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Matching energy intake to expenditure of isocaloric exercise at high- and moderate-intensities

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1.1 ABSTRACT

Background: Those seeking to manage their bodyweight use a variety of strategies, but the most common approaches involve attempting to exercise more and/or consume fewer calories. A poor comprehension of the energy cost of exercise and the energy content of food may contribute to weight-gain and the poor success rate of exercise weight-loss interventions.

Purpose: To investigate individuals' ability to consciously match energy intake with energy expenditure after isocaloric exercise at moderate and high intensity.

Method: In a counterbalanced cross-over study design, 14 low- to moderately-active, lean individuals (7 male, 7 female; mean age 23 ± 3 years; mean BMI 22.0 ± 3.2 $kg \cdot m^{-2}$) completed both a moderate-intensity (60% VO_{2max}, MOD) and a high-intensity (90% VO_{2max}, HIGH) exercise bout on a treadmill, matched for energy expenditure, EE, (450 kcal). Participants were blinded to the intensity and duration of each bout. Thirty minutes post exercise, participants were presented with a buffet, where they were asked to consume food in an attempt to match energy intake with the energy expended during the exercise bout. This was termed the "matching task," providing a matching task energy intake value (EI_{MATCH}). Upon finishing the matching task, a verbal estimate of energy expenditure (EST) was obtained before the participant was allowed to return to the buffet to consume any more food, if desired. This intake was covertly measured and added to EI_{MATCH} to obtain an *ad libitum* intake value ($EI_{AD\ LIB.}$).

Results: A significant condition x task interaction showed that, in MOD, EST was significantly lower than EE (298 ± 156 kcal vs. 443 ± 22 kcal, p = 0.01). In the HIGH condition, EE, EI_{MATCH} and EST were similar. In both conditions, participants tended to over-eat to a similar degree, relative to EST, with EI_{MATCH} 20% and 22% greater than EST in MOD and HIGH respectively. Between-condition comparisons demonstrated that EI_{MATCH} and EST were significantly lower in MOD, compared with HIGH (374 ± 220 kcal vs. 530 ± 248 kcal, p = 0.002 and 298 ± 156 kcal vs. 431 ± 129 kcal, p = 0.002 respectively). For both conditions, $EI_{AD\ LIB}$ was approximately 2-fold greater than EE.

Discussion: Participants exhibited a strong ability to estimate exercise energy expenditure after high-intensity exercise. Participants appeared to perceive moderate-intensity exercise to be less energetic than an isocaloric bout of high-intensity exercise. This may have implications for exercise recommendations for weight-loss strategies, especially when casual approaches to exercise and attempting to eat less are being implemented.

KEYWORDS: Energy balance, weight management, weight-loss, food intake, eating behaviour

1.2 INTRODUCTION

With obesity statistics now demonstrating that 63% of adults and 30% of children in England are overweight or obese [1], many individuals are seeking effective weight-management strategies. Those seeking to manage their bodyweight, whether it be attempting to lose weight or avoid weight-gain, use a variety of strategies to do so. The most common strategies involve attempting to exercise more and/or consume fewer calories [2]. For the effectively implementing rather crude weight-loss strategies, such as undertaking more regular exercise, eating less food and eating less fat, a sound appreciation of energy expenditure and energy intake is desirable. It has been extensively demonstrated that individuals are prone to underreporting energy intake when using techniques such as food diaries [3-6], with obese individuals likely to underreport to a greater extent [7-9]. A contributing factor to this underreporting may be individuals' poor understanding of the energy content of food [10-13] which, incidentally, has been suggested to be particularly awry in relation to the energy cost of exercise [14, 15]. Further, this may partly explain why exercise alone can prove an unsuccessful weight-loss strategy [14, 16], with large individual variability in response to increased exercise energy expenditure, when individuals eat *ad libitum* [17].

To the best knowledge of the authors, only two studies have acutely and directly assessed individuals' ability to estimate acute energy expenditure and intake. Harris and George [18] asked participants to estimate their energy expenditure after a 60 minute bout of treadmill exercise, at 65% of predicted maximum heart rate. Fifteen minutes post-exercise, an *ad libitum* buffet meal was provided. The participants were then asked to estimate their energy intake at an *ad libitum* meal. Estimated energy expenditure was significantly greater than the actual energy expenditure of the exercise bout. Conversely, estimated energy intake was significantly lower than actual intake, with participants eating almost twice as many calories as estimated. Willbond and colleagues [19] conducted a similar study, but after exercise (a 200kcal and a 300kcal bout of treadmill running at 50% VO_{2peak}), participants were asked to estimate the energy expenditure of the exercise bout and then consume the caloric equivalent from a buffet meal. The energy expenditure of exercise was significantly and substantially overestimated, with estimates 3-4 fold greater than actual expenditure. Intake significantly exceeded expenditure, by 2-3 fold. However, it may be argued that with such low total energy cost of exercise, overcompensation is likely. In addition, it is likely that the perception of energy cost of exercise is dependent on the intensity, as well as the duration of exercise.

Therefore, the aim of this study was to assess individuals' ability to match energy intake with energy expenditure after isoenergetic bouts of moderate- and high-intensity treadmill exercise. In light of the recent proposed health benefits of low volume, high-intensity interval training [20-22], it was deemed of interest to investigate how the intensity and duration of exercise may influence the perceived energy cost. It is hypothesised that participants will overestimate the expenditure of both exercise bouts, while underestimating the energy content of food, resulting in a greater intake than expenditure. It is also postulated that the overestimate of the energy cost of exercise will be greater after high-intensity exercise, with a greater perceived exertion leading to a higher perceived energy cost. A secondary aim was to assess *ad libitum* intake after high- and moderate-intensity isoenergetic treadmill exercise.

1.3 MATERIALS AND METHODS

1.3.1 Participants: Fourteen healthy-weight, low- to moderately active individuals were recruited primarily from The School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham. The characteristics of the participants are shown in **table 1**. The criterion for low to moderately active was a score of < 3000 METS on the International Physical Activity Questionnaire (IPAQ). Those suffering from illness such as cold or flu, those taking medication that was likely to affect appetite or that needed to be taken with food more frequently than once a day, those with food allergies and those suffering from diabetes were excluded from taking part. Ethical approval was obtained from the Ethics Committee of the University of Birmingham.

Age (years)	23 ± 3
BMI (kg•m^{-2})	22.0 ± 3.2
VO_{2max} (L•min^{-1})	3.36 ± 0.67*
IPAQ score (METS)	2207 ± 697

Table 1. Participant characteristics. Values are mean ± SD.
* VO_{2max} value for nine participants, VO_{2peak} value for five participants.

1.3.2 Study design: A within-subject, randomised cross-over study design was utilised, with participants randomly allocated to each of two exercise intensity conditions, termed moderate intensity (MOD – 60% VO_{2max}) and high intensity (HIGH - 90% VO_{2max}).

1.3.3 Preliminary testing: A single session of pre-testing preceded the study protocol in order to calculate specific exercise intensities to be used for each participant. Participants reported to the Exercise Metabolism Laboratory, in the School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham after an overnight fast. The participant information pack was administered and explained and the participant was given the opportunity to ask any questions regarding the study, prior to providing written consent for their participation. A health questionnaire was completed as a means of a health screening procedure and The International Physical Activity Questionnaire (IPAQ) was completed as a measure of habitual physical activity. Height and weight were then recorded. An incremental exercise test to volitional exhaustion was then completed on a motorised treadmill (H/P/ Cosmos. Nußdorf, Germany) in order to obtain VO_{2max}, and HR_{max} values and to establish the relationship between running speed and rate of oxygen uptake. To achieve this, the test comprised of two components: a constant gradient, steady-state component during which the relationship between running speed and rate of oxygen uptake was calculated; followed by a rapid speed and gradient increase component, from which maximum oxygen uptake (VO_{2max}) was calculated. The test began at a speed of 6 km h^{-1} and a gradient of 1%. Each stage in the initial section of the test lasted 3 minutes. The speed was increased to 8 km•h^{-1} at stage 2 and 10 km•h^{-1} at stage 3. From there on, the speed increased by 1 km•h^{-1} at each stage with the gradient remaining constant at 1%. This protocol was followed until an RER of 1.00 was reached. At this point, component two of the test commenced. Stages were shortened to 1 minute in duration and with each stage, speed or gradient increased in alternating fashion, by 1 km h^{-1} and 1% respectively. Participants were adjudged to have reached the end of the test when they voluntarily stopped running, if VO_2 ceased to increase with increasing workload or if it was felt that the participant was struggling to maintain the speed of the treadmill belt. Breath-by-breath measures of exhaled gas, averaged every eight breaths, were recorded using Oxycon Pro (Jaeger, Wuerzburg, Germany) apparatus. Prior to incremental exercise test, the gas analysers were calibrated using a calibration gas (BOC Gases, Guildford, Surry, UK) of mixed, known concentrations of O_2 (14.99%) and CO_2 (5.04%) and volume was calibrated using a 3 litre calibration syringe (Jaeger, Wuerzburg, Germany). Exhaled gas was collected throughout the entire test, but submaximal VO_2 values were obtained for each stage during the steady-state component of the test only from air collected during the final minute of the 3 minute stage. VO_{2max} was calculated as the highest average value obtained for any one minute period. From the VO_{2max} value obtained, linear regression was used to calculate an estimate for the speed that would elicit the desired VO_2 for each exercise session, equating to exercise intensities of 60% and 90% VO_{2max}.

1.3.4 Procedures & protocol: After a minimum period of 3 days after pre-testing, participants returned to the Exercise Metabolism Laboratory after a 10 hour overnight fast for the first of two exercise trials. Participants were provided with a standardised breakfast meal. This consisted of two slices of toast (Thick slice, 50/50 bread, ~90g), margarine (~16g), jam (mixed fruit, ~30g) with a choice of orange or apple juice (~200ml). The addition of jam was optional, although the breakfast selections made at the first trial were repeated for the second. The approximate energy content of this meal was 415 kcal (71% energy from carbohydrate, 19% from fat and 10% protein), based on the addition of jam and selection of orange juice. Once the breakfast was consumed, the participant began a two-hour rest period before the exercise bout commenced. The participant remained sedentary within the laboratory, leaving them free to watch television, read or use a computer.

At the end of this resting period, the exercise bout commenced. The exercise bout consisted of jogging/running on a motorised treadmill until an energy target of 450 kcal was reached. For two participants, whose VO_{2max} values were lower than 2.5 $L \bullet min^{-1}$, this target was revised to 400 kcal. This was done to ensure that the HIGH bout was manageable and also to limit between-subject variation in exercise duration. In the MOD condition, the treadmill was set at a speed estimated to elicit an intensity of 60% VO_{2max}. In the HIGH condition, the treadmill was set at a speed estimated to elicit an intensity of 90% VO_{2max}. During both trials, exhaled gas was collected intermittently, with 2 minute samples collected at approximately 10 minute intervals. Breath-by-breath measures of exhaled air, averaged every eight breaths, were recorded using Oxycon Pro (Jaeger, Wuerzburg, Germany) apparatus, allowing for real-time feedback. This allowed for the speed of the treadmill and the duration of the bout to be altered to ensure the target exercise intensity and target energy expenditure were attained. From the exhaled gas collection, VO_2 and RER were recorded and used to calculate energy expenditure. In addition, measures of heart rate were obtained using a heart rate monitor (Polar, S625X;

Polar Electro Oy, Kempele, Finland) for the entirety of the bout and ratings of perceived exertion, using the Borg Scale [23], were obtained at 5 minute intervals. Throughout both exercise trials, the participant was blinded to the speed and duration of the bout. The only verbal feedback provided, was to inform the participant that they were approximately half way through the bout.

Upon completing the exercise bout, the participant was free to shower and change, before being escorted to the research kitchen facility to complete the energy matching task (EI_{MATCH}). The participant was presented with an extensive pre-weighed buffet meal (content shown in Appendix 1). They were then given the following verbal instruction: "Consider the exercise bout that you have just completed and the amount of energy that you expended, or the number of calories that you burned. Now, try to match that energy, or number of calories in the food that you consume from the buffet." The participant was informed that, should they wish to eat any more food after the task, they would be free to do so once the matching task was complete. They were then left to complete the task in isolation. When the participant had finished eating, the buffet food was re-weighted and energy intake was calculated using energy density data derived from the manufacturer's nutritional information. The energy matching task was completed approximately 30 minutes (mean time from cessation of exercise to matching task, 31 ± 4 min.; 29 ± 4 min. for MOD and 32 ± 4 min. for HIGH) after the completion of the exercise bout.

After the energy matching task had been completed, the participant returned to the Exercise Metabolism Laboratory to remain seated until the buffet food had been re-weighed. During this time, they were asked to provide a verbal estimate of the energy expenditure of the exercise bout. After the re-weighing was completed, they were informed that the trial was finished. They were then told that they were free to consume any more food that they wished from the buffet. Participants commenced this second sitting at approximately 60 minutes post-exercise (56 ± 7 min.; 53 ± 4 min. for MOD and 58 ± 7 min. for HIGH). Food intake was covertly recorded, with the buffet food being re-weighted again after the participant had finished eating. The energy intake at this sitting was added to the intake of the energy matching task to provide an *ad libitum* energy intake value ($EI_{AD\ LIB.}$).

1.3.5 Measures: Energy expenditure (EE) was measured, in kcal, for both exercise bouts. This was calculated from exhaled air collected intermittently during the bout. Mean rate of oxygen utilisation (VO_2) and RER were calculated and energy expenditure was estimated using the RER-specific caloric equivalent of oxygen. EI_{MATCH} and $EI_{AD\ LIB.}$ were measures as described above, from the buffet meal provided and recorded in kcal. The verbal estimate of energy expenditure (EST) was recorded as a further outcome measure.

1.3.6 Statistical analysis: All values stated are mean values ± standard deviation (SD) in text and tables and mean ± standard error of the mean (SEM) in figures. Mean EE, EI_{MATCH} and EST values were investigated for energy measures and trial differences using a 3x2 repeated measures factorial ANOVA. Energy measures and trial comparisons of EE and $EI_{AD\ LIB.}$ were assessed by conducting a further 2x2 repeated measures factorial ANOVA. Comparisons of the dietary intakes for the EI_{MATCH} and $EI_{AD\ LIB}$. tasks in both conditions were made by conducting separate 2x2 repeated measures factorial ANOVA for each dietary characteristic investigated (total energy density, carbohydrate intake, fat intake and protein intake). Significant interactions and main effects from all AVOVA were further assessed by pairwise comparisons, using Bonferroni post-hoc analysis. Statistical significance level of $p < 0.05$ was in use for all comparisons. All statistical analysis was carried out using the SPSS software programme (SPSS inc., Chicago, Illinois, USA).

1.4 RESULTS

1.4.1 Exercise trials: Physiological measures of each exercise trial condition are shown in **table 2**. As intended, the exercise intensity was significantly different between the two exercise trials. Absolute and relative intensity, represented by absolute VO_2, absolute heart rate and percentage of VO_{2max} and percentage of maximum heart rate was significantly greater in HIGH, compared with MOD (all $p < 0.001$). Duration of exercise was significantly greater for MOD compared with HIGH ($p < 0.001$), while energy expenditure was the same for both conditions.

	MOD	***HIGH***
VO_2 ($L \cdot min^{-1}$)	2.00 ± 0.42	2.99 ± 0.59*
% VO_{2max}	60.4 ± 2.9	91.6 ± 4.6*
Heart rate (bpm)	137 ± 16	176 ± 9*
% HR_{max}	72 ± 6	91 ± 5*
Perceived Exertion	10 ± 2	15 ± 1*
Duration (min)	46.6 ± 8.8	30.2 ± 4.9*
Energy Expenditure (kcal)	443 ± 22	444 ± 21

Table 2. Characteristics of exercise. Values are mean ± SD. * = significant difference between MOD and HIGH, $p < 0.001$.

1.4.2 Energy expenditure, energy intake of the matching task and verbal estimate: Mean energy expenditure, energy estimate and energy matching task energy intakes are shown in **figure 1**. There was a significant condition (exercise intensity) x energy measure (EE, EI_{MATCH}, EST) interaction ($F(2) = 7.903$, $p = 0.002$). Pairwise comparisons for within-condition effects demonstrated that, in the MOD condition, EST was significantly lower than EE (298 ± 156 kcal vs. 443 ± 22 kcal, $p = 0.01$). There was no significant difference between EST and EI_{MATCH} (298 ± 156 kcal vs. 374 ± 220 kcal, $p = 0.123$). EE and EI_{MATCH} were similar. In the HIGH condition, there were no significant differences between EE, EI_{MATCH} and EST. Pairwise comparisons for between condition effects showed that EI_{MATCH} and EST were both significantly greater after HIGH, compared with MOD (530 ± 248 kcal vs. 374 ± 220 kcal, $p = 0.002$ and 431 ± 129 kcal vs. 298 ± 156 kcal, $p = 0.002$ respectively).

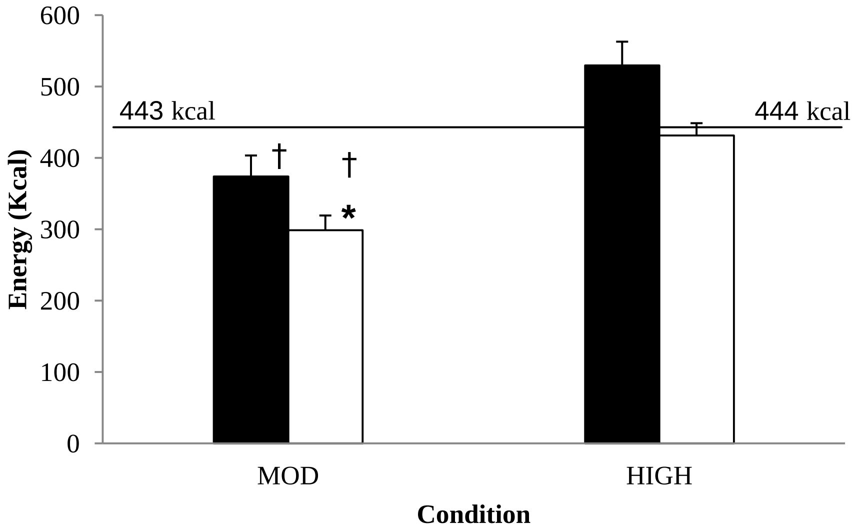

Figure 1. Energy expenditure, energy intake at the matching task and verbal EST of energy expenditure. Values are means ± SEM. Black bars = $EI_{(MATCH)}$, white bars = EST. Solid line indicates mean EE of 443 kcal for MOD, 444 kcal for HIGH. * = within-condition effect, significant different to EE. † = between-condition effect, significant different to HIGH.

1.4.3 Ad libitum energy intake: *Ad libitum* energy intake for both the MOD and HIGH conditions, along with the energy expenditure of exercise is shown in **figure 2**. A significant energy measure main effect was observed, with $EI_{AD\ LIB.}$ significantly greater than EE (914 ± 406 kcal vs. 443 ± 22 kcal, $F(1) = 23.706$, $p < 0.001$). There was no significant interaction, nor condition main effect.

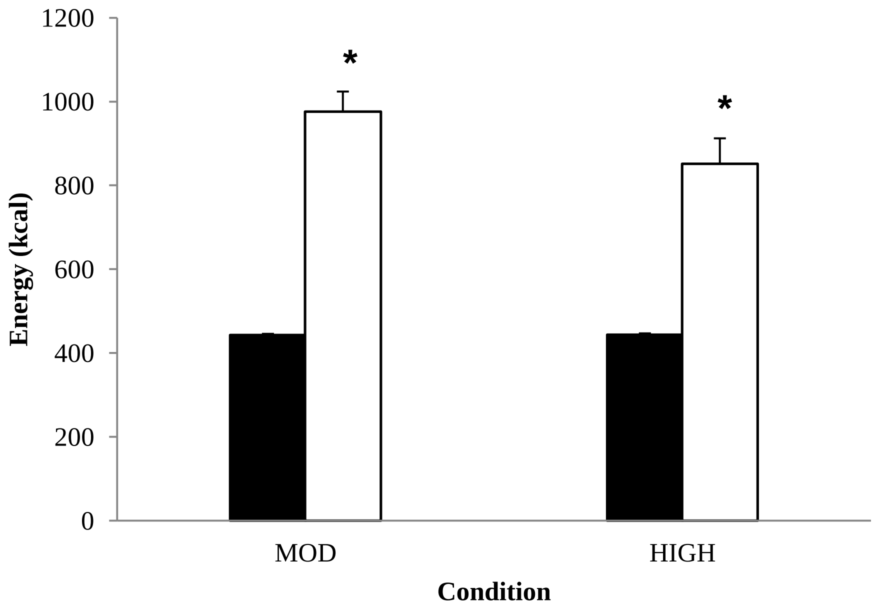

Figure 2. Energy expenditure and *ad libitum* energy intake. Values are mean ± SEM. Filled bars = EE, empty bars = $EI_{\mathit{AD\ LIB.}}$ * = $EI_{AD\ LIB.}$ significantly different to EE.

1.4.4 Food selection: energy density and macronutrient intake: The total energy density (expressed as kcal per 100g) and macronutrient content of the meal consumed (expressed in percentage of total energy consumed) are shown in **table 3** Energy density of the meal selected did not differ between conditions, however, a task main effect was present, demonstrating that energy density was significantly greater during the *ad libitum* intake, compared with the matching intake (112 kcal•$100g^{-1}$ vs. 92 kcal•$100g^{-1}$, $F(1) = 11.736$, $p = 0.005$). The percentage of total energy derived from carbohydrate and protein did not differ between condition and task. There was a significant task main effect for percentage of total energy obtained from fat ($F(1) = 7.951$, $p = 0.015$). Pairwise post-hoc comparisons showed that there was a greater percentage of energy from fat consumed in the $EI_{\mathit{AD\ LIB.}}$ task, compared with EI_{MATCH} (26.6% vs. 20.0%, $p = 0.021$).

	EI_{MATCH}				$EI_{AD\ LIB.}$			
	ED (kcal/100g)	**CHO (% E)**	**FAT (% E)**	**PRO (% E)**	**ED (kcal/100g)**	**CHO (% E)**	**FAT (% E)**	**PRO (% E)**
MOD	93.5 ± 32.4	59.0 ± 12	19.1 ± 9	21.9 ± 13	120.5 ± 45.6	54.0 ± 9.3	28.5 ± 12.0 [a]	17.5 ± 6.0
HIGH	90.8 ± 27.1	62.5 ± 10.9	19.9 ± 9.3	17.6 ± 5.9	103.3 ± 35.1	57.9 ± 12.1	24.7 ± 11.9	17.4 ± 5.2

Table 3 – Dietary characteristics of EI_{MATCH} and $EI_{AD\ LIB.}$ intakes for both MOD and HIGH conditions. ED = energy density, CHO = carbohydrate, FAT = fat, PRO = protein, % E = percentage of total energy consumed. a = significant task effect, $EI_{AD\ LIB}$. greater than EI_{MATCH}

1.5 DISCUSSION

The aim of this study was to assess individuals' ability to match energy intake with energy expenditure after isoenergetic bouts of high- and moderate-intensity treadmill exercise. It would appear that individuals accurately match EI with EE after high-intensity and moderate-intensity exercise. In the MOD condition, EI_{MATCH}, consumed at the matching task buffet was very similar to the energy expenditure of the exercise bout (402 ± 220 kcal vs. 443 ± 22 kcal). These values were also not significantly different to each other in the HIGH condition, despite EI_{MATCH} being 23% greater than EE. This is in conflict with the findings of Harris *et al*. [18] and Willbond *et al*. [19], who both demonstrated poor energy matching ability. However, with such an observed actual difference in these two values, it is possible that the lack of a statistically significant difference in HIGH may be due to a lack of statistical power, with a sample size of just 14.

This strong matching ability between EI and EE in the MOD condition was observed despite an undervaluation of the energy cost of exercise. The verbal estimate of energy expenditure of exercise was significantly lower than the exercise EE and EI_{MATCH}. This was not observed in the HIGH condition, with no difference between EST and either EE or EI_{MATCH}. The underestimation of the EE of moderate-intensity exercise was an unexpected finding. It not only contrasted with the hypothesis that EE would be overestimated in both exercise conditions but also contradicted the findings of Willbond and co-workers [19], who observed that the energy cost of treadmill running at an intensity of 50% VO_{2max} was overestimated 2-3 fold. The moderate-intensity exercise bout in the current study was of a considerably greater energy cost (450 kcal) than the two bouts of exercise used in the study of Willbond *et al.* (200 kcal and 300 kcal). With bouts of such low energy cost, overcompensation is much more easily achieved. However, it is suspected that the surprising findings of the current study may have been due to participants altering their behaviour under experimental conditions. It is possible that individuals over-compensated for their expected poor perception of the energy cost of exercise. Unfortunately, there is no means of assessing whether this was the case.

It would appear that an underestimate of the caloric content of food compensated for an undervaluation of the energy of moderate-intensity exercise. EI_{MATCH} was, on average, 117 kcal greater than EST. While these two values were not significantly different in either condition, there was a main effect for energy measure, which showed a significant difference between EI_{MATCH} and EST, with EI_{MATCH} being 28% greater. In the moderate-intensity condition, while EST was significantly lower than EE, this did not transpire into a significantly lower EI_{MATCH} than EE, as EI_{MATCH} exceeded EST by a mean of over 100 kcal (285 kcal vs. 389 kcal). This undervaluation of the energy content of food is in agreement with previous literature, which has found this to be the case particularly in foods that are considered more "healthy" [11, 13]. The findings of Harris and Colleagues [18] also suggest that the inability to match energy intake with exercise energy expenditure is driven primarily by an undervaluation of the energy content of food; the mean estimate of the caloric intake at a post-exercise *ad libitum* buffet was 435 kcal lower that the mean actual intake. In comparison, the energy content of the exercise bout was overestimated by 129 kcal.

Both EST and EI_{MATCH} were significantly greater after high-intensity exercise, compared with moderate-intensity exercise. Mean EI_{MATCH} was 159 kcal (33%) greater in the HIGH condition, despite the two exercise bouts being matched for energy cost. This could suggest that individuals perceive shorter, more strenuous bouts of exercise to be more energetic than longer, less strenuous bouts and that perception of the energy cost of exercise may be driven by the intensity of exercise, rather than the duration of exercise. If this is the case, this may provide an argument for the undertaking of sustained, moderate-intensity exercise bouts for those seeking to increase physical activity for weight-management purposes. If such exercise bouts result in an undervaluation of the energy expended, particularly compared with isocaloric bouts at a higher intensity, then this may help produce negative energy balance through the avoidance of overcompensation in post-exercise energy intake.

This may be particularly pertinent for those susceptible to increasing food intake due to using food as a reward. As eating palatable food is a pleasurable experience for the majority of individuals, some use food as a means of reward following behaviour that is deemed an achievement or reward-worthy. One such behaviour may be the undertaking of a bout of exercise. While it would appear that neural responses in areas of the brain associated with the reward system are decreased immediately post-exercise [24]; Crabtree, D. PhD thesis, University of Birmingham), possibly explaining the “anorexia of exercise” phenomenon, there is now also evidence for increases in reward system activation in the hours after exercise, sensitising it to images of food (Crabtree, D. PhD thesis, University of Birmingham). In addition, Finlayson and colleagues [25] found that some overweight and obese individuals exhibited increased liking and wanting of food items (components of the reward construct) following exercise . Further, those that did demonstrate this response were those who failed to experience weight-loss with a 12-week exercise programme. If exercise does sensitise individuals to the use or abuse of food as a reward and increase explicit wanting of food, then the perception of a less energetic bout may lower subsequent intake resulting from this response, as the conscious, explicit components of rewarding exercise may be reduced. Therefore, lower-intensity, longer duration bouts may prove preferable to shorter, higher intensity isocaloric bouts when devising exercise regimen to facilitate weight-loss.

One possible explanations for the perceived greater energy cost of shorter, higher-intensity exercise, compared with longer, moderate-intensity exercise, is that it is likely that metabolic rate was slightly higher after high-intensity exercise, due to excess post-exercise oxygen consumption (EPOC). EPOC has been shown to occur after high-intensity exercise [26]. A greater metabolic rate after HIGH, compared with MOD, may have contributed to a perception of greater energy cost; although, the only likely perception of EPOC will likely have been a slightly more sustained elevation in heart rate and breathing rate in the immediate post-exercise period, meaning that much of any EPOC effect will have been unperceivable within just two to three minutes of the cessation of exercise. Further, the EPOC effect was most likely very small, especially over a period of just 30 minutes. EPOC has been shown to contribute minimally to the total energy expenditure of exercise [27], meaning only a minimal increase in energy expenditure will have occurred. Another potential explanation is that the participants may not have fully appreciated the difference in duration of each bout. Anecdotally, exercise can feel longer when it is strenuous, with exercises experiencing a perceived slowing of time when exercising hard. This may have been the case here, with little perceived difference in the duration of the two bouts. It would perhaps have been interesting to have obtained estimates of the duration of exercise, as well as the energy cost.

In both exercise conditions, $EI_{AD\ LIB}$. was significantly greater than exercise EE, resulting in a positive energy balance of +533 ± 357 kcal for MOD and +408 ± 448 kcal for HIGH. Such large positive energy balance values would indicate the absence of a prolonged post-exercise suppression of appetite, or "anorexia of exercise" effect [28]. While this phenomenon is commonly observed in the immediate post-exercise period after exercise of ≥ 60% VO_{2max}, [28-32], this is not always reflected by a decrease in energy intake [Deighton et al., 2012; 33, 34, 35] and rarely persists when an energy intake measure is obtained at ≥ 60 minutes post-exercise [31, 36, 37]. In the current study, it is worth noting that such a suppression appears to be absent, even after undertaking running exercise of an intensity of 90% VO_{2max} – a particularly high intensity of continuous, aerobic exercise that is rarely utilised in such studies. The large energy intake values, and hence large positive energy balance observed in the current study may have been influenced by the large food choice available at the *ad libitum* buffet meal. It has been previously shown that allowing excessive food choice, such as in a "cafeteria diet" can lead to overfeeding [38, 39]. However, it was considered preferable to offer an extensive food choice for the energy matching task, to assess the influence of food selection on matching ability.

It is acknowledged that this study provides a weak measure of post-exercise appetite. As a measure of appetite was not a primary aim of the current study, subjective measures of appetite were not recorded. While these would have been integral for a thorough investigation of the effect of the exercise bouts on post-exercise appetite, they were forfeited to ensure that decisions made during the EI_{MATCH} task were influenced minimally by thoughts of appetite and hunger. Further, participants were allowed to shower between completing the exercise bout and feeding, and the duration and temperature of the shower were not controlled. Therefore, it is likely that this will have impacted upon body temperature. As changes in body temperature has been proposed as a mechanism underpinning the post-exercise appetite response [40-42], showering may have influenced appetite and influenced appetite differential across the two trials.

The substantially greater energy intake when relieved of the constraints of the matching task ($EI_{AD\ LIB}$. intake exceeded EI_{MATCH} intake by a mean of 602 ± 358 kcal (91%) in MOD and 322 ± 332 kcal (42%) in HIGH) was due not only to a greater absolute food intake, but also due, in part, to the selection of more energy dense foods. The total energy density of the *ad libitum* intake was 27 kcal•100g^{-1} (25%) greater in MOD and 13 kcal•100g^{-1} (13%) greater in HIGH, compared with the corresponding matching task intakes. It would appear that this may have been partly driven by a greater fat intake in the *ad libitum* feeding, with the percentage of total energy derived from fat significantly greater in the $EI_{AD\ LIB.}$ intake, compared with EI_{MATCH} (26.6% vs. 20.0%, data pooled for HIGH and MOD). Therefore, it would seem that individuals attempted to restrict energy intake in the matching task by not only eating less food, but also by successfully selecting less energy dense foods and foods lower in fat, or by avoided high calorie, fatty foods.

In light of the findings of this study, that individuals posses a strong ability to consciously match energy intake with energy expenditure, it may be worth asking the question: if this is the case, then why do people gain weight initially and fail to lose weight when initiating in weight-loss strategies involving increased physical activity? Firstly, it is likely that those that gain weight initially are those that do not exercise regularly, hence an ability to match intake with exercise-induced energy expenditure, whether consciously or not, is irrelevant. However, some exercisers do gain weight and some that begin exercising regularly in an attempt to lose weight fail to do so. It is possible that habitual eating behaviour can override any matching ability. Individuals' varying degree of eating restraint [43-45], emotional eating [44] and external eating [46] have all been implicated in weight-gain and the pathology of obesity, as well as in the success of attempted weight-loss [47, 48]. In the current study, *ad libitum* energy intake considerably exceeded the EI_{MATCH} intake and the exercise energy expenditure in both conditions, with large positive energy balances recorded (+533 ± 357 kcal and +408 ± 448 kcal for MOD and HIGH respectively). This suggests that when participants were free to consume as much as they desired, from a buffet-style meal providing considerable external food cues to the participant, little eating restraint was used and a restriction of food intake was not observed.

It should be noted that the participants in the current study were healthy-weight, low-activity level individuals. It may be the case that healthy-weight individuals do possess a strong ability to consciously match energy intake with energy expenditure, hence why they are not overweight. Those that are overweight and obese may exhibit a much poorer matching ability and this may have contributed to their weight-gain. It would be of interest to repeat the current study with overweight and obese participants.

1.6 CONCLUSION

In summary, participants demonstrated a strong ability to consciously match energy intake with exercise-induced energy expenditure after aerobic exercise at both a moderate- and high-intensity. It would appear that an undervaluation of the energy cost of exercise, particularly that of a moderate intensity was countered by an undervaluation of the energy content of food. Participants perceived exercise of a high intensity to be more energetic than that of isocaloric exercise of a moderate intensity, which may suggest that perception of energy expenditure is driven more by intensity than duration of exercise. This may have implications for the types of exercise bouts recommended during exercise regimes utilised as part of a weight-management strategy. Despite the conscious ability to match energy intake with exercise-induced energy expenditure, participants exhibited little restraint when the restriction of the energy matching task was lifted, resulting in large *ad libitum* intakes and acute positive energy balance. Hence, there was no evidence of a lasting post-exercise suppression of appetite, resulting in reduced food intake 60 minutes after exercise. This was despite a bout of running at 90% VO_{2max}. It remains to be seen whether such a sound matching ability is possessed by overweight and obese individuals, as well as the healthy-weight individuals of the current study.

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APPENDICES

Appendix 1. Buffet meal content, with nutritional information

Food item	Energy density (kcal•100g^{-1})	Carbohydrate (grams•100g^{-1})	Fat (grams•100g^{-1})	Protein (grams•100g^{-1})
Mixed leaf salad	19	1.5	0.5	2.2
Savoury rice	122	25.4	1	2.9
Strawberry yoghurt	80	12.6	1	5.3
Apple	49	11.6	0.1	0.4
Banana	95	20.9	0.3	1.2
Chocolate biscuit	520	62.4	27.7	5.2
Cookies	508	67.0	23.9	6.2
Bread	253	63.3	0.7	0.7
Chicken breast	148	0.1	2.2	32
Cheese (red Leicester)	399	0.1	23.8	33.7
Ham	118	0.9	2.8	22.3
Mini sausage roll	422	26.7	31.1	8.7
Mini blueberry muffins	293	65.2	8.1	6.3
Boiled potatoes	75	17.8	0.3	1.5
Pasta	357	73.1	1.7	12.3
Pasta sauce	105	22.4	0.2	3.5
Tuna	113	0.1	0.5	27
Cereal bar	391	72.8	8.8	5.1
Strawberry jam	253	63.3	0.7	0.7
Salad dressing (balsamic)	316	13.8	28.8	0.4
Salad dressing (honey and mustard)	366	15.4	33	1
Crisps)	538	47.4	36.8	4.3
Jelly beans	365	90.3	0.4	0.1
Margarine	354	2.8	38	0.1
Mayonnaise	298	6.5	29.8	0.7
Orange juice	42	9.1	0.1	0.5
Apple juice	44	10.4	0.1	0.1
Apple and blackcurrant squash	2	0.2	0.1	0.1
Pepsi	44	11.1	0	0

Appendix 1: Standardised breakfast meal content

Food	Portion	Energy (kcal)	Carbohydrate (g)	Fat (g)	Protein (g)
Toast	2 slices (~90g)	198	36.3	2.0	8.7
Margarine	~ 16g	57	0.4	6.1	0
Jam	~ 30g	76	19	0.2	0.2
Orange juice	200 ml	84	18.2	0.2	1
Apple juice	200 ml	88	20.8	0.2	0.2
TOTAL (based on addition of jam and selection of orange juice)		415	73.9	8.5	9.9