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

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

Introduction

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

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

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

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

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

Chronic exercise intervention studies (≥ 3 weeks duration) examining exercise-induced energy compensation with adolescents are limited, and have examined EI and EE independently. A study in which participants were prescribed a six-week activity and diet-induced energy deficit showed that exercise can lead to weight loss if EI compensation does not occur (25). However, the group were completing a large volume of exercise during an activity camp (6 h·d^{-1}), which is not representative of normal daily activities. A secondary analysis of data collected in the GameBike trial (1) showed marginal decreases in EI in response to a 10-week PA programme (46). The two available studies examining exercise-induced changes in total energy expenditure (TEE) reported no evidence of compensatory behaviours (9,51). When chronic compensatory behaviours in adolescents with obesity are considered, a meta-analysis of nine physical activity interventions, ranging from 3 to 12 months in duration, concluded that PA interventions favour a reduction in EI in this population but reiterated the clear need for further empirical research to confirm this finding (37). It is necessary to measure EI and EE compensatory behaviours simultaneously due to the dynamic interactions between these components and their subsequent influence on energy balance (47). Extending the available research, which has been conducted in young people, will further our understanding of compensatory behaviours and exercise EE as a viable vehicle for influencing paediatric health.

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

Methods

Participants

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

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

Experimental Design

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

A twelve-week supervised exercise programme was completed by EX. Three 30 min exercise sessions, at an intensity equivalent to 60 to 70% peak oxygen uptake $(\dot{V}O_2)$, were completed each week at the University or participants' school. Exercise sessions at the school took place after lessons between 15:30 and 16:30. The timing of the exercise sessions at the University varied to accommodate participant availability and increase retention (start times ranged from 08:00 to 16:00). Participants were asked to maintain their heart rate (HR) within an individual target training zone and the research team monitored this regularly during each session. Exercise intensity was quantified using downloadable HR monitors (Polar RS400). The exercise programme consisted of a variety of activities including team games, circuits, dance, running and cycling. The third exercise session in weeks 6 and 12 was a sub-maximal and maximal treadmill test in the laboratory for the purpose of Actiheart recalibration and reassessment of cardiorespiratory fitness (CRF; peak $\dot{V}O_2$).

Body size-composition and biological maturation

Anthropometry was completed at the University in weeks 0, 6, 12 and 18. Stature was recorded to the nearest 0.01 m using a stadiometer (Holtain Ltd, Crosswell, UK) and body mass to the nearest 0.1 kg using digital scales (Seca, Hamburg, Germany). Waist circumference was measured to the nearest 0.1 cm using a non-stretch tape measure. Body composition was assessed in weeks 0 and 12 by whole body DXA scan (Lunar Prodigy Advance, GE Medical Systems Lunar, Belgium). A standardised procedure for participant positioning for a total body scan was used. Participants were asked to wear the same light clothing for each scan, to remove all artefacts that could interfere with the scan and to empty their bladder immediately prior to each scan. The scans were re-analysed using iDXA paediatric software, as the Lunar Prodigy did not have paediatric software available to access age-specific algorithms. Participants were asked to provide a self-assessment of physical maturity using the Tanner pictorial rating system (43). In weeks 0, 6, 12 and 18 a four-stage, sub-maximal treadmill test and incremental treadmill test to exhaustion were completed to measure peak $\dot{V}O_2$ and calibrate the Actiheart. Participants wore a face mask (Hans Rudolph, USA) and expired air was analysed continuously using an online system that measures breath by breath ventilation, expired oxygen and expired carbon dioxide (Cosmed K4b^2, Cosmed, Rome, Italy). The criteria used to define the attainment of peak $\dot{V}O_2$ was the presence of a plateau in $\dot{V}O_2$ ($\leq$ 3%) with an increase in exercise intensity (i.e., treadmill gradient); a peak HR ≥ 95% age-predicted maximum (220 – chronological age); a respiratory exchange ratio of ≥ 1.05; and clear subjective signs of fatigue (4).

Dietary energy intake (EI)

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

Participants were shown to their buffet meal feeding room, in which food was presented in excess of expected consumption, and told they were free to choose whatever they wanted to eat until satisfied and were not restricted by time. Participants selected and consumed meals alone to reduce the influence of social distractions on selection and intake. Food and drink were weighed by the lead author using digital kitchen scales before and after each meal to determine EI via dietary analysis using CompEat Pro (Version 5.8.0, Nutrition Systems, Banbury, UK). There was no laboratory EI measurement in week 6 because the girls were not granted permission to be absent from school. The buffet meals included the following food items: cereals, semi-skimmed milk and croissants for breakfast; fruit, various cereal bars and biscuits for snacks; various sandwich fillings, low-fat dairy spread, brown and white sliced bread, a variety of potato chips and fruit for lunch; pasta, tomato-based sauce, garlic bread and muffins for dinner.

Participants also completed a photographic food intake diary of all food, drinks and leftovers using a digital camera (Kodak EasyShare C142, New York, US) for three days in weeks 0, 6, 12 and 18. Digital photographs were taken from a 45° angle, ensuring the whole plate could be seen in the photograph. Participants were instructed to check the photo - if the photo was blurred or missing some of the plate, they were asked to delete the photo and retake it. Participants were asked to follow the same protocol of photographing the food for all meals and snacks. A step-by-step guide of how to take photographs was provided to all participants for reference. A photographic food atlas for secondary school children (18) was used by the researchers to analyse the photographs. The food atlas image most closely resembling the type and portion size of each food item consumed was used to estimate the weight of that food from the database. If no leftover photograph was present, it was assumed all food was consumed. Participants had been asked to empty any packets of leftover food out onto the plate; therefore, any packets photographed were assumed to be empty.

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

Free-living estimated energy expenditure

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

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

Statistical Analyses

All data were analysed using the Statistical Package for Social Sciences Software (SPSS, Version 20, IBM Corporation, New York, USA). The normality and homogeneity of the data distributions and variances were confirmed using Shapiro-Wilk tests and Mauchly's test of sphericity, respectively. Student's independent t-tests were used to compare physical and physiological characteristics at baseline between EX and CON (Table 1). Physical maturity was compared between groups using a non-parametric Mann Whitney-U test (Table 1). Group by time (2 x 3) mixed measures ANCOVA, including age, percentage body fat and respective baseline measurements as covariates (i.e., when assessing the change in TEE, baseline TEE measurements were included as a covariate), were used to examine changes in body mass, peak $\dot{V}O_2$, EI, TEE and AEE. A one-way between measures ANCOVA, including age and baseline percentage body fat as covariates, was employed to examine changes in body composition. Group by time (2 x 2) mixed measures ANCOVA, including age, percentage body fat and respective baseline measurements as covariates, were used to examine changes in laboratory EI and REE. Interpretation of the data was based on 95% confidence intervals (CI) and effect sizes (ES). Changes in laboratory-based EI ≥ 8%, TEE ≥ 3% and AEE ≥ 10% were considered meaningful for an individual adolescent girl based on unpublished findings from our laboratory with similar samples of adolescent girls and extant literature for EE (10) and EI variation (5,22). An effect size of 0.2 was considered the minimum important difference for all outcome measures, with 0.2 to < 0.5, 0.5 to < 0.8 and ≥ 0.8 representing small, moderate and large effects, respectively (16). The ES for between measure comparisons at baseline were calculated using the pooled SD and for within measure comparisons using the population control SD. The respective equations were as follows (v, variable; SD, standard deviation):

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

Results

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

Participant Characteristics at Baseline

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

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[a]	0.99
Stature (m)	1.57 (0.10)	1.59 (0.07)	-0.09 to 0.06	0.22
Body mass index (kg·m^{-2})	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

Mean (SD); ***Median (IQR); CON - control; EX – exercise.
****95% confidence interval of the mean absolute difference between the groups. [a] Significant difference between CON and EX (P < 0.05).

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

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

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

	CON				EX			
Week	**0**	**6**	**12**	**18**	**0**	**6**	**12**	**18**
Peak $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	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)

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

Body Size

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

Energy Intake

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

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

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

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 ($kJ \cdot d^{-1}$)	9953 (2682)	-	9770 (1395)	10052 (1160)	9027 (1720)	-	9610 (1395)	9243 (1160)

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

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

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

Energy Expenditure

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

The group by time interaction for AEE was not significant (*P* = 0.17), indicating that changes in AEE over time were similar in EX and CON. Inspection of individual changes showed large variability in AEE from -1713 to 2814 kJ·d^{-1} and -1599 to 1940 kJ·d^{-1} for EX and CON, respectively (Figure 1d). In EX, six participants increased AEE, two decreased and three were stable. In CON, three participants increased, three decreased and two were stable. Individual changes between weeks 0 and 12 are shown in Figure 1d. Changes in TEE and AEE only accounted for a small proportion of the variance for changes in body mass ($r^2 \leq$ 3.6%, $P \geq 0.43$), percentage body fat ($r^2 \leq 2.3\%$, $P \geq 0.54$), percentage fat free mass ($r^2 \leq$ 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 difference in REE; the non-significant group by time interaction ($P = 0.87$) indicated that changes over time were small and similar for both EX and CON (Table 3). A strong, negative correlation was found between changes in laboratory EI and TEE in EX (r = -0.87, $P < 0.01$), whilst a positive correlation was observed in CON (r = 0.56, $P = 0.15$) (Figure 2).

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

Discussion

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

As anticipated in growing and maturing adolescent girls, there was no evidence of an exercise-induced reduction in body mass for EX over the twelve-week intervention period. Whilst differential changes in body mass following a chronic exercise programme in adults may provide evidence for energy compensation, weight loss was not a goal of the current intervention. The similar variation between EX and CON suggests the weight gain seen in EX cannot be attributed solely to compensatory behaviours in response to the exercise programme. Whilst approximately one third (*n* = 8; 3 EX and 5 CON) of the girls who completed the current study were classified as overweight or obese (44), the duration of the prescribed exercise programme was only 12 weeks. Consequently, meaningful changes in body composition were not expected. However, the use of DXA improves the ability to detect subtle changes compared to other field techniques (i.e., skinfolds and bioelectrical impedance analysis) (53). The mean percentage body fat for CON and EX (32.5 and 27.3%, respectively) were consistent with previous research assessing DXA-derived body fat values in 1251 British school children (39). The increase in body mass and fat mass could be expected in this age group due to the period of adolescence representing a time of rapid growth and maturation, affecting body size and composition (2). The individual variation in weight gain and fat mass changes for both CON and EX is characteristic of the growth spurts, occurring at varying rates and stages of puberty (54). Although not considered as part of this study, menstrual cycle stage should also be accounted for in future longitudinal designs.

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

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

The non-significant group by time interaction indicates that changes in AEE over the study, once baseline values were included as the covariate, were similar for EX and CON. However, the twelve week exercise programme led to an increase in AEE for six participants in EX. For these participants the results suggest a twelve week exercise intervention may lead to subsequent health behaviours conducive to a negative energy balance. This supports previous research that suggests an activity synergy occurs in response to active periods, which conflicts with the idea of subsequent free-living activity EE compensation (21). These findings provide partial support for the lack of EE compensation reported in adolescent boys with obesity by Blaak et al. (9), despite a lower ExEE in the present study (2.20 vs. 0.82 MJ per session). The current study extends these findings with the inclusion of a control group and use of objectively measured free-living PA, compared to estimating PA via HR monitoring and activity questionnaires. By design, although both state schools follow the English National Curriculum, it is possible CON and EX received different physical education lessons at school, and this could explain, in part, the variation in AEE for CON; where possible this should be accounted for in future studies. Whilst only trivial or small effects of the exercise intervention on TEE and AEE were reported between CON and EX, these results do suggest a degree of individual variation akin to that observed in EI. With high individual variability in CON, combined with only a weak association between EE and cardiorespiratory fitness, it is difficult to attribute the increase in EE for EX solely to the exercise programme. The extended nature of the chronic exercise programme mean the increases in free-living PA may be a seasonal effect, with more opportunities to be active during the spring and summer months (14). Only minor fluctuations in REE over the course of the 12-week intervention and follow up period were found. This is consistent with a well-designed calorimetry study examining the effect of a 12-week exercise programme on TEE and its components in adolescents (51). A large proportion of the adult-based literature examining changes in EE behaviours in response to structured exercise programmes has failed to provide evidence for changes in free-living EE. It is likely that more variation will be observed in young people due to a greater amount of leisure time, and thus more opportunities to change free-living PA.

This study extends the current evidence of chronic compensatory behaviours in young people, through the simultaneous assessment of free-living EI and EE recommended by Thivel (46). Although difficult to reach firm conclusions due to the small sample size and large inter-individual variation, EX appeared more likely to exhibit disruptions in EI and TEE behaviours than CON, when EI and EE are considered simultaneously. Figure 2 suggests better coupling between EI and EE to maintain energy balance in CON. Conversely, in EX, there appear to be different levels of disruption to energy behaviours in response to the exercise programme. Four girls displayed behaviours likely to induce a negative energy balance with an increase in TEE and simultaneous decrease in EI. On the other hand, two girls displayed compensatory behaviours in both EI and EE. Further research is required to address these initial findings with a larger sample and to identify whether specific participant characteristics modulate the tendency to display compensatory behaviours. In addition, investigation of different exercise modes, durations and intensities in inactive adolescents (lean and overweight) is also required.

The main strengths of the current study include the novel primary aim to identify EI and EE compensatory behaviours concurrently in adolescent girls. Furthermore, the 12-week exercise programme was supervised with individual HR monitoring of intensity; thus, variability in behavioural responses cannot be explained by differences in intervention fidelity. Previous studies investigating chronic energy compensation have not included control groups in their research design. This is a serious design fault, in particular for the comparison of individual differences (6). Interpreting individual differences in the response to an intervention without a control arm could lead to false conclusions and unethical further exploration (6). The inclusion of a control group is imperative with young people to account for the influence of on-going growth and maturation on EI and EE, aside from the effects of the exercise intervention. In addition, the stage of growth, development and maturation of the young person could mask or enhance the effect of structured exercise training (8). The current findings are important for the advancement of future research in this area. However, there are a number of limitations which must be acknowledged. As mentioned previously, the small sample size, coupled with large individual variation, makes it difficult to identify meaningful changes in EI and EE behaviours. Nevertheless, the intention of this early phase study was to explore the feasibility and value of continued research in this field. Free-living EI measures are necessary to supplement laboratory buffet meal test days, to account for daily variation in EI (15). However, they are often associated with poor compliance and/or under-reporting (29). Whilst, the current study attempted to reduce non-compliance using a technological based record of EI, poor compliance was still evident; thus, difficulties in the accurate quantification of changes in free-living EI are apparent. The use of more sophisticated methods, i.e., doubly labelled water, could circumvent these issues in future studies; in addition to assessing appetite ratings if feasible. This exploratory study examined global EE and EI compensatory responses, but it may be of interest for future studies to explore the breakdown in time spent in moderate-vigorous PA, light PA and sedentary behaviours.

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

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