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

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28 1.1 ABSTRACT

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

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

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

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

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

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60 **KEYWORDS:** Energy balance, weight management, weight-loss, food intake, eating
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78 **1.2 INTRODUCTION**

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

94 To the best knowledge of the authors, only two studies have acutely and directly
95 assessed individuals' ability to estimate acute energy expenditure and intake. Harris and George
96 [18] asked participants to estimate their energy expenditure after a 60 minute bout of treadmill
97 exercise, at 65% of predicted maximum heart rate. Fifteen minutes post-exercise, an *ad libitum*
98 buffet meal was provided. The participants were then asked to estimate their energy intake at an
99 *ad libitum* meal. Estimated energy expenditure was significantly greater than the actual energy
100 expenditure of the exercise bout. Conversely, estimated energy intake was significantly lower
101 than actual intake, with participants eating almost twice as many calories as estimated. Willbond
102 and colleagues [19] conducted a similar study, but after exercise (a 200kcal and a 300kcal bout
103 of treadmill running at 50% $\text{VO}_{2\text{peak}}$), participants were asked to estimate the energy expenditure

104 of the exercise bout and then consume the caloric equivalent from a buffet meal. The energy
105 expenditure of exercise was significantly and substantially overestimated, with estimates 3-4
106 fold greater than actual expenditure. Intake significantly exceeded expenditure, by 2-3 fold.
107 However, it may be argued that with such low total energy cost of exercise, overcompensation
108 is likely. In addition, it is likely that the perception of energy cost of exercise is dependent on
109 the intensity, as well as the duration of exercise.

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

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130 **1.3 MATERIALS AND METHODS**

131 **1.3.1 Participants:** Fourteen healthy-weight, low- to moderately active individuals were
132 recruited primarily from The School of Sport, Exercise and Rehabilitation Sciences, University
133 of Birmingham. The characteristics of the participants are shown in **table 1**. The criterion for
134 low to moderately active was a score of < 3000 METS on the International Physical Activity
135 Questionnaire (IPAQ). Those suffering from illness such as cold or flu, those taking medication
136 that was likely to affect appetite or that needed to be taken with food more frequently than once
137 a day, those with food allergies and those suffering from diabetes were excluded from taking
138 part. Ethical approval was obtained from the Ethics Committee of the University of
139 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
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142 **Table 1.** Participant characteristics. Values are mean ± SD.
143 * VO_{2max} value for nine participants, VO_{2peak} value for five participants.

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145 **1.3.2 Study design:** A within-subject, randomised cross-over study design was utilised,
146 with participants randomly allocated to each of two exercise intensity conditions, termed
147 moderate intensity (MOD – 60% VO_{2max}) and high intensity (HIGH - 90% VO_{2max}).

148 **1.3.3 Preliminary testing:** A single session of pre-testing preceded the study protocol in
149 order to calculate specific exercise intensities to be used for each participant. Participants
150 reported to the Exercise Metabolism Laboratory, in the School of Sport, Exercise and
151 Rehabilitation Sciences, University of Birmingham after an overnight fast. The participant
152 information pack was administered and explained and the participant was given the opportunity

153 to ask any questions regarding the study, prior to providing written consent for their
154 participation. A health questionnaire was completed as a means of a health screening procedure
155 and The International Physical Activity Questionnaire (IPAQ) was completed as a measure of
156 habitual physical activity. Height and weight were then recorded. An incremental exercise test
157 to volitional exhaustion was then completed on a motorised treadmill (H/P/ Cosmos. Nußdorf,
158 Germany) in order to obtain VO_{2max} and HR_{max} values and to establish the relationship between
159 running speed and rate of oxygen uptake. To achieve this, the test comprised of two
160 components: a constant gradient, steady-state component during which the relationship between
161 running speed and rate of oxygen uptake was calculated; followed by a rapid speed and gradient
162 increase component, from which maximum oxygen uptake (VO_{2max}) was calculated. The test
163 began at a speed of 6 km h^{-1} and a gradient of 1%. Each stage in the initial section of the test
164 lasted 3 minutes. The speed was increased to $8 \text{ km}\cdot\text{h}^{-1}$ at stage 2 and $10 \text{ km}\cdot\text{h}^{-1}$ at stage 3. From
165 there on, the speed increased by $1 \text{ km}\cdot\text{h}^{-1}$ at each stage with the gradient remaining constant at
166 1%. This protocol was followed until an RER of 1.00 was reached. At this point, component
167 two of the test commenced. Stages were shortened to 1 minute in duration and with each stage,
168 speed or gradient increased in alternating fashion, by 1 km h^{-1} and 1% respectively. Participants
169 were adjudged to have reached the end of the test when they voluntarily stopped running, if VO_2
170 ceased to increase with increasing workload or if it was felt that the participant was struggling
171 to maintain the speed of the treadmill belt. Breath-by-breath measures of exhaled gas, averaged
172 every eight breaths, were recorded using Oxycon Pro (Jaeger, Wuerzburg, Germany) apparatus.
173 Prior to incremental exercise test, the gas analysers were calibrated using a calibration gas
174 (BOC Gases, Guildford, Surrey, UK) of mixed, known concentrations of O_2 (14.99%) and CO_2
175 (5.04%) and volume was calibrated using a 3 litre calibration syringe (Jaeger, Wuerzburg,
176 Germany). Exhaled gas was collected throughout the entire test, but submaximal VO_2 values
177 were obtained for each stage during the steady-state component of the test only from air
178 collected during the final minute of the 3 minute stage. VO_{2max} was calculated as the highest
179 average value obtained for any one minute period. From the VO_{2max} value obtained, linear

180 regression was used to calculate an estimate for the speed that would elicit the desired VO_2 for
181 each exercise session, equating to exercise intensities of 60% and 90% $\text{VO}_{2\text{max}}$.

182 ***1.3.4 Procedures & protocol:*** After a minimum period of 3 days after pre-testing,
183 participants returned to the Exercise Metabolism Laboratory after a 10 hour overnight fast for
184 the first of two exercise trials. Participants were provided with a standardised breakfast meal.
185 This consisted of two slices of toast (Thick slice, 50/50 bread, ~90g), margarine (~16g), jam
186 (mixed fruit, ~30g) with a choice of orange or apple juice (~200ml). The addition of jam was
187 optional, although the breakfast selections made at the first trial were repeated for the second.
188 The approximate energy content of this meal was 415 kcal (71% energy from carbohydrate,
189 19% from fat and 10% protein), based on the addition of jam and selection of orange juice.
190 Once the breakfast was consumed, the participant began a two-hour rest period before the
191 exercise bout commenced. The participant remained sedentary within the laboratory, leaving
192 them free to watch television, read or use a computer.

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

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

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

226 After the energy matching task had been completed, the participant returned to the
227 Exercise Metabolism Laboratory to remain seated until the buffet food had been re-weighed.
228 During this time, they were asked to provide a verbal estimate of the energy expenditure of the
229 exercise bout. After the re-weighing was completed, they were informed that the trial was
230 finished. They were then told that they were free to consume any more food that they wished
231 from the buffet. Participants commenced this second sitting at approximately 60 minutes post-
232 exercise (56 ± 7 min.; 53 ± 4 min. for MOD and 58 ± 7 min. for HIGH). Food intake was
233 covertly recorded, with the buffet food being re-weighed again after the participant had finished

234 eating. The energy intake at this sitting was added to the intake of the energy matching task to
235 provide an *ad libitum* energy intake value ($EI_{AD\ LIB.}$).

236 **1.3.5 Measures:** Energy expenditure (EE) was measured, in kcal, for both exercise
237 bouts. This was calculated from exhaled air collected intermittently during the bout. Mean rate
238 of oxygen utilisation (VO_2) and RER were calculated and energy expenditure was estimated
239 using the RER-specific caloric equivalent of oxygen. EI_{MATCH} and $EI_{AD\ LIB.}$ were measures as
240 described above, from the buffet meal provided and recorded in kcal. The verbal estimate of
241 energy expenditure (EST) was recorded as a further outcome measure.

242 **1.3.6 Statistical analysis:** All values stated are mean values \pm standard deviation (SD)
243 in text and tables and mean \pm standard error of the mean (SEM) in figures. Mean EE, EI_{MATCH}
244 and EST values were investigated for energy measures and trial differences using a 3x2 repeated
245 measures factorial ANOVA. Energy measures and trial comparisons of EE and $EI_{AD\ LIB.}$ were
246 assessed by conducting a further 2x2 repeated measures factorial ANOVA. Comparisons of the
247 dietary intakes for the EI_{MATCH} and $EI_{AD\ LIB.}$ tasks in both conditions were made by conducting
248 separate 2x2 repeated measures factorial ANOVA for each dietary characteristic investigated
249 (total energy density, carbohydrate intake, fat intake and protein intake). Significant interactions
250 and main effects from all ANOVA were further assessed by pairwise comparisons, using
251 Bonferroni post-hoc analysis. Statistical significance level of $p < 0.05$ was in use for all
252 comparisons. All statistical analysis was carried out using the SPSS software programme (SPSS
253 inc., Chicago, Illinois, USA).

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258 **1.4 RESULTS**

259 **1.4.1 Exercise trials:** Physiological measures of each exercise trial condition are shown
 260 in **table 2**. As intended, the exercise intensity was significantly different between the two
 261 exercise trials. Absolute and relative intensity, represented by absolute VO₂, absolute heart rate
 262 and percentage of VO_{2max} and percentage of maximum heart rate was significantly greater in
 263 HIGH, compared with MOD (all p < 0.001). Duration of exercise was significantly greater for
 264 MOD compared with HIGH (p < 0.001), while energy expenditure was the same for both
 265 conditions.

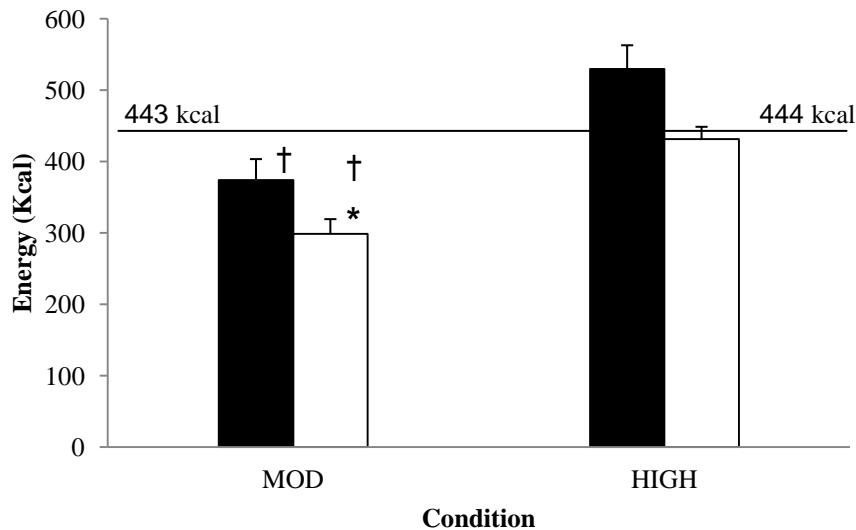
	<i>MOD</i>	<i>HIGH</i>
VO ₂ (L•min ⁻¹)	2.00 ± 0.42	2.99 ± 0.59*
% VO _{2max}	60.4 ± 2.9	91.6 ± 4.6*
Heart rate (bpm)	137 ± 16	176 ± 9*
% HR _{max}	72 ± 6	91 ± 5*
Perceived Exertion	10 ± 2	15 ± 1*
Duration (min)	46.6 ± 8.8	30.2 ± 4.9*
Energy Expenditure (kcal)	443 ± 22	444 ± 21

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 268 **Table 2.** Characteristics of exercise. Values are mean ± SD. * = significant difference between
 269 MOD and HIGH, p < 0.001.
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271 **1.4.2 Energy expenditure, energy intake of the matching task and verbal estimate:**
 272 Mean energy expenditure, energy estimate and energy matching task energy intakes are shown
 273 in **figure 1**. There was a significant condition (exercise intensity) x energy measure (EE,
 274 EI_{MATCH}, EST) interaction (F(2) = 7.903, p = 0.002). Pairwise comparisons for within-condition
 275 effects demonstrated that, in the MOD condition, EST was significantly lower than EE (298 ±
 276 156 kcal vs. 443 ± 22 kcal, p = 0.01). There was no significant difference between EST and
 277 EI_{MATCH} (298 ± 156 kcal vs. 374 ± 220 kcal, p = 0.123). EE and EI_{MATCH} were similar. In the
 278 HIGH condition, there were no significant differences between EE, EI_{MATCH} and EST. Pairwise
 279 comparisons for between condition effects showed that EI_{MATCH} and EST were both

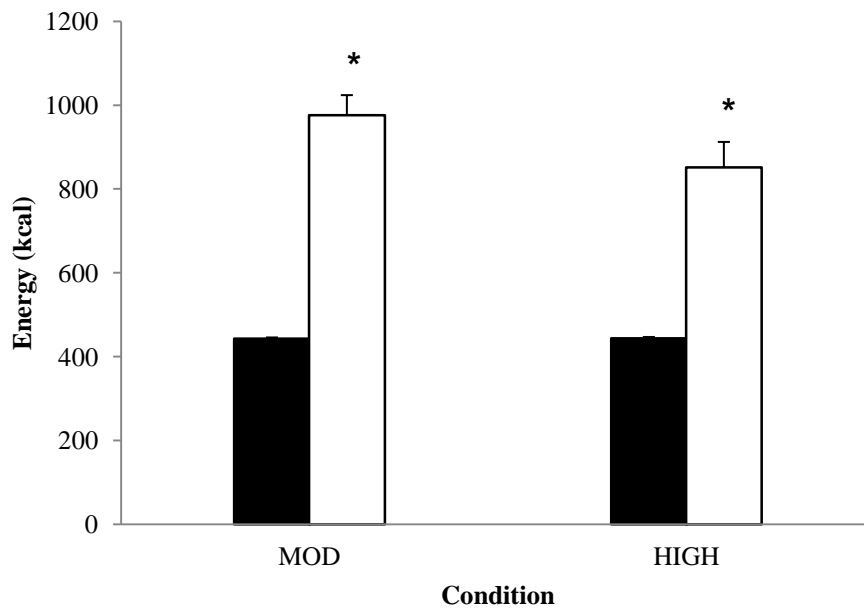
280 significantly greater after HIGH, compared with MOD (530 ± 248 kcal vs. 374 ± 220 kcal, $p =$
281 0.002 and 431 ± 129 kcal vs. 298 ± 156 kcal, $p = 0.002$ respectively).

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283 **Figure 1.** Energy expenditure, energy intake at the matching task and verbal EST of energy
284 expenditure. Values are means \pm SEM. Black bars = EI_(MATCH), white bars = EST. Solid line
285 indicates mean EE of 443 kcal for MOD, 444 kcal for HIGH. * = within-condition effect,
286 significant different to EE. † = between-condition effect, significant different to HIGH.
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289 **1.4.3 Ad libitum energy intake:** Ad libitum energy intake for both the MOD and HIGH
290 conditions, along with the energy expenditure of exercise is shown in **figure 2**. A significant
291 energy measure main effect was observed, with EI_{AD LIB} significantly greater than EE (914 ± 406
292 kcal vs. 443 ± 22 kcal, $F(1) = 23.706$, $p < 0.001$). There was no significant interaction, nor
293 condition main effect.



294 **Figure 2.** Energy expenditure and *ad libitum* energy intake. Values are mean \pm SEM. Filled bars
 295 = EE, empty bars = EI_{AD LIB}. * = EI_{AD LIB}. significantly different to EE.
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298 **1.4.4 Food selection: energy density and macronutrient intake:** The total energy
 299 density (expressed as kcal per 100g) and macronutrient content of the meal consumed
 300 (expressed in percentage of total energy consumed) are shown in **table 3** Energy density of the
 301 meal selected did not differ between conditions, however, a task main effect was present,
 302 demonstrating that energy density was significantly greater during the *ad libitum* intake,
 303 compared with the matching intake (112 kcal \cdot 100g⁻¹ vs. 92 kcal \cdot 100g⁻¹, F(1) = 11.736, p =
 304 0.005). The percentage of total energy derived from carbohydrate and protein did not differ
 305 between condition and task. There was a significant task main effect for percentage of total
 306 energy obtained from fat (F(1) = 7.951, p = 0.015). Pairwise post-hoc comparisons showed that
 307 there was a greater percentage of energy from fat consumed in the EI_{AD LIB}. task, compared with
 308 EI_{MATCH} (26.6% vs. 20.0%, p = 0.021).

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	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

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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}

334 1.5 DISCUSSION

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

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

359 It would appear that an underestimate of the caloric content of food compensated for an
360 undervaluation of the energy of moderate-intensity exercise. EI_{MATCH} was, on average, 117 kcal

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

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

383 This may be particularly pertinent for those susceptible to increasing food intake due to using
384 food as a reward. As eating palatable food is a pleasurable experience for the majority of individuals,
385 some use food as a means of reward following behaviour that is deemed an achievement or reward-
386 worthy. One such behaviour may be the undertaking of a bout of exercise. While it would appear that
387 neural responses in areas of the brain associated with the reward system are decreased immediately
388 post-exercise [24]; Crabtree, D. PhD thesis, University of Birmingham), possibly explaining the

389 “anorexia of exercise” phenomenon, there is now also evidence for increases in reward system
390 activation in the hours after exercise, sensitising it to images of food (Crabtree, D. PhD thesis,
391 University of Birmingham). In addition, Finlayson and colleagues [25] found that some overweight
392 and obese individuals exhibited increased liking and wanting of food items (components of the reward
393 construct) following exercise . Further, those that did demonstrate this response were those who failed
394 to experience weight-loss with a 12-week exercise programme. If exercise does sensitise individuals
395 to the use or abuse of food as a reward and increase explicit wanting of food, then the perception of a
396 less energetic bout may lower subsequent intake resulting from this response, as the conscious,
397 explicit components of rewarding exercise may be reduced. Therefore, lower-intensity, longer
398 duration bouts may prove preferable to shorter, higher intensity isocaloric bouts when devising
399 exercise regimen to facilitate weight-loss.

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

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

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

441 The substantially greater energy intake when relieved of the constraints of the matching task
442 ($EI_{AD\ LIB.}$ intake exceeded EI_{MATCH} intake by a mean of 602 ± 358 kcal (91%) in MOD and 322 ± 332
443 kcal (42%) in HIGH) was due not only to a greater absolute food intake, but also due, in part, to the

444 selection of more energy dense foods. The total energy density of the *ad libitum* intake was 27
445 kcal•100g⁻¹ (25%) greater in MOD and 13 kcal•100g⁻¹ (13%) greater in HIGH, compared with the
446 corresponding matching task intakes. It would appear that this may have been partly driven by a
447 greater fat intake in the *ad libitum* feeding, with the percentage of total energy derived from fat
448 significantly greater in the EI_{AD LIB.} intake, compared with EI_{MATCH} (26.6% vs. 20.0%, data pooled for
449 HIGH and MOD). Therefore, it would seem that individuals attempted to restrict energy intake in the
450 matching task by not only eating less food, but also by successfully selecting less energy dense foods
451 and foods lower in fat, or by avoided high calorie, fatty foods.

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

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

472 contributed to their weight-gain. It would be of interest to repeat the current study with overweight
473 and obese participants.

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497 **1.6 CONCLUSION**

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

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521 **1.7 REFERENCES**

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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

660 **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

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