Title: Daily-running exercise may induce incomplete energy intake compensation: a 7-day crossover trial

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Abstract

Understanding daily-exercise effects on energy balance is important. This study examined the effects of seven days of imposed exercise (EX) and no exercise (N-EX) on free-living energy intake (EI) and physical activity energy expenditure (PAEE) in nine men. Free-living EI was higher in EX compared with N-EX. Total and vigorous PAEE were higher, with PAEE in sedentary activities lower, during EX compared with N-EX. Daily-running (for 7 days) induced EI compensation of ~60% exercise-induced EE.

Novelty bullet

- Daily running for seven days induced incomplete EI compensation accounting for~60% of the exercise-induced EE.

Key words: Energy expenditure, energy intake, gut hormones, physical activity, running, weight management.

Introduction

Body weight is often well regulated via various behavioral and physiological compensatory mechanisms (Martin et al. 2019). Manipulating individual components of energy balance leads to compensatory alterations in the remaining components (Foright et al. 2018; Silva et al. 2019). Considering energy intake (EI) compensation, a single bout of moderate-to-vigorous aerobic exercise does not result in increased EI for up to two days post-exercise (King et al. 1997; Douglas et al. 2015; King et al. 2015). This may be due to the decline in hunger that lasts for ~60 min after exercise and is concomitant with reductions in orexigenic (i.e. acylated ghrelin) and increases in anorexigenic (e.g., peptide YY (PYY)) hormone concentrations (Stensel 2010). As changes in energy balance are required to elicit changes in body mass, the effects of daily exercise bouts and a focus on both EI and energy expenditure (EE) is important.

In well-controlled crossover studies that have estimated EE with continuous heart rate (HR) monitoring and EI using weighed dietary records, a modest increase in EI or reduced EE outside of prescribed exercise were reported in response to five to seven days of imposed exercise (~1.6 to 3.4 $MJ \cdot day^{-1}$) in normal weight adults (Stubbs et al. 2002; Stubbs et al. 2004). However, this small evidence base did not include measures of appetite regulation, such as gut hormones, to provide a more complete understanding of EI compensation. Furthermore, previous research has not provided a comprehensive assessment of possible changes in physical activity energy expenditure (PAEE). The primary objective of this study was to examine the effect of seven consecutive days of imposed exercise on free-living EI and PAEE in men. The secondary aim was to examine the possible mechanisms via which changes in free-living EI could occur by assessing gut hormone and appetite perception responses to a standardised meal before and after short-term exercise.

Materials and methods

All study procedures were approved by the University of Bedfordshire's Ethical Advisory Committee. Ten healthy, regularly active men (21.5 ± 2.1 y; 1.76 ± 0.07 m; 48.7 ± 3.9 $ml \cdot kg^{-1} \cdot min^{-1}$) volunteered for this study providing written informed consent to participate.

Preliminary measurements

Each participant arrived at 09:00 after an overnight fast. Height and body mass were collected. The participants completed a submaximal and maximal oxygen uptake test on a treadmill (Woodway ELG 55, Weil am Rhein, Germany)**.**

Experimental conditions

Each participant completed two 7-day experimental conditions in a randomized order: daily imposed exercise (EX) and no exercise (N-EX) (Fig. 1a) separated by a 7-day washout period. During EX, the participants completed daily, supervised, treadmill running at the speed corresponding to 70% peak oxygen uptake ($\dot{V}O_{2peak}$) to elicit an EE of ~3347 $kJ \cdot session^{-1}$. During N-EX the participants were asked to complete no exercise induced energy expenditure (Fig. 1a). Free-living PAEE was estimated throughout conditions via combined HR-accelerometer (Actiheart, CamNTech, Cambridge, UK). Metabolic equivalent (MET) values were used to define sedentary (1.0-1.4 METs), light (1.5-2.9 METs), moderate (3.0-5.9 METs) and vigorous (>5.9 METs) activity. Free-living EI was recorded throughout using a combined written and photographic food diary (Foster et al. 2010). 24 h before the first baseline test day EI was recorded and replicated in the 24 h period before the 70 h post-condition test day.

Appetite Regulation Test Days

Appetite regulation test days were completed at baseline (24 h before), and 24 h and 70 h after each condition (Fig. 1b). Participants arrived at 08:30 (~12 h fasted) and consumed a breakfast, and at 3 hours an *ad libitum* pasta meal. The *ad libitum* meal was weighed before and after to determine quantity consumed. Blood samples and appetite perceptions were collected as detailed in Fig. 1b. Samples were stored at -80°C until later analysis. Enzyme linked immunosorbant assays were used to analyze acylated ghrelin (Bertin Pharma, Montigny le Bretonneux, France) and total PYY (Merck, Nottingham, UK) concentrations. The within batch intra-assay CV was 5% for acylated ghrelin and 7% for PYY.

INSERT FIGURE 1a. & b.

Statistical analysis

A sample size estimation is outlined in supplementary Methods S1. Statistical analyses were completed using IBM SPSS 23 (SPSS Inc., IBM, Chicago, USA). All data were checked for normality using Kolmogorov-Smirnov analysis. Linear mixed models were used to determine if there were any differences between conditions (EX , N-EX), appetite regulation test day (24 h pre; 24 h post and 70 h post experimental conditions) and time (time point in the test day). Interactions between conditions, test day and time were analysed where appropriate. Cohen's d effects sizes were checked to gauge the magnitude of the significant differences (Cohen 1988). Data are presented as mean ± SD unless stated otherwise. Statistical significance was accepted at $P \leq 0.05$.

Results

The final sample consisted of nine male participants, one withdrawing due to ill health. There were no effects of condition or test day, and no condition by test day interaction (all $P \leq 0.126$) for body mass (Table 1).

A large condition effect was found for daily EI ($P = 0.003$; d=1.15). It was higher in EX (9740 ± 1685 kJ·day^{-1}) compared with N-EX (7694 ± 1858 kJ·day^{-1}) and compensated for 60% of the exercise EE (Table 1).

Seven participants met the wear time criteria (>10 h·d^{-1}); the mean wear time was 14.3 ± 0.6 h·d^{-1} for EX and 14.1 ± 0.8 h·d^{-1} for N-EX ($P = 0.542$). Total daily estimated PAEE was higher during EX compared with N-EX ($P < 0.0001$; d=1.44); this was due to the higher PAEE from vigorous intensities ($P < 0.0001$; d=3.49), whereas PAEE from light and moderate PA intensities did not differ between the conditions ($P \geq 0.072$). PAEE in sedentary intensities was lower during EX compared with N-EX ($P = 0.016$; d=0.49).

INSERT TABLE 1

A main effect of condition, test day and time were found for delta acylated ghrelin (all $P \leq 0.022$) (Fig. 2). It was greater in EX compared to N-EX and during the 70 h post compared with the 24 h post test day. The delta acylated ghrelin was elevated above baseline at 2.5 h and remained elevated at 3 h (all $P < 0.039$). The main effect of condition did not interact with test day, indicating that this was an overall effect of condition rather than a pre- to post- condition response ($P \geq 0.245$).

A main effect of test day for delta PYY (P = 0.019) was found; post-hoc analysis indicated that the delta response on the 24 h test days was lower compared to the 70 h trials (P = 0.015; d=0.41) (Fig. 2). There were no main effects of condition or time and no interactions for delta PYY responses (all $P \geq 0.600$).

INSERT FIGURE 2 a. & b.

There was no main effect of condition for EI during the *ad libitum* meal with a mean of 5192 ± 209 kJ (EX) and 4556 ± 176 kJ (N-EX) consumed (P = 0.276). There was also no effect of test day and no condition by test day interaction found for EI during the *ad libitum* meal; all were non-significant ($P \geq 0.534$). A main effect of time was found for hunger, fullness, satisfaction and PFC scores (all $P \leq 0.0001$). All scores were different than baseline (0 h) up until 3 h for hunger, satisfaction and fullness scales and until 2.5 h for PFC ($P \leq 0.04$ for all). (Supplementary Figure S1).

Discussion

This study indicates that seven days of imposed exercise increased free-living daily EI to account for ~60% of the daily exercise-induced energy deficit when compared with no imposed exercise in men. There was no indication of compensatory changes in free-living PAEE, body mass or appetite responses to standardized meals as a result of the imposed exercise.

The 60% EI compensation reported here is larger than studies showing 30-33% EI compensation over seven days in women and over 16 days in a mixed-sex adult sample (Stubbs et al. 2002; Whybrow et al. 2001). The EE in the current study (3.3 $MJ \cdot d^{-1}$) is towards the upper

end of that in previous research (1.5-4.0 $MJ \cdot d^{-1}$) (Stubbs et al. 2002; Whybrow et al. 2001), which may have contributed to the higher EI compensation reported here. Interestingly there was no alteration in EI during the *ad libitum* meal consumed during the test days. This inconsistency in EI responses may be due to the timing (i.e., the days after exercise rather than the day of exercise) and type (i.e., an *ad libitum* pasta lunch rather than free-living daily EI) of assessment.

Minimal PAEE compensation was evident with the vigorous PAEE ~3357 $kJ \cdot day^{-1}$ higher during EX compared with N-EX, this is due to the imposed exercise EE (~3393 ± 38 $kJ \cdot session^{-1}$). Given the lack of PAEE compensation and incomplete EI compensation, the present findings support previous research that high dose exercise for seven days results in a significant energy deficit, which if repeated over the long term, could lead to body mass and fat loss (Stubbs et al. 2004).

No change in gut hormone or perceived appetite responses to the standardized test meals provided pre- and post- each condition were found. This suggests that increases in 'sensitivity' of appetite control take longer than seven days of exercise to emerge. As variability in resting acylated ghrelin (~160%) and PYY (~40%) concentrations have been previously reported (Deighton et al. 2014), it is possible that large daily intra-individual variability in gut hormone concentrations may have masked differences in appetite regulation across all test days in each condition.

Addressing the limitations of the present study, the assessment of free-living EI has well-documented limitations, including underreporting. In addition recruiting a relative small sample size make conclusions on gut hormones action in appetite sensitivity difficult. The

active nature of the participants may mean that the results may not be reflective of other populations (e.g. sedentary). The research strength lies in the period of the measurement completed, as there is a lack of reliable data on energy balance related responses to daily exercise for periods beyond 1 to 2 days.

In conclusion, a seven day period of imposed exercise resulted in a significant increase in free-living EI that compensated for ~60% of the exercise induced energy deficit in healthy men. The mechanism unpinning the EI compensation may not be related to changes in appetite sensitivity when assessed under standardized conditions. On the other side of the energy balance equation, free-living PAEE appears resistant to the imposed exercise. Further research is required to determine the mechanisms underpinning compensatory responses to exercise in different populations, such as the inactive and overweight or obese.

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Conflict of interest

The authors have no conflicts of interest to report.

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	EX				N-EX			
Mean free-living daily energy intake ($kJ.day^{-1}$)†	9740 ± 1685*				7694 ± 1858			
Total free-living PAEE ($kJ.d^{-1}$)†	9715 ± 3661*				4939 ± 2926			
Physical activity intensity levels	**Sedentary activity**	**Light activity**	**Moderate activity**	**Vigorous activity**	**Sedentary activity**	**Light activity**	**Moderate activity**	**Vigorous activity**
Mean daily PAEE partitioned by intensity levels ($kJ.d^{-1}$)‡	188 ±105	2147 ±1849	3418 ± 2044	3962 ± 1143*	242 ± 117**	1671 ±1202	2419 ±1583	605 ± 783

†n = 9
‡n = 7
* Higher than N-EX
** Higher than EX

Table title

Table 1. Mean free-living daily energy intake, physical activity energy expenditure (PAEE) (total and partitioned by intensity levels) during seven days of imposed exercise (EX) and no imposed exercise (N-EX).

Figure captions

Fig. 1. (a) Study protocol with two, 7-day experimental conditions. (b) Appetite regulation test day protocol.

Fig. 2. (a) Delta plasma acylated ghrelin and (b) Delta plasma total PYY concentrations in response to a standardized meal at baseline (24 hours before) and 24 h post and 70 h after seven days of imposed exercise (EX) and no imposed exercise (N-EX). The black filled box indicates the standardized breakfast meal. Values are means ± SD.
† = significantly different than 0 h.
* = significantly different than N-EX.
** = significantly different than 24 h Post.