

1 **Effects of a twelve-week exercise intervention on subsequent compensatory behaviours**  
2 **in adolescent girls: an exploratory study**

3 **Purpose:** Chronic exercise programmes can induce adaptive compensatory behavioural  
4 responses through increased energy intake (EI) and/or decreased free-living physical activity  
5 in adults. These responses can negate the benefits of an exercise-induced energy deficit;  
6 however, it is unclear whether young people experience similar responses. This study  
7 examined whether exercise-induced compensation occurs in adolescent girls. **Methods:**  
8 Twenty-three adolescent girls, heterogeneous for weight status, completed the study. Eleven,  
9 13-year-old adolescent girls completed a twelve-week supervised exercise intervention (EX).  
10 Twelve body size matched girls comprised the non-exercise control group (CON). Body  
11 composition, EI, free-living energy expenditure (EE) and peak oxygen uptake ( $\dot{V}O_2$ ) were  
12 measured repeatedly over the intervention. **Results:** Laboratory EI (EX: 9027, 9610, 9243  
13  $\text{kJ}\cdot\text{d}^{-1}$  and CON: 9953, 9770, 10052  $\text{kJ}\cdot\text{d}^{-1}$  at 0, 12 and 18 weeks respectively) ( $ES = 0.26$ ,  $P =$   
14  $0.46$ ) and free living EI (EX: 7288, 6412, 5273, 4916  $\text{kJ}\cdot\text{d}^{-1}$  and CON: 7227, 7128, 6470,  
15  $6337 \text{kJ}\cdot\text{d}^{-1}$  at 0, 6, 12 and 18 weeks respectively) ( $ES \leq 0.26$ ,  $P = 0.90$ ) did not change  
16 significantly over time and were similar between groups across the duration of the study.  
17 Free-living EE was higher in EX than CON (13295 vs. 12115  $\text{kJ}\cdot\text{d}^{-1}$ ,  $ES \geq 0.88$ ,  $P \geq 0.16$ ),  
18 but no significant condition by time interactions were observed ( $P \geq 0.17$ ). **Conclusion:** The  
19 current findings indicate that compensatory changes in EI and EE behaviours did not occur at  
20 a group level within a small cohort of adolescent girls. However, analysis at the individual  
21 level highlights large inter-individual variability in behaviours, which suggest a larger study  
22 may be prudent to extend this initial exploratory research.

23 **Keywords:** adolescent girls, energy compensation, energy intake, energy expenditure,  
24 physical activity, intervention

## 25 **Introduction**

26 The annual Health Survey for England shows that many 11 to 15 year old girls and boys do  
27 not reach the international recommended daily accumulated level of physical activity (PA)  
28 for health (60 min per day) and approximately 32% of 11 to 15 year old children are  
29 overweight or obese (23). These body size related problems arise when a person is in a state  
30 of energy imbalance (energy intake (EI) is greater than energy expenditure (EE)). Despite  
31 increasing EE, weight loss and maintenance are not always possible in the long term (40).  
32 Whilst lack of motivation and adherence to the programme have often explained the  
33 ineffectiveness of exercise for weight loss (24,27), research with high intervention adherence  
34 rates has suggested the problem could be a result of compensatory disruptions to energy  
35 balance as a consequence of expending energy (12,28). Due to the dynamic and closely  
36 related components of energy balance, the measurement of EI, EE and body composition is  
37 necessary to examine potential compensatory behaviours (30).

38 ‘Compensation’ refers to the behaviours that negate the positive health benefits accrued from  
39 increasing PA; for example, an increase in EI or decrease in free-living activity EE. Indeed,  
40 exercise-induced energy expenditure (ExEE) can create negative energy balance, but  
41 increasing subsequent EI in the post-exercise period can rapidly reverse these effects and  
42 even result in a positive energy balance.

43 The majority of acute (<1 week) studies in adults report no meaningful increase in  
44 subsequent EI post-exercise (36). However, there is some evidence in adults of exercise-  
45 induced compensation after approximately three weeks of regular exercise; hence, measuring  
46 energy compensation over a period longer than fourteen days to capture any compensatory  
47 behaviour has been recommended (41). This evidence further suggests that exercise-induced  
48 weight loss is complex with large inter-individual variability after completing an exercise  
49 programme (26). Further research focusing on compensatory changes related to free-living

50 EE, resting metabolic rate (RMR) or lean mass, in addition to EI, has also been suggested  
51 (42). Nevertheless, it would appear that compensation is an important factor in understanding  
52 why some adults benefit (e.g. lose weight) when they complete an exercise programme  
53 whereas others, completing the same programme, do not.

54 The interaction between exercise and compensatory responses is in its infancy in young  
55 people. The available evidence is derived predominantly from acute exercise studies and  
56 research that has focused on only one behavioural component in isolation – either EI  
57 (17,34,48,49) or EE (7,20,21,45). In general, the compensatory responses observed after an  
58 acute bout of exercise are inconsistent. This is perhaps unsurprising given the array of  
59 exercise stimuli and experimental designs employed. However, a recent systematic review  
60 and meta-analysis concluded that whilst acute exercise does not appear to affect EI in lean  
61 youth, intense exercise (>70% of an individual's maximal capacity) appears to reduce EI in  
62 adolescents with obesity (50). Additionally, empirical data support the notion that both the  
63 timing and characteristics of an acute exercise bout might modulate compensatory  
64 behaviours. Lower EI was observed when moderate to vigorous physical activity (MVPA)  
65 was performed immediately before meal consumption compared with prior light physical  
66 activity in very young children (32). In the first study to directly investigate exercise timing  
67 in relation to EI, a meal consumed in close proximity to a 30 min bout of MVPA, led to a  
68 reduction in EI compared to when the meal was delayed for 2 hours in 15 to 20 year old  
69 males (3).

70 Chronic exercise intervention studies ( $\geq 3$  weeks duration) examining exercise-induced  
71 energy compensation with adolescents are limited, and have examined EI and EE  
72 independently. A study in which participants were prescribed a six-week activity and diet-  
73 induced energy deficit showed that exercise can lead to weight loss if EI compensation does  
74 not occur (25). However, the group were completing a large volume of exercise during an

75 activity camp (6 h·d<sup>-1</sup>), which is not representative of normal daily activities. A secondary  
76 analysis of data collected in the GameBike trial (1) showed marginal decreases in EI in  
77 response to a 10-week PA programme (46). The two available studies examining exercise-  
78 induced changes in total energy expenditure (TEE) reported no evidence of compensatory  
79 behaviours (9,51). When chronic compensatory behaviours in adolescents with obesity are  
80 considered, a meta-analysis of nine physical activity interventions, ranging from 3 to 12  
81 months in duration, concluded that PA interventions favour a reduction in EI in this  
82 population but reiterated the clear need for further empirical research to confirm this finding  
83 (37). It is necessary to measure EI and EE compensatory behaviours simultaneously due to  
84 the dynamic interactions between these components and their subsequent influence on energy  
85 balance (47). Extending the available research, which has been conducted in young people,  
86 will further our understanding of compensatory behaviours and exercise EE as a viable  
87 vehicle for influencing paediatric health.

88 This study examined whether adolescent girls experience exercise-induced compensatory  
89 behaviours and whether there is variation in compensatory behaviours between individuals  
90 completing a chronic twelve-week exercise programme compared with a body size matched  
91 non-exercise control group. Although body mass and composition measures were included as  
92 study outcomes, it is important to note that weight reduction was not a study objective.

93

## 94 **Methods**

### 95 *Participants*

96 Thirty-one adolescent girls aged 12 to 15, from two local secondary schools, volunteered to  
97 participate in this study. Fifteen girls from one school were assigned to the exercise  
98 intervention group (EX), whilst the remaining 16 girls from the other school were assigned to  
99 a non-exercise control group (CON). EX and CON were assigned, non-randomly, at the  
100 school level to minimise contamination and promote retention associated with friendship  
101 groups (31). The study received approval from NHS-REC (14/EM/0205) and University  
102 Ethical Advisory Committee (R13-P168). Participant assent and parental informed consent  
103 were obtained from each participant prior to the study.

104 Results are presented for the 23 girls who completed the study (EX = 11; CON = 12). Four  
105 girls in CON dropped out of the study, one for no defined reason, and three due to conflicting  
106 family commitments. Four girls in EX did not complete the study due to injury (not  
107 associated with the intervention), relocation and a friend dropping out of the study.

108

### 109 *Experimental Design*

110 An 18 week, non-random, controlled prospective study was conducted in which EX  
111 completed a twelve-week exercise programme, whilst CON continued with normal daily  
112 activities for the duration of the intervention. Anthropometry and free-living EI and EE  
113 behaviours were assessed pre- (week 0), mid- (week 6), post- (week 12) intervention and  
114 after a six week follow up period (week 18). Laboratory-based measures of EI were collected  
115 in weeks 0, 12 and 18. Body composition data (DXA) were collected in weeks 0 and 12.

116 A twelve-week supervised exercise programme was completed by EX. Three 30 min exercise  
117 sessions, at an intensity equivalent to 60 to 70% peak oxygen uptake ( $\dot{V}O_2$ ), were completed  
118 each week at the University or participants' school. Exercise sessions at the school took place

119 after lessons between 15:30 and 16:30. The timing of the exercise sessions at the University  
120 varied to accommodate participant availability and increase retention (start times ranged from  
121 08:00 to 16:00). Participants were asked to maintain their heart rate (HR) within an individual  
122 target training zone and the research team monitored this regularly during each session.  
123 Exercise intensity was quantified using downloadable HR monitors (Polar RS400). The  
124 exercise programme consisted of a variety of activities including team games, circuits, dance,  
125 running and cycling. The third exercise session in weeks 6 and 12 was a sub-maximal and  
126 maximal treadmill test in the laboratory for the purpose of Actiheart recalibration and  
127 reassessment of cardiorespiratory fitness (CRF; peak  $\dot{V}O_2$ ).

128

### 129 *Body size-composition and biological maturation*

130 Anthropometry was completed at the University in weeks 0, 6, 12 and 18. Stature was  
131 recorded to the nearest 0.01 m using a stadiometer (Holtain Ltd, Crosswell, UK) and body  
132 mass to the nearest 0.1 kg using digital scales (Seca, Hamburg, Germany). Waist  
133 circumference was measured to the nearest 0.1 cm using a non-stretch tape measure. Body  
134 composition was assessed in weeks 0 and 12 by whole body DXA scan (Lunar Prodigy  
135 Advance, GE Medical Systems Lunar, Belgium). A standardised procedure for participant  
136 positioning for a total body scan was used. Participants were asked to wear the same light  
137 clothing for each scan, to remove all artefacts that could interfere with the scan and to empty  
138 their bladder immediately prior to each scan. The scans were re-analysed using iDXA  
139 paediatric software, as the Lunar Prodigy did not have paediatric software available to access  
140 age-specific algorithms. Participants were asked to provide a self-assessment of physical  
141 maturity using the Tanner pictorial rating system (43). In weeks 0, 6, 12 and 18 a four-stage,  
142 sub-maximal treadmill test and incremental treadmill test to exhaustion were completed to  
143 measure peak  $\dot{V}O_2$  and calibrate the Actiheart. Participants wore a face mask (Hans Rudolph,

144 USA) and expired air was analysed continuously using an online system that measures breath  
145 by breath ventilation, expired oxygen and expired carbon dioxide (Cosmed K4b<sup>2</sup>, Cosmed,  
146 Rome, Italy). The criteria used to define the attainment of peak  $\dot{V}O_2$  was the presence of a  
147 plateau in  $\dot{V}O_2$  ( $\leq 3\%$ ) with an increase in exercise intensity (i.e., treadmill gradient); a peak  
148 HR  $\geq 95\%$  age-predicted maximum (220 – chronological age); a respiratory exchange ratio of  
149  $\geq 1.05$ ; and clear subjective signs of fatigue (4).

150

### 151 *Dietary energy intake (EI)*

152 Before starting the study, participants were asked to complete the Dutch Eating Behaviour  
153 Questionnaire for children (DEBQ-c) (52) and a food preference questionnaire to assess  
154 eating behaviours and food preferences, respectively. Dietary intake was measured using two  
155 complimentary methods. Objective dietary intake was measured using a laboratory-based  
156 buffet meals day protocol. Each participant took part in four buffet meal testing days. The  
157 first day was used to familiarise participants with the environment and food availability, with  
158 the second buffet meals day conducted four days later. Following a 10 h overnight fast,  
159 participants attended the laboratory in pairs or groups of three at 07:30 for the buffet meals  
160 day. Participants rested in the laboratory for 10 h and five buffet test meals/snacks were  
161 provided. Test meals/snacks were provided at prescribed times reflecting a typical school  
162 day; breakfast 08:00, snack 10:30, lunch 13:00, snack 15.00 and evening meal 17.00.

163 Participants were shown to their buffet meal feeding room, in which food was presented in  
164 excess of expected consumption, and told they were free to choose whatever they wanted to  
165 eat until satisfied and were not restricted by time. Participants selected and consumed meals  
166 alone to reduce the influence of social distractions on selection and intake. Food and drink  
167 were weighed by the lead author using digital kitchen scales before and after each meal to  
168 determine EI via dietary analysis using CompEat Pro (Version 5.8.0, Nutrition Systems,

169 Banbury, UK). There was no laboratory EI measurement in week 6 because the girls were not  
170 granted permission to be absent from school. The buffet meals included the following food  
171 items: cereals, semi-skimmed milk and croissants for breakfast; fruit, various cereal bars and  
172 biscuits for snacks; various sandwich fillings, low-fat dairy spread, brown and white sliced  
173 bread, a variety of potato chips and fruit for lunch; pasta, tomato-based sauce, garlic bread  
174 and muffins for dinner.

175 Participants also completed a photographic food intake diary of all food, drinks and leftovers  
176 using a digital camera (Kodak EasyShare C142, New York, US) for three days in weeks 0, 6,  
177 12 and 18. Digital photographs were taken from a 45° angle, ensuring the whole plate could  
178 be seen in the photograph. Participants were instructed to check the photo - if the photo was  
179 blurred or missing some of the plate, they were asked to delete the photo and retake it.

180 Participants were asked to follow the same protocol of photographing the food for all meals  
181 and snacks. A step-by-step guide of how to take photographs was provided to all participants  
182 for reference. A photographic food atlas for secondary school children (18) was used by the  
183 researchers to analyse the photographs. The food atlas image most closely resembling the  
184 type and portion size of each food item consumed was used to estimate the weight of that  
185 food from the database. If no leftover photograph was present, it was assumed all food was  
186 consumed. Participants had been asked to empty any packets of leftover food out onto the  
187 plate; therefore, any packets photographed were assumed to be empty.

188 A written diary was also completed to supplement the photographic record. The diary  
189 included a description of the food/drink consumed including the name and brand. A single  
190 researcher entered all weights into CompEat Pro, to estimate EI for each participant.

191

192 *Free-living estimated energy expenditure*

193 Participants were asked to wear an Actiheart monitor, positioned horizontally on the upper  
194 chest, for seven consecutive days in weeks 0, 6, 12 and 18. The Actiheart was set-up and  
195 fitted by the researcher to record at a 15 second epoch. The data were downloaded to estimate  
196 both total energy expenditure (TEE) and activity energy expenditure (AEE) using the  
197 appropriate branched equation model (Child: Group Act/Ind HR) within the Actiheart  
198 Software. The Actiheart software was used to clean and recover or interpolate noisy and  
199 missing HR data for gaps of < 5 min. To limit the impact of missing values and non-wear  
200 time on the results, minute-by-minute AEE missing values were replaced with a mean  
201 estimate of minute-by-minute AEE of the same day. Only participants with four valid days  
202 (including one weekend day) were considered for data analysis. A valid day was considered  
203 to be when data were available for  $\geq 70\%$  of the day, including time spent sleeping ( $\geq 1008$   
204 min) (35). When exercise sessions overlapped a period of free-living EE measurement, EE  
205 for this time period was replaced with measured REE values to ensure an appropriate  
206 examination of possible compensation between EX and CON.

207 Energy expenditure at rest was measured in a fasted state prior to the buffet meals day in  
208 weeks 0, 12 and 18. Participants lay in the supine position for 20 min and expired air was  
209 analysed continuously using a Cosmed gas-exchange device (K4b2, Cosmed, Rome, Italy).  
210 The data were averaged over 5 min periods and the lowest  $\dot{V}O_2$  and  $\dot{V}CO_2$  values were used  
211 to estimate resting energy expenditure (REE) (19). These data were used with the sub-  
212 maximal exercise data for individual calibration of the Actiheart.

213

#### 214 *Statistical Analyses*

215 All data were analysed using the Statistical Package for Social Sciences Software (SPSS,  
216 Version 20, IBM Corporation, New York, USA). The normality and homogeneity of the data  
217 distributions and variances were confirmed using Shapiro-Wilk tests and Mauchly's test of

218 sphericity, respectively. Student's independent t-tests were used to compare physical and  
 219 physiological characteristics at baseline between EX and CON (Table 1). Physical maturity  
 220 was compared between groups using a non-parametric Mann Whitney-U test (Table 1).  
 221 Group by time (2 x 3) mixed measures ANCOVA, including age, percentage body fat and  
 222 respective baseline measurements as covariates (i.e., when assessing the change in TEE,  
 223 baseline TEE measurements were included as a covariate), were used to examine changes in  
 224 body mass, peak  $\dot{V}O_2$ , EI, TEE and AEE. A one-way between measures ANCOVA, including  
 225 age and baseline percentage body fat as covariates, was employed to examine changes in  
 226 body composition. Group by time (2 x 2) mixed measures ANCOVA, including age,  
 227 percentage body fat and respective baseline measurements as covariates, were used to  
 228 examine changes in laboratory EI and REE. Interpretation of the data was based on 95%  
 229 confidence intervals (CI) and effect sizes (ES). Changes in laboratory-based  $EI \geq 8\%$ ,  $TEE \geq$   
 230  $3\%$  and  $AEE \geq 10\%$  were considered meaningful for an individual adolescent girl based on  
 231 unpublished findings from our laboratory with similar samples of adolescent girls and extant  
 232 literature for EE (10) and EI variation (5,22). An effect size of 0.2 was considered the  
 233 minimum important difference for all outcome measures, with 0.2 to < 0.5, 0.5 to < 0.8 and  $\geq$   
 234 0.8 representing small, moderate and large effects, respectively (16). The ES for between  
 235 measure comparisons at baseline were calculated using the pooled SD and for within measure  
 236 comparisons using the population control SD. The respective equations were as follows (v,  
 237 variable; SD, standard deviation):

$$238 \quad ES = \frac{Mean v_2 - Mean v_1}{\sqrt{(SDv_1^2 + SDv_2^2)/2}} \quad ES = \frac{Mean v_2 - Mean v_1}{Population Control SD}$$

239

240

241 **Results**

242 For the 11 girls who completed the 12 week supervised exercise programme, attendance was  
 243 94% (34 out of 36 exercise sessions). The average estimated exercise induced EE was 816 kJ  
 244 per session. When comparing weeks 0 and 12, free-living EI data were only available for 6  
 245 girls in CON and 9 girls in EX, whilst EE data were available for 8 girls in CON and 11 girls  
 246 in EX.

247 *Participant Characteristics at Baseline*

248 Baseline physical and physiological characteristics of participants are presented in Table 1.  
 249 Girls in CON were, on average, 0.5 years older than EX ( $P = 0.03$ ) (Table 1). Although not  
 250 significant, EX had a moderately lower percentage body fat at baseline (ES = 0.61,  $P = 0.16$ )  
 251 and a moderately higher peak  $\dot{V}O_2$  than CON at baseline (ES = 0.57,  $P = 0.20$ ) (Tables 1 and  
 252 2); thus, baseline percentage body fat and peak  $\dot{V}O_2$  were included as covariates in  
 253 subsequent analyses. The between group differences for the other physical variables were  
 254 small (ES  $\leq 0.43$ ,  $P \geq 0.61$ ) (Table 1).

255 **Table 1.** Physical and physiological characteristics at baseline (week 0)

	CON (n = 12)	EX (n = 11)	CON vs. EX 95% CI**	Effect Size
Age (years)	13.5 (0.5)	13.0 (0.4)	0.1 to 0.8 <sup>a</sup>	0.99
Stature (m)	1.57 (0.10)	1.59 (0.07)	-0.09 to 0.06	0.22
Body mass index (kg·m <sup>-2</sup> )	19.8 (4.1)	19.6 (3.1)	-3.0 to 3.4	0.05
Breast development*	3 (1)	3 (2)	-	0.38
Pubic hair development*	4 (2)	4 (1)	-	0.08

256 Mean (SD); \*Median (IQR); CON - control; EX – exercise.

257 \*\*95% confidence interval of the mean absolute difference between the groups. <sup>a</sup> Significant  
 258 difference between CON and EX ( $P < 0.05$ ).

259 *Cardiorespiratory Fitness (peak  $\dot{V}O_2$ )*

260 Mean peak  $\dot{V}O_2$  values for weeks 0, 6, 12 and 18 are presented in Table 2; time ( $P = 0.82$ )  
 261 and group ( $P = 0.33$ ) main effects and the interaction ( $P = 0.22$ ) were not significant when  
 262 considering the covariate adjusted marginal means.

263 **Table 2.** Mean values for peak  $\dot{V}O_2$  and anthropometric measures in CON and EX

Week	CON				EX			
	0	6	12	18	0	6	12	18
Peak $\dot{V}O_2$ (mL·kg <sup>-1</sup> ·min <sup>-1</sup> )	41.6 (3.3)	46.4 (3.9)	45.9 (3.1)	43.7 (2.6)	45.4 (5.9)	45.6 (3.9)	48.1 (3.1)	45.9 (2.6)
Body mass (kg)	48.7 (11.3)	50.0 (1.2)	50.7 (1.6)	50.8 (1.9)	49.7 (10.8)	50.6 (1.2)	50.6 (1.6)	50.9 (1.8)
Body fat (%)	32.5 (8.6)	-	33.4 (8.6)	-	27.3 (8.4)	-	27.8 (8.1)	-
Fat free mass (%)	63.7 (8.3)	-	63.0 (8.5)	-	68.6 (8.2)	-	68.1 (7.9)	-
Waist circumference (cm)	68.4 (9.2)	71.1 (9.8)	70.2 (8.5)	71.3 (10.0)	68.2 (7.0)	68.2 (6.1)	69.5 (5.8)	69.3 (5.6)

264 Baseline and covariate adjusted means (SD). CON - control; EX - exercise intervention;  $\dot{V}O_2$  -  
 265 oxygen uptake.

### 266 *Body Size*

267 The group main effect ( $P = 0.81$ ) and group by time interaction ( $P = 0.54$ ) for body mass  
 268 were not significant; thus, the small changes across the study were similar in CON and EX.  
 269 Within both CON and EX there was large inter-individual variability in body mass changes  
 270 between 0 and 12 weeks; for EX, body mass increases ranged from 0.1 to 4.6 kg and for  
 271 CON from 0.4 to 3.9 kg. Changes in percentage body fat between weeks 0 and 12 (mean  
 272 increase of 0.9% and 0.5% for CON and EX, respectively) and percentage fat free mass  
 273 (mean decrease of 1.0% and 0.4% for CON and EX, respectively) followed a similar pattern  
 274 to body mass in the two groups ( $P \geq 0.94$ ). The individual variation in percentage body fat  
 275 changes ranged between -1.6% and 2.4% for EX, and between -1.0% and 4.4% for CON.  
 276 Percentage changes in body mass and body fat were not correlated with DEBQ scores.

277

278 *Energy Intake*

279 Energy intake was similar between groups during the laboratory testing days ( $P = 0.29$ )  
 280 (Table 3). The non-significant, small ( $ES = 0.26$ ,  $P = 0.46$ ) group by time interaction in buffet  
 281 meals day EI reflected large individual changes between girls in EX and CON. In EX,  
 282 between weeks 0 and 12, four girls increased their EI, four decreased and two were stable. In  
 283 CON, four increased, three decreased and three were stable (Figure 1a). Change in EI varied  
 284 from  $-2518$  to  $2016 \text{ kJ}\cdot\text{d}^{-1}$  in EX and  $-2960$  to  $2567 \text{ kJ}\cdot\text{d}^{-1}$  in CON.

285 Pooled changes in EI for CON and EX only explained a small amount of the variation in the  
 286 change in body mass ( $r = -0.40$ ,  $r^2 = 16.0\%$ ,  $P = 0.08$ ), percentage body fat ( $r = 0.08$ ,  $r^2 =$   
 287  $0.6\%$ ,  $P = 0.74$ ), and percentage fat free mass ( $r = -0.08$ ,  $r^2 = 0.6\%$ ,  $P = 0.74$ ) from week 0 to  
 288 12. A significant positive correlation was found between the domain of external eating and  
 289 change in EI between weeks 0 and 12 ( $\rho = 0.67$ ,  $P \leq 0.01$ ), however no significant  
 290 correlations were found for the domains of emotional and restrained eating.

291 There was a large, but non-significant, between group difference in free-living EI ( $ES = 1.04$ ,  
 292  $P = 0.14$ ). However, fluctuations in free-living EI were similar between groups over time  
 293 (condition by time interaction,  $ES \leq 0.26$ ;  $P = 0.90$ ) (Table 3). Individual analyses showed  
 294 the change in free-living EI varied from  $-2077$  to  $2076 \text{ kJ}\cdot\text{d}^{-1}$  for EX and  $-4020$  to  $1523 \text{ kJ}\cdot\text{d}^{-1}$   
 295 for CON between week 0 and 12 (Figure 1b); furthermore, some girls from both EX and  
 296 CON did not complete the measures in week 12.

297 **Table 3.** Mean energy intake and energy expenditure across the study in CON and EX.

	CON				EX			
	week 0	week 6	week 12	week 18	week 0	week 6	week 12	week 18
Laboratory EI ( $\text{kJ}\cdot\text{d}^{-1}$ )	9953 (2682)	-	9770 (1395)	10052 (1160)	9027 (1720)	-	9610 (1395)	9243 (1160)

Free-living	7227	7128	6470	6337	7288	6412	5273	4916
EI (kJ·d <sup>-1</sup> )	(1109)	(1613)	(1539)	(2207)	(1858)	(1580)	(1508)	(2162)
TEE	12710	11801	12770	11775	12645	13560	13574	12752
(kJ·d <sup>-1</sup> )	(3172)	(1601)	(1925)	(1759)	(2970)	(1562)	(1879)	(1716)
AEE	3762	2634	3663	2944	3340	4096	3942	3796
(kJ·d <sup>-1</sup> )	(2268)	(1208)	(1090)	(1145)	(1423)	(1180)	(1065)	(1118)
REE	7560	-	7827	7717	8486	-	8144	7880
(kJ·d <sup>-1</sup> )	(992)	-	(1319)	(1445)	(1288)	-	(1307)	(1430)

298 Baseline and covariate adjusted means (SD). CON - control; EX - exercise; EI - energy  
 299 intake; TEE - total energy expenditure; AEE - activity energy expenditure; REE - resting  
 300 energy expenditure.

301

302 **Figure 1.** Individual participant changes in (a) laboratory *ad libitum* energy intake (EI), (b)  
 303 free-living EI, (c) total energy expenditure (TEE) and (d) activity energy expenditure (AEE)  
 304 from week 0 to 12. Bar represents the mean value.

### 305 *Energy Expenditure*

306 The mean valid wear time was 1319 (81) min·d<sup>-1</sup> for EX and 1308 (90) min·d<sup>-1</sup> for CON. A  
 307 small to moderate, non-significant main effect for time (ES = 0.29 to 0.62,  $P = 0.34$ ) coupled  
 308 with a non-significant group by time interaction ( $P = 0.69$ ) indicated that the changes in TEE  
 309 were not meaningful, but were consistent for EX and CON. Close examination of the data  
 310 revealed large inter-individual variation in TEE; in EX, six participants increased, three  
 311 decreased, and two were stable over time. Similarly, four CON participants increased, three  
 312 decreased, and one was stable. Individual changes between weeks 0 and 12 varied from -1097  
 313 to 4681 kJ·d<sup>-1</sup> in EX and -2257 to 1988 kJ·d<sup>-1</sup> in CON (Figure 1c).

314 The group by time interaction for AEE was not significant ( $P = 0.17$ ), indicating that changes  
 315 in AEE over time were similar in EX and CON. Inspection of individual changes showed  
 316 large variability in AEE from -1713 to 2814 kJ·d<sup>-1</sup> and -1599 to 1940 kJ·d<sup>-1</sup> for EX and CON,  
 317 respectively (Figure 1d). In EX, six participants increased AEE, two decreased and three

318 were stable. In CON, three participants increased, three decreased and two were stable.  
319 Individual changes between weeks 0 and 12 are shown in Figure 1d. Changes in TEE and  
320 AEE only accounted for a small proportion of the variance for changes in body mass ( $r^2 \leq$   
321  $3.6\%$ ,  $P \geq 0.43$ ), percentage body fat ( $r^2 \leq 2.3\%$ ,  $P \geq 0.54$ ), percentage fat free mass ( $r^2 \leq$   
322  $3.0\%$ ,  $P \geq 0.48$ ) and peak  $\dot{V}O_2$  ( $r^2 \leq 0.5\%$ ,  $P \geq 0.78$ ). There was a small, non-significant  
323 difference in REE; the non-significant group by time interaction ( $P = 0.87$ ) indicated that  
324 changes over time were small and similar for both EX and CON (Table 3). A strong, negative  
325 correlation was found between changes in laboratory EI and TEE in EX ( $r = -0.87$ ,  $P < 0.01$ ),  
326 whilst a positive correlation was observed in CON ( $r = 0.56$ ,  $P = 0.15$ ) (Figure 2).

327

328 **Figure 2.** Individual changes in energy intake (EI) and total energy expenditure (TEE)  
329 between week 0 and 12 for (a) CON ( $n = 8$ ) and (b) EX ( $n = 10$ ).

330

## 331 Discussion

332 As far as we are aware, this is the first study to examine the effect of a medium-term exercise  
333 programme on EI and EE compensation simultaneously in adolescent girls and highlights a  
334 number of important issues. First, the collective exploratory results indicate medium-term  
335 compensatory behaviours in adolescent girls did not occur at the group level. However,  
336 evaluation at the group level may mask potentially meaningful individual variation. Second,  
337 it is important to consider EI and EE simultaneously at the individual level. Finally,  
338 refinement of free-living EI and EE measures are required to extend this research field. An as  
339 yet unpublished process evaluation suggested numerous positive outcomes resulted from  
340 participation with no known adverse effects.

341 As anticipated in growing and maturing adolescent girls, there was no evidence of an  
342 exercise-induced reduction in body mass for EX over the twelve-week intervention period.  
343 Whilst differential changes in body mass following a chronic exercise programme in adults  
344 may provide evidence for energy compensation, weight loss was not a goal of the current  
345 intervention. The similar variation between EX and CON suggests the weight gain seen in  
346 EX cannot be attributed solely to compensatory behaviours in response to the exercise  
347 programme. Whilst approximately one third ( $n = 8$ ; 3 EX and 5 CON) of the girls who  
348 completed the current study were classified as overweight or obese (44), the duration of the  
349 prescribed exercise programme was only 12 weeks. Consequently, meaningful changes in  
350 body composition were not expected. However, the use of DXA improves the ability to detect  
351 subtle changes compared to other field techniques (i.e., skinfolds and bioelectrical impedance  
352 analysis) (53). The mean percentage body fat for CON and EX (32.5 and 27.3%,  
353 respectively) were consistent with previous research assessing DXA-derived body fat values  
354 in 1251 British school children (39). The increase in body mass and fat mass could be  
355 expected in this age group due to the period of adolescence representing a time of rapid

356 growth and maturation, affecting body size and composition (2). The individual variation in  
357 weight gain and fat mass changes for both CON and EX is characteristic of the growth spurts,  
358 occurring at varying rates and stages of puberty (54). Although not considered as part of this  
359 study, menstrual cycle stage should also be accounted for in future longitudinal designs.

360 The present findings indicate the magnitude of the changes in EI over time in both EX or  
361 CON at the group level were within daily variation and, thus, not meaningful with regard to  
362 exercise-induced compensatory behaviours. These results support short acute exercise studies  
363 in healthy weight adolescents whereby no meaningful changes in EI were reported  
364 (11,34,49). It is possible that the lack of measurement sensitivity when estimating EI,  
365 particularly in a free-living environment, could explain the null findings in the current study  
366 when also considering the limited sample size after several drop-outs. Nevertheless, the high  
367 individual variation observed corroborates that reported from other chronic exercise  
368 programmes (26,46). On an individual basis, Figures 1 and 2 suggest that some adolescent  
369 girls do increase their EI during a medium-term exercise programme; however, the small  
370 sample size does not allow meaningful comparisons to be made between the participants  
371 displaying different behaviours. Whilst this study examined the changes in EI with reference  
372 to baseline DEBQ scores, examining changes in eating behaviour traits across the  
373 intervention is important and may explain some variation in EI, particularly for adolescents  
374 who are overweight or obese (33). There was no meaningful evidence to suggest changes in  
375 EI were correlated with changes in body size. Fat free mass has been shown to be a main  
376 predictor of EI in adolescents (13); yet non-significant (small) correlations coupled with  
377 small group changes in fat free mass in this study suggest changes in EI would not be  
378 expected on the basis of fat free mass alone. Multiple measures of EI are necessary to capture  
379 the potential variety of compensatory behaviours including, 'increased frequency of eating,  
380 increased meal size, selection of larger portions and increased energy density of food' (24) (p.

381 1376). The use of two complimentary measures in this study was an important addition to the  
382 study to provide an overall view of EI compensation and assess coherence, from objectively  
383 measured buffet meals days and estimates of free-living EI (digital photographs). Free-living  
384 EI was consistently lower than laboratory-measured EI for CON and EX. The mean EI during  
385 the buffet meal testing days corresponds with the guidelines of 8.8 to 10.0 MJ·d<sup>-1</sup> for girls  
386 aged 12 to 15 years (38), which suggests EI was not artificially elevated due to food  
387 availability. The lower free-living EI reported is probably indicative of under-reporting,  
388 which is common in the literature (29). Although not significant, there was a trend for free-  
389 living EI to decrease over time. It is likely this is due to reduced compliance with the self-  
390 report digital photographs and written diary over the course of the intervention, as this  
391 occurred in both CON and EX, rather than behavioural changes in response to the exercise  
392 programme.

393 The non-significant group by time interaction indicates that changes in AEE over the study,  
394 once baseline values were included as the covariate, were similar for EX and CON. However,  
395 the twelve week exercise programme led to an increase in AEE for six participants in EX. For  
396 these participants the results suggest a twelve week exercise intervention may lead to  
397 subsequent health behaviours conducive to a negative energy balance. This supports previous  
398 research that suggests an activity synergy occurs in response to active periods, which  
399 conflicts with the idea of subsequent free-living activity EE compensation (21). These  
400 findings provide partial support for the lack of EE compensation reported in adolescent boys  
401 with obesity by Blaak et al. (9), despite a lower ExEE in the present study (2.20 vs. 0.82 MJ  
402 per session). The current study extends these findings with the inclusion of a control group  
403 and use of objectively measured free-living PA, compared to estimating PA via HR  
404 monitoring and activity questionnaires. By design, although both state schools follow the  
405 English National Curriculum, it is possible CON and EX received different physical

406 education lessons at school, and this could explain, in part, the variation in AEE for CON;  
407 where possible this should be accounted for in future studies. Whilst only trivial or small  
408 effects of the exercise intervention on TEE and AEE were reported between CON and EX,  
409 these results do suggest a degree of individual variation akin to that observed in EI. With high  
410 individual variability in CON, combined with only a weak association between EE and  
411 cardiorespiratory fitness, it is difficult to attribute the increase in EE for EX solely to the  
412 exercise programme. The extended nature of the chronic exercise programme mean the  
413 increases in free-living PA may be a seasonal effect, with more opportunities to be active  
414 during the spring and summer months (14). Only minor fluctuations in REE over the course  
415 of the 12-week intervention and follow up period were found. This is consistent with a well-  
416 designed calorimetry study examining the effect of a 12-week exercise programme on TEE  
417 and its components in adolescents (51). A large proportion of the adult-based literature  
418 examining changes in EE behaviours in response to structured exercise programmes has  
419 failed to provide evidence for changes in free-living EE. It is likely that more variation will  
420 be observed in young people due to a greater amount of leisure time, and thus more  
421 opportunities to change free-living PA.

422 This study extends the current evidence of chronic compensatory behaviours in young  
423 people, through the simultaneous assessment of free-living EI and EE recommended by  
424 Thivel (46). Although difficult to reach firm conclusions due to the small sample size and  
425 large inter-individual variation, EX appeared more likely to exhibit disruptions in EI and TEE  
426 behaviours than CON, when EI and EE are considered simultaneously. Figure 2 suggests  
427 better coupling between EI and EE to maintain energy balance in CON. Conversely, in EX,  
428 there appear to be different levels of disruption to energy behaviours in response to the  
429 exercise programme. Four girls displayed behaviours likely to induce a negative energy  
430 balance with an increase in TEE and simultaneous decrease in EI. On the other hand, two

431 girls displayed compensatory behaviours in both EI and EE. Further research is required to  
432 address these initial findings with a larger sample and to identify whether specific participant  
433 characteristics modulate the tendency to display compensatory behaviours. In addition,  
434 investigation of different exercise modes, durations and intensities in inactive adolescents  
435 (lean and overweight) is also required.

436 The main strengths of the current study include the novel primary aim to identify EI and EE  
437 compensatory behaviours concurrently in adolescent girls. Furthermore, the 12-week exercise  
438 programme was supervised with individual HR monitoring of intensity; thus, variability in  
439 behavioural responses cannot be explained by differences in intervention fidelity. Previous  
440 studies investigating chronic energy compensation have not included control groups in their  
441 research design. This is a serious design fault, in particular for the comparison of individual  
442 differences (6). Interpreting individual differences in the response to an intervention without  
443 a control arm could lead to false conclusions and unethical further exploration (6). The  
444 inclusion of a control group is imperative with young people to account for the influence of  
445 on-going growth and maturation on EI and EE, aside from the effects of the exercise  
446 intervention. In addition, the stage of growth, development and maturation of the young  
447 person could mask or enhance the effect of structured exercise training (8). The current  
448 findings are important for the advancement of future research in this area. However, there are  
449 a number of limitations which must be acknowledged. As mentioned previously, the small  
450 sample size, coupled with large individual variation, makes it difficult to identify meaningful  
451 changes in EI and EE behaviours. Nevertheless, the intention of this early phase study was to  
452 explore the feasibility and value of continued research in this field. Free-living EI measures  
453 are necessary to supplement laboratory buffet meal test days, to account for daily variation in  
454 EI (15). However, they are often associated with poor compliance and/or under-reporting  
455 (29). Whilst, the current study attempted to reduce non-compliance using a technological

456 based record of EI, poor compliance was still evident; thus, difficulties in the accurate  
457 quantification of changes in free-living EI are apparent. The use of more sophisticated  
458 methods, i.e., doubly labelled water, could circumvent these issues in future studies; in  
459 addition to assessing appetite ratings if feasible. This exploratory study examined global EE  
460 and EI compensatory responses, but it may be of interest for future studies to explore the  
461 breakdown in time spent in moderate-vigorous PA, light PA and sedentary behaviours.

462 In conclusion, the current findings are consistent with research in adults, suggesting no  
463 evidence of compensatory behaviours at a group level after an exercise training programme  
464 of 12 weeks. However, examples of compensatory behaviours were evident in the adolescent  
465 girls when examining the individual variation in responses to chronic exercise. Nevertheless,  
466 further work is first required to refine the methods used to estimate free-living EI and EE  
467 with the consistency and degree of precision necessary to detect meaningful changes over  
468 time. Subsequently, exploring energy compensation in adolescents who need to either  
469 increase their habitual PA, baseline cardiorespiratory fitness and/or lose weight, or body fat,  
470 on a larger scale may enable greater clarity of the behaviours occurring in individuals.

471

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