Upon arrival for lunch, participants verbally confirmed that they had not eaten/drunk anything except water since breakfast and upon returning uneaten evening food, that they had only eaten food items from the food pack

Subjective Appetite Sensations

Using paper and pen scales, participants rated their feelings of hunger 'How hungry do you feel?', fullness 'How full do you feel?', desire to eat (DTE) 'How strong is your desire to eat?', and prospective food consumption (PFC) 'How much food do you think you could eat?' on 100 mm visual analogue scales throughout the day. Verbal anchors of "not at all/none at all/no desire at all" and "extremely/a lot" were placed at 0 and 100 mm, respectively.

Statistical Analysis

Data were analysed using SPSS 23.0 (SPSS Inc., Somers, NY, USA). All data were checked for normality of distribution using a Shapiro-Wilk test. Sex differences were initially explored through two-way (sex*trial) or three-way (sex*trial*time) repeated measures ANOVA. Where interaction effects were observed (energy expenditure during the 1 h exercise/rest and fullness), data were analysed with sexes separated and combined. All other data were analysed for both sexes combined. Significant interaction effects were followed by Bonferroni-adjusted paired t-tests or Bonferroni-adjusted Wilcoxon signed-rank tests, as appropriate. Data containing one factor were analysed using a t-test or Wilcoxon signed-rank test, as appropriate. Data sets were determined to be significantly different when $P < 0.05$. Data are presented as mean ± standard deviation throughout, unless otherwise stated.

Results

Pre-trial measures

There were no differences between trials for pre-trial body mass (t = -1.243; $P = 0.229$), or subjective appetite sensations of hunger (Z = -0.318; $P = 0.763$), fullness (Z = -0.201; $P = 0.852$), DTE (Z = -0.486; $P = 0.641$) and PFC (Z = -1.007; $P = 0.327$).

Energy and Macronutrient Intake

Energy intake at the different eating occasions and over the 24 h is presented in Table 2. Energy intake at breakfast (Z = -0.485; $P = 0.648$) and during the evening (Z = -0.299; $P = 0.784$) were similar between trials, but lunch energy intake was increased by ~11% in EX compared to REST (t = 3.324; $P = 0.004$). Furthermore, total pre-exercise/rest energy intake (breakfast + lunch) was ~9% greater in EX compared to REST (t = 2.212; $P = 0.039$). However, total 24 h energy intake was similar between trials (Z = -0.896; $P = 0.388$). Relative energy intake (total 24 h energy intake minus energy expended through exercise/rest) was reduced by ~16% in EX compared to REST (EX 9694 ± 3313 kJ; REST 11517 ± 4023 kJ; Z = -2.800; $P = 0.004$).

There were no differences between trials for carbohydrate, fat, protein and fibre intakes ($P \geq 0.245$) at breakfast or over the evening (Table 2). However, protein (t = 2.657; $P = 0.016$) and fat (t = 3.369; $P = 0.003$) intakes at lunch were greater in EX compared to REST, with carbohydrate and fibre intake at lunch similar between trials ($P \geq 0.059$).

There were no sex*trial interaction effects for energy intake at breakfast ($F(1) = 0.061$; $P = 0.808$), lunch ($F(1) = 0.018$; $P = 0.893$), breakfast + lunch ($F(1) = 0.019$; $P = 0.893$), in the evening ($F(1) = 1.218$; $P = 0.284$) or over the 24 h ($F(1) = 0.702$; $P = 0.413$). There was a sex*trial interaction effect for energy expenditure during the 1 h exercise/rest ($F(1) = 22.835$; $P < 0.001$), with the energy expended during exercise representing a greater proportion of energy expenditure during the 1 h rest in males (Male 939 ± 164 %; female 776 ± 142 %; P = 0.028). Consequently, there was a trend for a sex*trial interaction for relative energy intake ($F(1) = 3.660$; $P = 0.072$).

Subjective appetite sensations

There were time and trial*time interaction effects for all subjective appetite ratings (Figure 2; $P < 0.05$). Additionally, there were trial effects for hunger ($F(1) = 4.611$; $P = 0.045$), DTE ($F(1) = 4.741$; $P = 0.042$) and PFC ($F(1) = 10.251$; $P = 0.005$), but not fullness ($F(1) = 0.352$; $P = 0.560$). participants reported lower hunger, PFC and DTE at 1600 h and 1630 h (i.e. mid-exercise and post-exercise, respectively) in EX ($P < 0.05$), with DTE also reduced at 1530 h (i.e. pre-exercise). PFC was lower, and fullness was higher at 1230 h (i.e. immediately post-lunch) in EX vs REST ($P < 0.01$), with fullness lower after the evening meal in EX vs REST ($P < 0.05$).

There was a trial*time*sex interaction effect for fullness ($F(6.095) = 2.315$; $P = 0.038$), with the only significant post-hoc difference within or between sex, being that males reported greater fullness at 1230 h (i.e. post-lunch) in EX vs REST (EX 87 ± 7 mm; REST 79 ± 9 mm; $t = 5.622$; $P = 0.005$).

Steady state exercise and energy expenditure

Mean RPE and heart rate during the 60-min exercise in EX were 12 ± 1 and 147 ± 19 bpm, respectively. Mean RER, VO_2, carbohydrate and fat oxidation over the 60 min exercise/rest were all greater during EX compared to REST ($P < 0.001$; Table 3).

Discussion

This study investigated the effect of a planned 60-min late-afternoon aerobic exercise session on appetite and energy intake both before (i.e. at breakfast and lunch) and after (i.e. over the evening) exercise compared to an identical resting control trial. It was hypothesised that energy intake before exercise (i.e. at breakfast and lunch) would be greater than before rest, but that energy intake in the evening would be similar between trials. In line with this hypothesis, energy intake in the pre-exercise/pre-rest period was significantly greater (~9%) in the EX trial, whilst energy intake over the evening was similar between trials. Interestingly, the increased energy intake before exercise was mainly caused by an ~11% increase in energy intake at lunch, whilst energy intake at breakfast was not different between trials.

To our knowledge, this is the first study to investigate energy intake and appetite responses at meals consumed both before and after a planned exercise session, compared to a resting control trial. Previous studies examining the acute effects of exercise on energy intake have generally employed the approach of assessing appetite and energy intake following exercise/rest (6,24,25). Aerobic exercise has been shown to modulate circulating concentrations of acylated ghrelin and PYY, hormones secreted from the gatrointestinal tract that are thought to play a role in the regulation of appetite and energy intake (26,27). Interestingly, and perhaps counterintuitively, aerobic exercise decreases acylated ghrelin concentrations and increases PYY concentrations, producing a hormonal melieu conducive to the suppression of appetite/energy intake (7). Despite these consistent effects on hormonal mediators of appetite, acute exercise studies mainly suggest that energy intake after exercise is no different to after a similar duration of rest (8). Therefore, relative energy intake (energy intake minus energy expended through exercise/rest) is reduced with aerobic exercise, suggesting exercise helps to facilitate an acute negative energy balance. The present study supports the findings of these previous studies as energy intake after exercise was similar between EX and REST trials, but demonstrates that regular exercisers might increase their energy intake in anticipation of an exercise session. However, this increase in pre-exercise energy intake was not sufficient to offset the extra energy expended during exercise, meaning that exercise reduced relative energy intake compared to the rest trial.

In a similar recent study, Sim, Lee and Cheon (20) investigated the effects of a future exercise bout on pre-exercise energy intake in inactive overweight males. After standardised breakfast and lunch meals, participants were provided an *ad-libitum* snack (potato chips) an hour before a known exercise (self-selected exercise duration/intensity) or a rest session. Whilst overall there was no effect of exercise on energy intake, the authors observed that restrained eaters ate significantly more (~162 kcal or ~677 kJ) before exercise, an effect that was not present in the unrestrained eaters. In contrast to the results of Sim *et al.* (20), the present study observed that unrestrained eaters increased their energy intake at a pre-exercise meal in anticipation of a 1 h aerobic exercise session. There are a number of differences in study design that likely account for these discordant findings. Firstly, in the present study, participants were provided with two multi-item buffet meals (breakfast and lunch) 7.5 h and 3.5 h before exercise, respectively, whilst in the study of Sim *et al.* (20) participants were provided only a pre-exercise *ad-libitum* snack of potato chips 1 h before exercise. The additional opportunities to eat, choice of foods or the more distal (but more realistic) positioning of meals relative to exercise in the present study might have provided greater opportunity to increase energy intake in the exercise trial. Furthermore, participants in the present study were regular exercisers, whereas those in the study of Sim *et al.* (20) were inactive individuals. The lack of experience with exercise of the participants in this previous study (20), compared to participants in the present study, may have reduced their propensity to increase energy intake in anticipation of exercise. Alternatively, the fact that participants in the present study were not attempting to lose weight might mean that they were more likely to increase their energy intake in anticipation of exercise (although exercise still created an energy deficit). Future studies should look to examine these effects in those attempting to lose weight, who might be less likely to increase energy intake.

Previous work has demonstrated that there are elements of eating behaviour that are learned, with experience of a food influencing expectations about a food's satiation (28). Indeed, expected satiety/satiation are strong predictors of portion size selection (29,30). Although speculative, it might be hypothesised that exercise (or energy expenditure *per se*) might illicit a similar response, where previous experience with an exercise task might facilitate learned increases in portion size selection and energy intake. In line with this hypothesis, Werle *et al.* (31) observed that energy served from snacks was increased in participants who answered a series of questions related to exercise, compared to those that answered questions unrelated to exercise (31). Thus in the present study, participants' previous experience with aerobic exercise might have meant they had 'learned' to increase their energy intake in the pre-exercise period to prepare for the coming exercise/energy expenditure. Whilst speculative, this hypothesis might go some way to explain the results of chronic training studies, where weight loss slows down over time (11,32). Alternatively, it is possible that the pre-execise period represents a time where exercisers are more likely to increase energy intake to compensate for impending energy expenditure. Indeed, in support of this theory, a recent study (33) observed that planned energy intake at a future lunch meal was increased when participants were told the meal would be consumed after 1 h of hard aerobic exercise compared after a period of rest.

Alternatively, the results of the present study might be explained by other possible mechanisms. Firstly, the Compensatory Health Beliefs Model (34) postulates that certain unhealthy behaviours can be compensated for by positive (healthy) behaviours, and this model might, at least partially, explain the findings. Knowledge of a planned future exercise session (perceived as a healthy behaviour) might allow an exerciser to justify, to themselves, having extra energy/food (perceived as an unhealthy behaviour) in the lead up to exercise (35,36). Secondly, and on a similar line to the health beliefs model, general scientific recommendations are for athletes to increase energy, and particularly carbohydrate, intake in the hours before exercise (37). As these recommendations, which are made for athletes, permeate into lay publications/online resources, they might promulgate the idea that exercisers (not only athletes) should increase their food and energy intake to appropriately prepare for a future exercise session. Interestingly, there was no difference in pre-exercise carbohydrate intake, although energy, protein and fat intake where all higher in the EX trial. However, an increase in energy (or indeed carbohydrate) intake after exercise would also be predicted by the compensatory health beliefs model and would also be consistent with current scientific recommendations for athletes (37), but this was not found. Therefore, the finding that energy and macronutrient intakes in the evening were similar between REST/EX trials suggests that these possible mechanisms are not likely to explain the findings. One consideration is the wording used to inform participants of which trial they are on. We aimed to ensure participants had the impending exercise/rest in mind when making decisions about food to consume, although this meant that the wording was possibly leading. Whilst this possibly represents a limitation of the present work, the fact that an increased energy intake was observed at lunch, but not at breakfast, suggests that the wording did not bias participants to eat more food (energy) in the exercise trial. That said, given this is one of the first studies to investigate these effects, future studies should carefully consider how information about the impending exercise sessions is given to participants.

Whilst the mechanism explaining the present results remains to be elucidated, the findings suggest that energy intake is increased in anticipation of, rather than in response to, exercise. These findings for post-exercise energy intake are similar to those reported in the vast majority of the previous literature in this area (8). Although energy intake was significantly increased before exercise, the increase was only ~518 kJ (~124 kcal) and when this was combined with the energy intake post-exercise, there was no significant difference between trials, although mean energy intake was arithmetically greater in the EX trial. Furthermore, when the energy expended during the 60 min exercise/rest was factored in, relative energy intake was ~1823 kJ (~436 kcal) less in the EX trial. In this regard, the present study is consistent with the vast majority of the previous literature examining the short-term effects of exercise on *ad-libitum* energy intake (6,8,24–26). The present study, along with these previous studies, demonstrates that a single bout of aerobic exercise does not induce a substantial increase in energy intake around exercise, thus facilitating an energy deficit that should be conducive to weight loss if exercise training continues. The present study only explored the period immediately preceding an exercise session and given that exercise sessions are generally planned well in advance (i.e. an exerciser might habitually do exercise classes on a particular day of the week every week), there may be further opportunity to increase energy intake prior to exercise. Future studies should examine eating behaviour over longer periods before exercise, as well as how eating behaviour before and after exercise is affected by long-term exercise training. Furthermore, whether diet goals (i.e. maintain vs lose weight) influence these responses should also be investigated.

In conclusion, this study demonstrates that energy intake is increased in anticipation of aerobic exercise (i.e. before exercise), rather than in response to the exercise session (i.e. after exercise). The increase in energy intake was not sufficient to offset the energy deficit created by the exercise session, meaning that aerobic exercise reduced energy balance relative to rest, which is consistent with previous literature examining post-exercise energy intake. However, the finding that energy intake is increased in anticipation of an aerobic exercise session perhaps changes our understanding of how exercise might influence energy intake and, speculatively, suggests regular exercisers might 'learn' to increase their energy intake in preparation for an exercise session, a behaviour that might attenuate the negative energy balance induced by exercise. However, clearly further research is needed to better understand this phenomonen.

Acknowledgements

LJJ is part of the National Institute for Health Research (NIHR) Leicester Biomedical Research Centre, which is a partnership between University Hospitals of Leicester NHS Trust, Loughborough University and the University of Leicester. This report is independent research by the National Institute for Health Research. The views expressed in this publication are those of the authors and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health. No other funding was received for this study.

The authors declare no conflict of interest.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

References

1. Conolly A, Saunders C. Health Survey for England: 2016: Adult overweight and obesity. NHS Digit. 2017;1(December):1–21.

2. Abarca-Gómez L, Abdeen ZA, Hamid ZA, Abu-Rmeileh NM, Acosta-Cazares B, Acuin C, et al. Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. Lancet. 2017;390(10113):2627–42.

3. Schrauwen P. High-fat diet, muscular lipotoxicity and insulin resistance. Proc Nutr Soc. 2007;66(1):33–41.

4. Lean MEJ, Astrup A, Roberts SB. Making progress on the global crisis of obesity and weight management. BMJ. 2018;361.

5. Ostbye T, Malhotra R, Landerman LR. Body mass trajectories through adulthood: results from the National Longitudinal Survey of Youth Cohort (1981–2006). Int J Epidemiol 2011;40(1):240–50.

6. King JA, Miyashita M, Wasse LK, Stensel DJ. Influence of prolonged treadmill running on appetite, energy intake and circulating concentrations of acylated ghrelin. Appetite. 2010;54(3):492–8.

7. Dorling J, Broom DR, Burns SF, Clayton DJ, Deighton K, James LJ, et al. Acute and chronic effects of exercise on appetite, energy intake, and appetite-related hormones: The modulating effect of adiposity, sex, and habitual physical activity. Nutrients. 2018;10(9).

8. Schubert MM, Desbrow B, Sabapathy S, Leveritt M. Acute exercise and subsequent

energy intake. A meta-analysis. Appetite. 2013;63:92–104.

9. Caudwell P, Gibbons C, Hopkins M, Naslund E, King N, Finlayson G, et al. The influence of physical activity on appetite control: An experimental system to understand the relationship between exercise-induced energy expenditure and energy intake. Proc Nutr Soc. 2011;70(2):171–80.

10. Wu T, Gao X, Chen M, Van Dam RM. Long-term effectiveness of diet-plus-exercise interventions vs. diet-only interventions for weight loss: A meta-analysis: Obesity Management. Obes Rev. 2009;10(3):313–23.

11. Turner JE Betts JA, Thompson D MD. Non prescribed physical activity energy expenditure is maintained with structured exercise and implicates a compensatory increase in energy intake. Am J Clin Nutr. 2010;92:1009–16.

12. Rocha J, Paxman J, Dalton C, Winter E, Broom DR. Effects of a 12-week aerobic exercise intervention on eating behaviour, food cravings, and 7-day energy intake and energy expenditure in inactive men. Appl Physiol Nutr Metab. 2016;41(11):1129–36.

13. Myers A, Dalton M, Gibbons C, Finlayson G, Blundell J. Structured, aerobic exercise reduces fat mass and is partially compensated through energy intake but not energy expenditure in women. Physiol Behav. 2019 Feb;199:56–65.

14. Hopkins M, King NA, Blundell JE. Acute and long-term effects of exercise on appetite control: Is there any benefit for weight control? Curr Opin Clin Nutr Metab Care. 2010;13(6):635–40.

15. Kozey-Keadle S, Staudenmayer J, Libertine A, Mavilia M, Lyden K, Braun B, et al. Changes in Sedentary Time and Physical Activity in Response to an Exercise Training and/or Lifestyle Intervention. J Phys Act Heal. 2014;11(7):1324–33.

16. Speakman JR, Selman C. Physical activity and resting metabolic rate. Proc Nutr Soc. 2003;62(03):621–34.

17. Lee MG, Sedlock DA, Flynn MG, Kamimori GH. Resting metabolic rate after endurance exercise training. Med Sci Sports Exerc. 2009;41(7):1444–51.

18. Fedewa M V., Hathaway ED, Williams TD, Schmidt MD. Effect of Exercise Training on Non-Exercise Physical Activity: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Sport Med. 2017;47(6):1171–82.

19. Blundell JE. The contribution of behavioural science to nutrition: Appetite control. Nutr Bull. 2017;42(3):236–45.

20. Sim AY, Lee LL, Cheon BK. When exercise does not pay: Counterproductive effects of impending exercise on energy intake among restrained eaters. Appetite. 2018;123:120–7.

21. Stunkard AJ, Messick S. The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. J Psychosom Res. 1985;29(1):71-83.

22. Durnin J V, Womersley J. and Its Estimation From Skinfold Thickness : Measurements on. Br J Nutr. 1973;32(1):77–97.

23. Borg GAV. Psychophysical bases of perceived exertion. Med Sci Sport Exerc. 1982;14(5):377–81.

24. King JA, Wasse LK, Broom DR, Stensel DJ. Influence of brisk walking on appetite, energy intake, and plasma acylated ghrelin. Med Sci Sports Exerc. 2010;42(3):485–92.

25. Deighton K, Zahra JC, Stensel DJ. Appetite, energy intake and resting metabolic responses to 60min treadmill running performed in a fasted versus a postprandial state.

Appetite. 2012;58(3):946–54.

26. Douglas JA, King JA, McFarlane E, Baker L, Bradley C, Crouch N, et al. Appetite, appetite hormone and energy intake responses to two consecutive days of aerobic exercise in healthy young men. Appetite. 2015;92:57–65.

27. King JA, Garnham JO, Jackson AP, Kelly BM, Xenophontos S, Nimmo MA. Appetite-regulatory hormone responses on the day following a prolonged bout of moderate-intensity exercise. Physiol Behav. 2015;141:23–31.

28. Wilkinson LL, Brunstrom JM. Conditioning “fullness expectations” in a novel dessert. Appetite. 2009;52(3):780–3.

29. Brunstrom JM, Rogers PJ. How many calories are on our plate expected fullness, not liking, determines meal-size selection. Obesity. 2009;17(10):1884–90.

30. Brunstrom JM, Shakeshaft NG. Measuring affective (liking) and non-affective (expected satiety) determinants of portion size and food reward. Appetite. 2009;52(1):108–14.

31. Werle COC, Wansink B, Payne CR. Just thinking about exercise makes me serve more food. Physical activity and calorie compensation. Appetite. 2011;56(2):332–5.

32. Curioni CC, Lourenço PM. Long-term weight loss after diet and exercise: A systematic review. Int J Obes. 2005;29(10):1168–74.

33. Barutcu A, Witcomb GL, James LJ. Anticipation of aerobic exercise increases planned energy intake for a post-exercise meal. Appetite. 2019;138:198-203.

34. Thongworn S, Sirisuk V. Weight control specific compensatory health beliefs: Hypothetical testing and model extension. Kasetsart J Soc Sci. 2018;39(2):312–9.

35. Rabiau MA, Knäuper B, Nguyen TK, Sufrategui M, Polychronakos C. Compensatory beliefs about glucose testing are associated with low adherence to treatment and poor metabolic control in adolescents with type 1 diabetes. Health Educ Res. 2009;24(5):890–6.

36. King NA. What processes are involved in the appetite response to moderate increases in exercise-induced energy expenditure? Proc Nutr Soc. 1999;58(01):107–13.

37. Burke LM, Hawley JA, Wong SHS, Jeukendrup AE. Carbohydrates for training and competition. J Sports Sci. 2011;29(Supp 1):S17-S27.

Table 1. Food items provided at meals.

Breakfast buffet items		
White bread	Cornflakes – cereal	Peanut butter spread
Brown Bread	Weetabix - cereal	Nutella spread
Rice crispies - cereal	Strawberry yoghurt	Strawberry jam spread
Crunchy nut – cereal	Raspberry yoghurt	Banana
Shreddies – cereal	Cherry yoghurt	Apples
Coco pops – cereal	Apple juice	Clementine
Cheerios – cereal	Orange juice	Milk
Lunch buffet items		
White bread	Cherry yoghurt	Salt and vinegar crisps
Brown Bread	Strawberry yoghurt	Cheese and onion crisps
Mature cheddar cheese	Raspberry yoghurt	Orange squash
Honey smoked ham	Cadbury mini rolls	Summer fruits squash
Grilled chicken pieces	Mayonnaise	Apples
Can of tuna	Butter	Clementine
Lettuce	Chocolate chip cookies	
Tomato	Salted crisps	
Evening meal		
Nutrigrain apple cereal bar	Cheese and onion crisps	Clementine
Nutrigrain blueberry cereal bar	Prawn cocktail crisps	Banana
Nutrigrain strawberry cereal bar	Salt and vinegar crisps	Strawberry yoghurt
Mars chocolate – fun size	Salted crisps	Cherry yoghurt
Twix chocolate – fun size	Mini cookies	Raspberry yoghurt
Maltesers chocolate – fun size	Apple	Tomato pasta meal

Table 2. Total energy (kJ), carbohydrate (CHO), protein (PRO), fat, and fibre intake over the course of each trial.

	Energy (kJ)	CHO (g)	PRO (g)	FAT (g)	Fibre (g)
			Breakfast		
EX	2656 ± 1291	108.5 ± 49.9	18.9 ± 11.3	12.5 ± 9.6	6.3 ± 4.9
REST	2484 ± 1156	103.8 ± 45.9	18.3 ± 9.5	10.5 ± 6.9	5.6 ± 4.1
			Lunch		
EX	3450 ± 1049 †	74.3 ± 22.9	38.7 ± 13.7 †	39.5 ± 17.4 †	8.3 ± 2.5
REST	3103 ± 927	70.3 ± 20.7	34.4 ± 12.9	34.2 ± 15.2	7.7 ± 2.3
			Bfast + Lunch		
EX	6105 ± 1980 †	182.8 ± 68.3	57.7 ± 21.1 †	52.0 ± 19.7 †	14.6 ± 7.0
REST	5588 ± 1933	174.0 ± 64.4	52.7 ± 19.3	44.6 ± 19.0	13.4 ± 6.0
			Evening Meal		
EX	6249 ± 2216	223.2 ± 81.0	40.1 ± 14.1	43.8 ± 15.7	10.2 ± 4.3
REST	6240 ± 2585	229.4 ± 100.8	41.6 ± 15.7	45.7 ± 19.2	10.5 ± 4.9
			Total 24h		
EX	12354 ± 3920	405.9 ± 141.7	97.7 ± 32.4	95.8 ± 27.7	24.8 ± 10.7
REST	11827 ± 4069	403.4 ± 151.5	94.3 ± 31.9	90.3 ± 31.7	23.9 ± 9.9

† Indicates significantly different from REST. Data are mean ± SD.

Table 3. Mean RER, VO2, carbohydrate and fat oxidation values for EX and REST trials.

	VO_2 (l.min^{-1})	**RER**	**Carbohydrate oxidation (g.min^{-1})**	**Fat Oxidation (g.min^{-1})**
EX	2.02 ± 0.166 †	0.96 ± 0.03 †	2.369 ± 0.088 †	0.125 ± 0.098 †
REST	0.29 ± 0.003	0.86 ± 0.01	0.338 ± 0.001	0.019 ± 0.001

† Indicates significantly different from REST. Data are mean ± SD.

Figure 1. A) Energy intake (kJ) at each meal; B) Total and relative energy intake (kJ) for EX (■) and REST (▢) trials. † Indicates significantly different from REST trial. Data are mean ± SD.

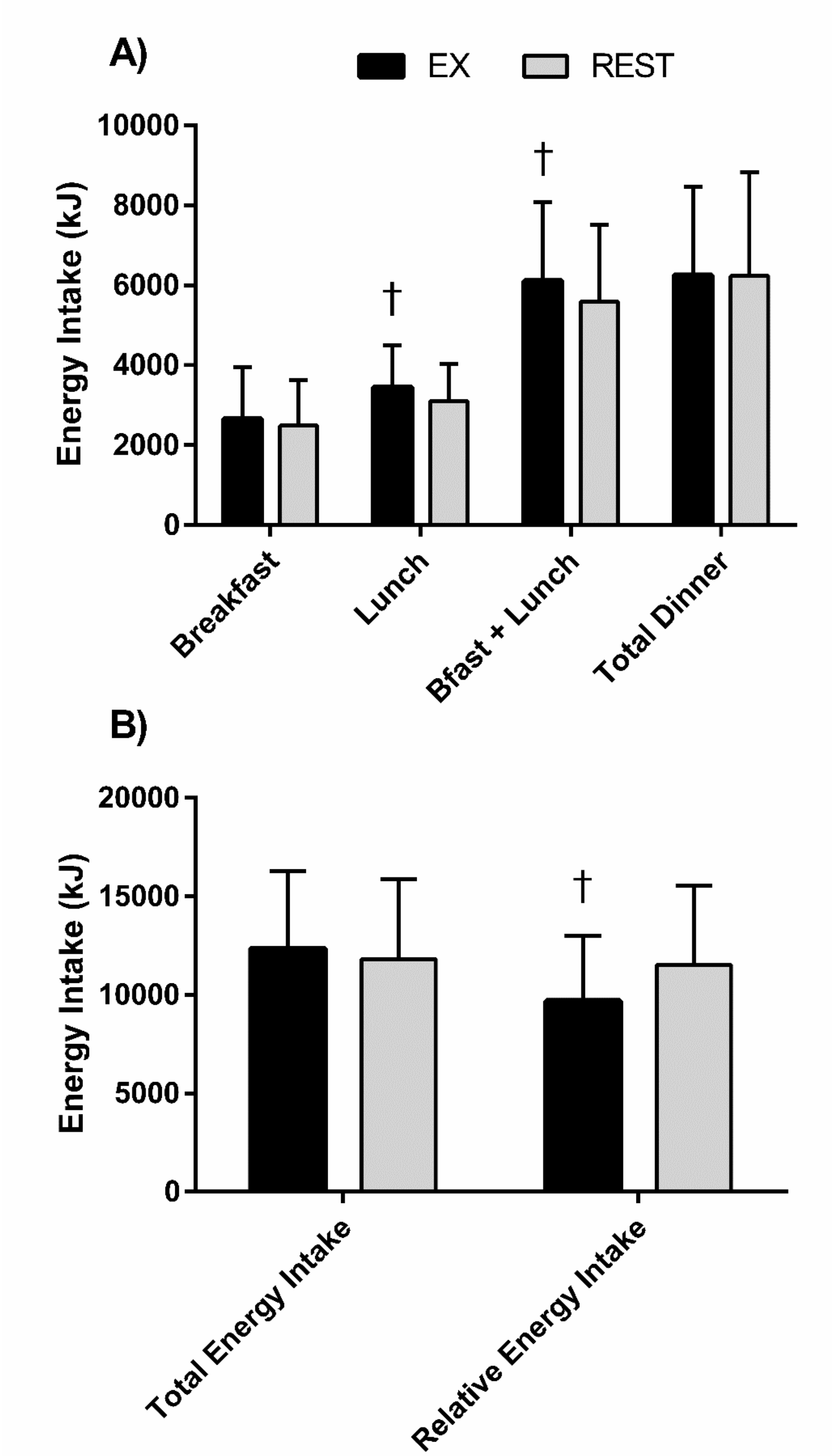

Figure 2. Change in A) Hunger, B) Fullness, C) Desire to eat (DTE) and D) Prospective food consumption (PFC) over the trial day for both EX (– –) and REST (——). † Indicates significantly different from REST trial. Data are mean ± SEM.