



Acute appetite and eating behaviour responses to apparatus-free, high-intensity intermittent exercise in inactive women with excess weight

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ABSTRACT

High-intensity intermittent exercise (HIIE) has been shown to transiently suppress appetite, but such exercise has traditionally required the use of specialist apparatus (e.g., cycle ergometer). This study aimed to determine appetite and eating behaviour responses to acute apparatus-free HIIE in inactive women with excess weight. A preliminary study ($n = 18$ inactive women, 9 healthy weight, $18.0\text{--}24.9 \text{ kg}\cdot\text{m}^{-2}$; 9 with excess weight, $25.0\text{--}34.9 \text{ kg}\cdot\text{m}^{-2}$) revealed that intervals of 30 s of “all out” star jumping elicited physiological responses akin to intervals of 30 s of “all out” cycling. Twelve women ($29.2 \pm 2.9 \text{ kg}\cdot\text{m}^{-2}$, 38 ± 7 years, 28 ± 39 min MVPA $\cdot\text{week}^{-1}$) then completed three trials in a within-subject, randomised cross-over design: 4×30 s “all out” star jumping (4×30 s); 2×30 s “all out” star jumping (2×30 s); resting control (CONT). Upon completing each late-morning exercise trial, lunch was provided upon request from the participant. The time from the exercise bout to lunch request – termed eating latency – was recorded, and ad libitum food intake at lunch was measured. Subjective appetite was measured using a visual analogue scale before and after exercise, and at lunch request. Free-living energy intake (EI) and energy expenditure (EE) were recorded for the remainder of the trial day and the three days following. Change-from-baseline in subjective appetite was significantly lower immediately after 4×30 s (-9.6 ± 18.4 mm) and 2×30 s (-11.5 ± 21.2 mm) vs. CONT ($+8.1 \pm 9.6$ mm), (both $p < 0.05$, $d = 0.905$ and 1.027 , respectively). Eating latency (4×30 s: 32 ± 33 min, 2×30 s: 31 ± 26 min, CONT: 27 ± 23 min, $p = 0.843$; $\eta_p^2 = 0.017$) and lunch EI (4×30 s: 662 ± 178 kcal, 2×30 s: 715 ± 237 kcal, CONT: 726 ± 268 kcal, $p = 0.451$; $\eta_p^2 = 0.077$) did not differ significantly between conditions. No significant differences were observed in trial day EI and EE, or in EI and EE on the three days following exercise (all $p > 0.05$). Mean trial day relative EI (EI – EE) was 201 ± 370 kcal lower after 4×30 s than CONT, but this difference was not statistically significant ($p = 0.303$, $d = 0.585$). In conclusion, very low-volume star jumping elicited a transient suppression of appetite without altering eating behaviour. (313 words)

1. Introduction

An acute bout of HIIE can transiently reduce subjective appetite, yet reductions in post-exercise ad libitum absolute energy intake (EI) are seldom observed [4,18,28]. This is not surprising, given that the majority of acute exercise studies utilise an ad libitum test meal at pre-determined time points such as 45–120 min post-exercise, when the transient suppression of appetite may have subsided [4,18,28,48]. As such, this approach may miss any resultant effects of a

transient suppression of appetite on eating behaviour, thus failing to detect true differences in energy and food intake post-exercise. In addition, the assessment of other eating behaviours (including eating initiation) is not possible using this design.

Lessening the restriction on timing of eating would likely better reflect free-living food and energy intake responses to exercise. King, Wasse and Stensel [36] did assess post-exercise feeding latency, observing a significant delay in voluntary feeding of ~35 min after 60 min of treadmill running, compared with a resting condition, in active

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men. Despite an unaffected absolute EI, it is possible that such a delay to feeding following an acute bout of exercise may prevent additional food intake prior to a scheduled mealtime and suggests exercise may be efficacious for manipulating eating initiation as a specific characteristic of eating behaviour.

Nonetheless, if an acute bout of HIIE was to successfully influence appetite and eating behaviour in the immediate post-exercise period for the promotion of energy deficit, it must be feasible and time-efficient in order to be effectively implemented in a free-living setting. High intensity intermittent exercise bouts and interventions are typically apparatus-based. Those that have seen transient reductions in appetite and/or EI post-exercise require apparatus such as a cycle ergometer [28] or a treadmill [4]. Such a reliance on specialised apparatus may pose a barrier to compliance given that poor access to equipment and facilities, as well as limited access to equipment at home, have previously been highlighted as negative correlates of regular physical activity [112], [52]]. Moreover, the true time-efficiency of HIIE has been challenged [26], and a need to seek access to specialist apparatus is unlikely to aid the time-efficiency potential of HIIE. Furthermore, in order to achieve more translational findings from the laboratory to public health policy, HIIE should be low cost and accessible [24].

As such, if an apparatus-free mode of HIIE can replicate the physiological stimuli of ergometer-based HIIE previously shown to transiently suppress appetite, this could feasibly be implemented in close proximity to meals in a free-living setting, to manipulate energy balance towards a deficit. If such a bout of exercise can offer an effective acute perturbation in energy balance, via an increase in energy expenditure (EE) and a decrease in EI, this would give rise to effective exercise protocols for not only health benefits but also weight management.

Therefore, the aim of this study was two-fold. Firstly, a preliminary study was conducted to determine the acute physiological responses to two modes of apparatus-free HIIE (“all out” star jumping and weighted squats) compared with traditional, ergometer-based “all-out” cycling in inactive women of a healthy weight and with excess weight. Subsequently, the aim was to elucidate responses of appetite and eating behaviour to an apparatus-free HIIE bout (star jumps) of varying volumes (4×30 s vs. 2×30 s vs. rest) in inactive women with excess weight.

2. Materials and methods

2.1. Preliminary study

A detailed description of the methods of the preliminary study can be found in Supplementary Material (S1 – Preliminary Study Method). In brief, eighteen inactive women with a body mass index (BMI) of $18.0 - 34.9 \text{ kg}\cdot\text{m}^{-2}$ (BMI: $25.5 \pm 4.2 \text{ kg}\cdot\text{m}^{-2}$, age: 35 ± 12 years, activity: 74 ± 54 min moderate-vigorous PA (MVPA) $\cdot\text{week}^{-1}$) were randomly assigned to each of three conditions: high-intensity, “all out” squats (SQUAT), high-intensity, “all out” star jumps (JUMP) and high-intensity, “all out” cycling (CYCLE). Participants arrived at the laboratory fasted for trial visits, after an initial visit for enrolment, screening and familiarisation of the exercises. Two hours after consuming a standardised breakfast (providing 20% of estimated total daily energy requirements), participants completed 4×30 s of “all out” cycling, squatting, or star jumping with 90 s recovery in the squatting and star jumping conditions, and 180 s recovery in the cycling condition. The shorter recovery in JUMP and SQUAT was informed by pilot testing which highlighted a quicker perceived recovery time; participants felt they “had their breath back” and that they “were ready to go again” after 90 s of rest after a 30 s interval of JUMP and SQUAT, but it took longer to feel similarly recovered after cycling.

Cycling was conducted on an electronically braked cycle ergometer. Star jumping consisted of participants bending at the knees, touching the floor, and then making a maximal vertical jump, stretching out both arms and legs as laterally as possible. This was repeated as many times as

possible in 30 s. Squatting consisted of completing a squat movement from standing, to the height of a chair (47 cm), before returning to standing again. A 5 kg weight was held at chest height when descending and ascending, and then lifted above the head upon standing. Participants performed as many squats as possible in 30 s whilst maintaining a safe technique.

Heart rate, rating of perceived exertion (RPE), blood lactate (BLa) concentration and change in plasma volume (Δ PV, as a marker of muscle glycogen breakdown) were measured at baseline and after intervals 1, 2 and 4. Differences in these measures between conditions and across time points were assessed by factorial repeated-measures analysis of variance (ANOVA). Sampling allowed for sub-group analysis based on body-weight status. Participants were identified as either a healthy weight (BMI of $18.0 - 24.9 \text{ kg}\cdot\text{m}^{-2}$, $n = 9$) or having excess weight (BMI of $25.0 - 34.9 \text{ kg}\cdot\text{m}^{-2}$, $n = 9$), and a mixed-design ANOVA was conducted to assess between-group differences after interval 4 of each exercise condition.

2.2. Main study

2.2.1. Study design

A within-subject, counterbalanced, crossover study design was utilised, with participants randomly assigned to each of the three conditions in a counterbalanced manner: resting control (CONT), 2×30 s of star jumps (2×30) and 4×30 s of star jumps (4×30).

2.2.2. Participants

An *a priori* power calculation was conducted using the G*Power software (G*Power, Düsseldorf, Germany). Given the effect sizes seen for the change in subjective appetite (as a proxy measure) following a similar HIIE protocol in previous research [28] and for eating latency in the study of King, Wasse and Stensel [36] and based on an expected large effect ($f = 0.4$), alpha level of 0.05 and a statistical power of 0.8, a sample size of 12 participants was deemed sufficient to detect a meaningful change in subjective appetite and hence a likely meaningful change in feeding latency (actual power = 0.82).

Twelve inactive women with excess weight (BMI: $29.2 \pm 2.9 \text{ kg}\cdot\text{m}^{-2}$, age: 38 ± 7 years, DEBQ score (restraint): 2.58 ± 0.56 , physical activity: 28 ± 39 min MVPA $\cdot\text{week}^{-1}$) completed the study. Inclusion criteria were BMI of $25.0 - 34.9 \text{ kg}\cdot\text{m}^{-2}$, self-reporting <150 min MVPA per week on the International Physical Activity Questionnaire (IPAQ) [16], pre-menopausal, aged 18–50 years and non-smokers. Exclusion criteria were known pregnancy, breast feeding, dieting, intent to diet or attempting weight-loss, taking any medication that would influence appetite, a score of >3.5 on the restraint scale on the Dutch Eating Behaviour Questionnaire (DEBQ; [55]), resting blood pressure $>140/90$ mmHg, and any known musculoskeletal, metabolic, or cardiovascular disorder. Ethical approval was obtained from the local ethics committee of the XXX at the University of XXX, and the XXX at the University of XXX.

2.2.3. Preliminary visit and familiarisation

Participants received written and verbal information about the study, before written informed consent was obtained. A pre-participation health questionnaire, based on ACSM pre-screening guidelines [3], was completed by participants for health screening purposes. Height, weight and resting blood pressure were then measured and the IPAQ [16] was completed to assess current physical activity behaviour. The DEBQ [55] was completed by participants to assess dietary restraint. Following this, participants received a demonstration of the required star jump technique and completed one 30 s bout. Participants were also explained of the measures that would be taken during the experimental trials and were familiarised with the questionnaires and measures to be administered during the experimental trials. Participants were given a weighed food diary record in which they were asked to record 24 h food intake prior to their first experimental trial and

were again instructed that it was expected that this intake was to be replicated 24 h prior to each of the remaining trials.

Participants then undertook a continuous, submaximal graded exercise test on an electronically braked cycle ergometer (Lode Excalibur Sport, Lode, Netherlands) to determine a prediction of $\dot{V}O_{2peak}$. This was required for the calibration of the Actiheart activity monitors (CamNtech, Cambridge, UK) and hence the measure of EE. The test consisted of cycling at an initial workload of 20 W and a constant cadence of 60–70 rpm. Workload was increased in 20 W increments every 3 min until 80% of age-predicted heart rate (HR) was reached, using the Karvonen formula [34]. HR (Polar H7, Polar Electro OY, Kempele, Finland) was recorded and expired gases were measured throughout using an online gas calorimetry system (MetaLyzer 3B, Cortex Medical, Peipzig, Germany). Measures of HR, respiratory exchange ratio (RER) and rate of oxygen utilisation ($\dot{V}O_2$) were averaged during the final minute of each 3 min stage. The resulting mean values were used to calculate the corresponding, predicted EE by multiplying the $\dot{V}O_2$ with the RER-specific caloric equivalent of oxygen [21]. Thus, the relationship between individual HR and rate of EE was predicted using regression. The additional measurement of each individual's estimated calculation of resting energy expenditure (REE) ensured calibrated recording and analysis of estimations of activity and total EE when wearing the monitors.

Finally, participants were presented with a familiarisation ad libitum 12-item buffet meal (see Table 1 for composition of the buffet meal). A hedonic scale was completed after consumption of the meal to ensure that no hedonic bias was associated with this buffet meal. This was done using a standard 9-point hedonic scale [43] and any items rated 1 ("dislike extremely") or 9 ("like extremely") were not included in the buffet during experimental trials [48] to prevent possible hedonic bias. Foods excluded were not replaced with alternative items. An average of 2 items were excluded per participant (range: 0–6), leaving an average of 10 food items included.

Table 1
Food items, with nutritional information, of the ad libitum lunch meal CHO, carbohydrate; FAT, fat; PRO, protein.

Food	Energy density (kcal·100 g ⁻¹)	CHO (grams·100 g ⁻¹)	FAT (grams·100 g ⁻¹)	PRO (grams·100 g ⁻¹)
Bread (with margarine)	232	42.5	1.7	9.2
Margarine	708	0.9	78	0.5
Cheese and onion sandwich filler	320	5.1	28	11
Egg mayonnaise sandwich filler	197	3.8	16	10
Tuna mayonnaise sandwich filler	190	11	12	8.6
Ready salted crisps	134	12	8.4	1.7
Salt and vinegar crisps	132	13	7.9	1.5
Cheese and onion crisps	132	13	7.9	1.8
Chocolate cereal bar	112	16	3.2	2.2
Cranberry cereal bar	108	16	2.9	1.9
Banana	103	23.2	0.5	1.2
Apple	47	12	0.5	0.5
Orange	40	7.8	0.5	0.8

2.2.4. Experimental trials

Participants returned to the laboratory at 08:00 on their first experimental trial and at 08:30 on the subsequent experimental trials. Eumenorrheic participants undertook each experimental trial at least five days apart during the follicular phase of the menstrual cycle (days 1–14; mean day 8 ± 3, 9 ± 5 and 6 ± 3 for 4 × 30, 2 × 30 and CONT, respectively). Participants taking contraceptive medication preventing menstruation undertook each experimental trial 28 ± 2 days apart. Participants' adherence dietary and physical activity controls were checked verbally by the researcher upon participant arrival to each experimental trial. Energy and macronutrient intake did not differ on the day prior to each trial ($p > 0.05$).

2.2.5. Protocol

The study protocol is outlined in Fig. 1. During the first experimental visit, participants first underwent a measurement of resting metabolic rate (RMR) using an online gas calorimetry system (MetaLyzer 3B, Cortex Medical). Participants were instructed to be fasted and to minimise physical activity prior to the test, including arriving at the laboratory by car where possible. Participants rested for 25 min, motionless, in a supine position in a darkened, quiet room in as close proximity to waking as possible, with continuous measurement of pulmonary gas exchange. $\dot{V}O_2$ measurements were averaged during the final 10 min of the measurement period and used to calculate the predicted EE by multiplying the $\dot{V}O_2$ by the RER-specific caloric equivalent of oxygen [21]. At 9:00am on all experimental trials, participants were provided with a standardised breakfast consisting of: porridge made with oats, milk and brown sugar and a glass of orange juice. The meal provided approximately 20% of the estimated daily energy needs for a sedentary day for each individual, [41].

Following breakfast consumption, participants began a rest period where they were invited to read or work at a desk. Food cues were avoided during this period. An individually calibrated Actiheart activity monitor was applied, with recording set to begin at 12:00pm. Following the cessation of this rest period, a finger-prick capillary blood sample was obtained for the assessment of BLA. A measure of subjective appetite was recorded at this point.

Each exercise/resting control condition commenced at 11:45am. For the resting condition, participants were instructed to continue reading or working at a desk in a seated position. Each exercise condition started with a warm-up period of 1 min of marching on the spot at a self-selected pace. Participants then began either 2 × 30 s or 4 × 30 s "all-out" star jumps.

Measures of HR, RPE and subjective appetite were repeated immediately following the cessation of each condition and a further finger prick blood sample was obtained. At 12:15pm, participants were made aware that a buffet-style lunch meal was available at any point and that food would be available throughout the remainder of the trial. Upon request of this meal, a measure of subjective appetite was repeated, and an additional capillary blood sample was taken.

Participants returned to and remained in the laboratory following their meal. To ensure that participants did not leave the laboratory before requesting their lunch buffet meal or request their lunch buffet meal sooner in order to leave the laboratory sooner (thus allowing for true request of eating initiation), a final measure of RMR was recorded at 2 h following the cessation of each condition (~2:15pm). Following this, participants were free to leave the laboratory, but instructed to continue wearing the Actiheart monitor for the remainder of the testing day as well as the following 3 consecutive days. Participants were also provided with a weighed food diary and scales (if required), being instructed to record all food and drink consumption for the remainder of the testing day and the following 3 days.

During the first experimental visit, the drinking of water was permitted and offered ad libitum until all measurements had been obtained. Water intake was measured, and this amount was provided on all

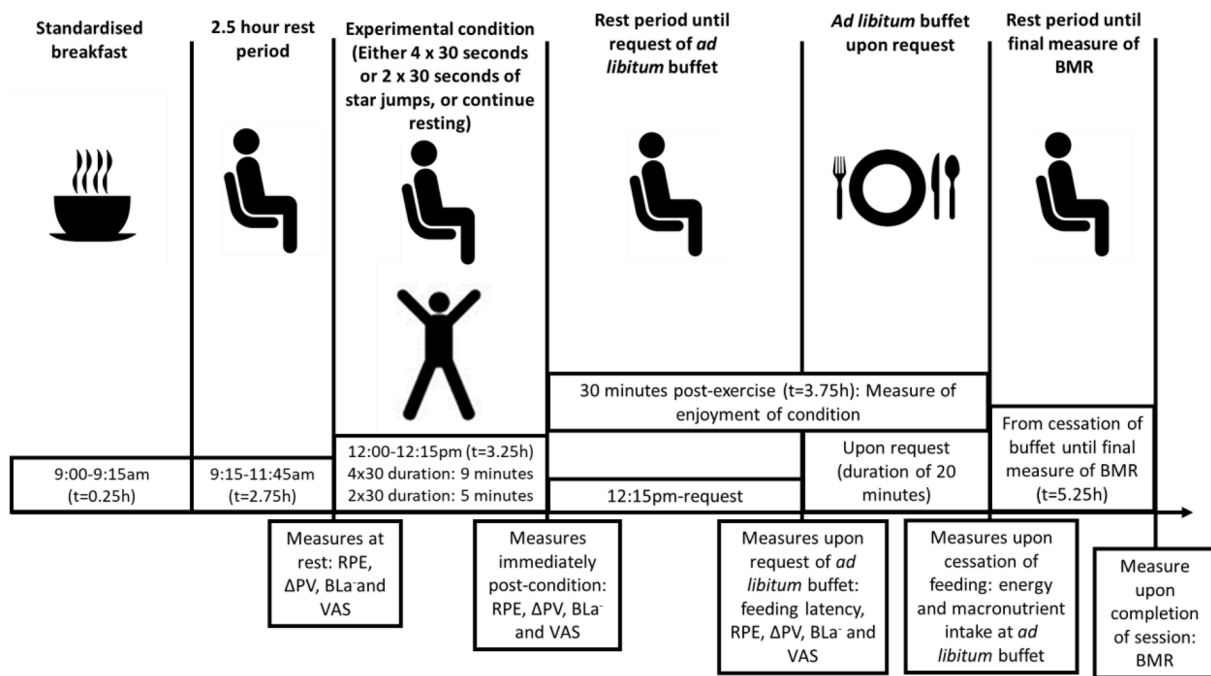


Fig. 1. . Experimental design.

subsequent experimental trials and the participant was encouraged to consume the whole amount.

Room temperature was maintained by an air conditioning system at an ambient temperature of ~ 21 °C while humidity ranged from 32 to 56%.

2.2.6. Measures

2.2.6.1. Eating latency and laboratory ad libitum lunch intake. Participants were not made explicitly aware that eating behaviour was being assessed and instead were told that the primary outcome of the study was to investigate the physiological and psychological responses of differing volumes of high-intensity intermittent exercise. Feeding latency was measured as time (in minutes) from cessation of condition (12:15pm) until participants verbally requested the buffet. At this point of request, latency was measured. The buffet was presented identically in each trial and items were provided in considerable excess of expected consumption (no participant consumed all food on offer and on only two trials did the participant consume all of a single food item). The twelve items offered, along with nutritional information (obtained from food labels), are shown in Table 1. Sandwiches were offered in quarters to remove familiar, cognitive, or visual cues that may influence self-regulated food intake [49]. At the meal, participants ate in isolation with no social interactions, or additional food cues. No time limit was placed on the meal, but participants were instructed to “eat until they are comfortably full”. Energy and macronutrient values of items consumed were calculated covertly, according to manufacturer information. Lunch relative energy intake was calculated as ad libitum lunch intake minus the energy cost of exercise.

2.2.6.2. Subjective appetite. At the time points when subjective appetite was assessed, participants completed the Visual Analogue Scale (VAS; [27]) that assessed subjective feelings of hunger, fullness, desire to eat and prospective food consumption using 150 mm visual analogue scales. A composite appetite score was then generated as the mean of these four values after fullness was reverse scored [28].

2.2.6.3. Free-living energy intake. Free-living energy and macronutrient

intake were assessed using self-report weighed food diaries. Participants were asked to weigh intakes where possible and to estimate portions as accurately as possible when weighing was not possible, as well as detail brands and preparation. All self-reported food diaries were analysed using the dietary analysis software Nutritics (version 5; Nutritics, Ireland). Where individual items were not available on the database within the programme, nutritional information was entered manually using manufacturer information. Accuracy of reporting was confirmed verbally with the participant and any lack of clarity in the reporting of intake was clarified. All participants adhered to the weighed 3-day data collection.

2.2.6.4. Energy expenditure. Energy expenditure was assessed objectively using a chest worn Actiheart monitor (CamNtech, Cambridge, UK). Both HR and accelerometer measures were entered into a validated branched-model calculation [7], then used to determine EE. Heart rate was individually calibrated [8] through an individual assessment of HR and $\dot{V}O_2$ relationship during a submaximal exercise test and the ‘Group Cal JAP2007’ energy model available in the Actiheart software (version 4.0.116, CamNtech, Cambridge, UK) was used. Recordings during wear time of the Actiheart device were made in 15 s epochs. Minimum wear time was set at 80% of the 24 h period for each day (19.2 h).

The Actiheart monitor was also used to estimate the energy cost of the bouts of exercise and comparative time spent sedentary in CONT. Indirect calorimetry was not used for this measure due to the potential restriction of movement with star jumping when using an online gas calorimetry system, and the error associated with using indirect calorimetry for estimating exercise with a large anaerobic component.

2.2.6.5. Physiological responses to exercise. A10 μ L capillary blood sample was obtained from the finger for measures of blood glucose and blood lactate concentrations using a desktop analyser (Biosen C_Line, EKF Diagnostics, Cardiff, UK). All measures were analysed in duplicate. Further capillary blood samples were obtained for the measurement of haematocrit and haemoglobin (HemoCue Hb 201+ System, HemoCue AB, Ängelholm, Sweden), allowing for a measure of haemodilution. Values uncorrected for haemodilution are presented and used for ease of comparison with previous literature. Statistical analysis confirmed that

any effects observed were not due to changes in haemodilution.

2.2.7. Statistical analysis

For both studies, all data are presented as mean \pm standard deviation in the text and tables, and as mean \pm standard error in figures. Prior to all analyses, normality of data was confirmed using the Shapiro-Wilk test. Significant interaction and main effects of analysis of variance (ANOVA) were investigated further by conducting *post-hoc* analyses using Bonferroni tests. For each ANOVA, effect size was calculated using partial eta squared (η_p^2). For *post-hoc* pairwise comparisons, Cohen's *d*, with 95% confidence intervals (95% CI), was used to determine effect size. An effect size of 0.2 or greater was considered small, 0.5 or greater considered medium and 0.8 or greater considered large [47]. To address missing data, missing data analysis was conducted using the multiple imputations technique, with the mean value of five imputations used. Throughout, statistical significance was accepted at the level of $p < 0.05$. All statistical analysis was undertaken using the software SPSS (SPSS version 23.0, SPSS inc., Chicago, Illinois, USA).

In the main study, a one-way repeated measures ANOVA was used to assess differences between conditions in feeding latency; EI and macronutrient intake at the ad libitum buffet meal; trial day EI, EE and relative EI (trial day EI – trial day recorded EE, from the point at which the activity monitor was fitted); and EI, EE and energy balance (EB) over the three days following the trial. A one-way repeated measures ANOVA was also used to assess differences in change-from-baselines subjective appetite immediately after exercise and at the point of lunch request. Separate one-way ANOVAs were conducted rather than a factorial ANOVA due to the inconsistency in the time factor (different duration exercise bout and the “on request” measure occurring at different times between participants and trials). Separate one-way ANOVAs were also conducted before and after exercise, and at the point of lunch request for blood glucose and lactate concentrations.

Outliers were identified and removed based on variance in baseline subjective appetite score (coefficient of variation $> \pm 1.5 \times$ interquartile range from the upper or lower quartile), as a large within-subject variance at baseline compromises the assessment of between-condition differences in appetite response, and may indicate lack of adherence to pre-trial dietary control.

3. Results

3.1. Preliminary study

There were no significant differences between conditions at baseline in any measures. A thorough report of data for the preliminary study can be found in the Supplementary Material (S2 – Preliminary Study Results). The primary findings are highlighted here.

Despite a significant condition \times time interaction effect for HR_{peak} ($p = 0.001$), there was no significant difference between the conditions by the end of interval 4 (156 ± 18 beats·min⁻¹, 162 ± 13 beats·min⁻¹, and 164 ± 12 beats·min⁻¹ for SQUAT, JUMP and CYCLE, respectively). Following interval 2, BLA was significantly higher in CYCLE versus SQUAT (6.0 ± 1.5 mmol·L⁻¹ vs. 3.4 ± 0.7 mmol·L⁻¹, $p < 0.001$) and JUMP versus SQUAT (4.6 ± 1.4 mmol·L⁻¹ vs. 3.4 ± 0.7 mmol·L⁻¹, $p = 0.001$). BLA was also significantly greater in CYCLE versus JUMP ($p = 0.001$). Following interval 4, BLA was significantly higher in both CYCLE (11.1 ± 1.6 mmol·L⁻¹) and JUMP (7.3 ± 2.4 mmol·L⁻¹) versus SQUAT (5.0 ± 1.8 mmol·L⁻¹, $p < 0.001$ and $p = 0.003$, respectively). BLA was also significantly greater in CYCLE versus JUMP following interval 4 ($p < 0.001$). Δ PV immediately post-exercise was significantly lower than rest in all conditions (all $p < 0.05$). No significant differences were found between conditions immediately post-exercise ($p = 0.957$). Following interval 4, RPE was significantly greater in CYCLE (18 ± 2) versus SQUAT (14 ± 3 , $p = 0.001$) and JUMP (16 ± 3 , $p = 0.036$). RPE was also significantly greater in JUMP compared with SQUAT at this time point ($p = 0.034$).

For each outcome measure, no differences were found between those of a healthy-weight and those with excess weight after interval 4 of each exercise condition (all $p > 0.05$).

3.2. Main study

One participant was identified as an outlier and removed from the dataset prior to analyses. No order effects were observed for any of the outcome measures (all $p > 0.1$), and there were no differences at baseline in any of the outcome measures (all $p > 0.05$).

3.2.1. Feeding latency

No significant main effect was found for feeding latency ($p = 0.843$, $\eta_p^2 = 0.017$). Feeding latency was 32 ± 33 min, 31 ± 26 min and 27 ± 23 min for 4×30 , 2×30 and CONT, respectively.

3.2.2. Subjective appetite

Subjective appetite profiles are presented in Fig. 2a. Individual appetite responses to exercise are shown in Figs. 2b (2×30 s) and 2c (4×30 s). There was a significant condition main effect for change-from-baseline (Δ) subjective appetite score immediately after exercise ($p = 0.005$, $\eta_p^2 = 0.409$). Post-hoc pairwise comparisons revealed a significant difference between 4×30 and CONT (-9.6 ± 18.4 mm vs. $+8.1 \pm 9.6$ mm, $p = 0.04$, $d = 0.905$, 95%CI = $0.77 - 34.7$ mm), and between 2×30 and CONT (-11.5 ± 21.2 mm vs. $+8.1 \pm 9.6$ mm, $p = 0.020$, $d = 1.027$, 95%CI = $3.06 - 36.1$ mm). There was no difference in Δ subjective appetite between conditions at the point of requesting lunch ($p = 0.655$, $\eta_p^2 = 0.026$).

3.2.3. Absolute and relative ad libitum lunch food intake

There was no significant main effect of condition for absolute EI ($p = 0.451$, $\eta_p^2 = 0.077$; Fig. 3). Macronutrient intake did not differ between conditions ($p > 0.05$ for percentage energy intake from CHO, FAT and PRO. Data not presented). There was also no significant main effect of condition for relative lunch energy intake ($4 \times 30 = 611 \pm 177$ kcal, $2 \times 30 = 692 \pm 235$ kcal, CONT = 720 ± 268 kcal; $p = 0.130$, $\eta_p^2 = 0.184$). Relative energy intake was calculated by subtracting the energy cost of the 4×30 (51 ± 9 kcal), 2×30 (23 ± 5 kcal) and CONT (7 ± 1 kcal) from the respective absolute energy intake.

3.2.4. Trial day and 3-day free-living energy intake, energy expenditure and energy balance

Trial day EI and EE are shown in Figs. 4a, b, respectively. EI, EE and EB for the three days following the trial are shown in Table 2. Wear time adherence to the Actiheart was not met on a total of three days (one for 4×30 day 1 in one participant and one for both 2×30 day 2 and day 3 in another participant). In these cases, values were replaced using multiple imputations, with the mean value of five imputations used. For days where Actiheart adherence was met, average wear time adherence was $97.0 \pm 1.5\%$ of the 24 h period for each day.

Twenty-four-hour trial day energy intake did not differ between conditions ($4 \times 30 = 2012 \pm 496$ kcal, $2 \times 30 = 2058 \pm 670$ kcal, CONT = 2123 ± 416 kcal; $p = 0.782$, $\eta_p^2 = 0.024$). Trial day EE was measured from the start of the trial, when the Actiheart was fitted. There was no difference in EE across the trial day between conditions ($4 \times 30 = 1343 \pm 224$ kcal, $2 \times 30 = 1314 \pm 218$ kcal, CONT = 1253 ± 234 kcal, $p = 0.242$, $\eta_p^2 = 0.132$). Relative energy intake for the trial day was calculated as total daily EI minus total measured EE. Relative energy intake did not differ between conditions ($4 \times 30 = 668 \pm 402$ kcal, $2 \times 30 = 744 \pm 638$ kcal, CONT = 870 ± 277 kcal, $p = 0.408$, $\eta_p^2 = 0.086$).

Energy intake was recorded on the three days following the trial day. Energy intake did not differ between conditions on any of these days ($p > 0.05$ for each day). Consequently, mean daily EI across these three days was not different ($4 \times 30 = 1871 \pm 659$ kcal, $2 \times 30 = 2016 \pm 616$ kcal, CONT = 1919 ± 430 kcal, $p = 0.608$, $\eta_p^2 = 0.049$).

Energy expenditure was recorded on the three days following the

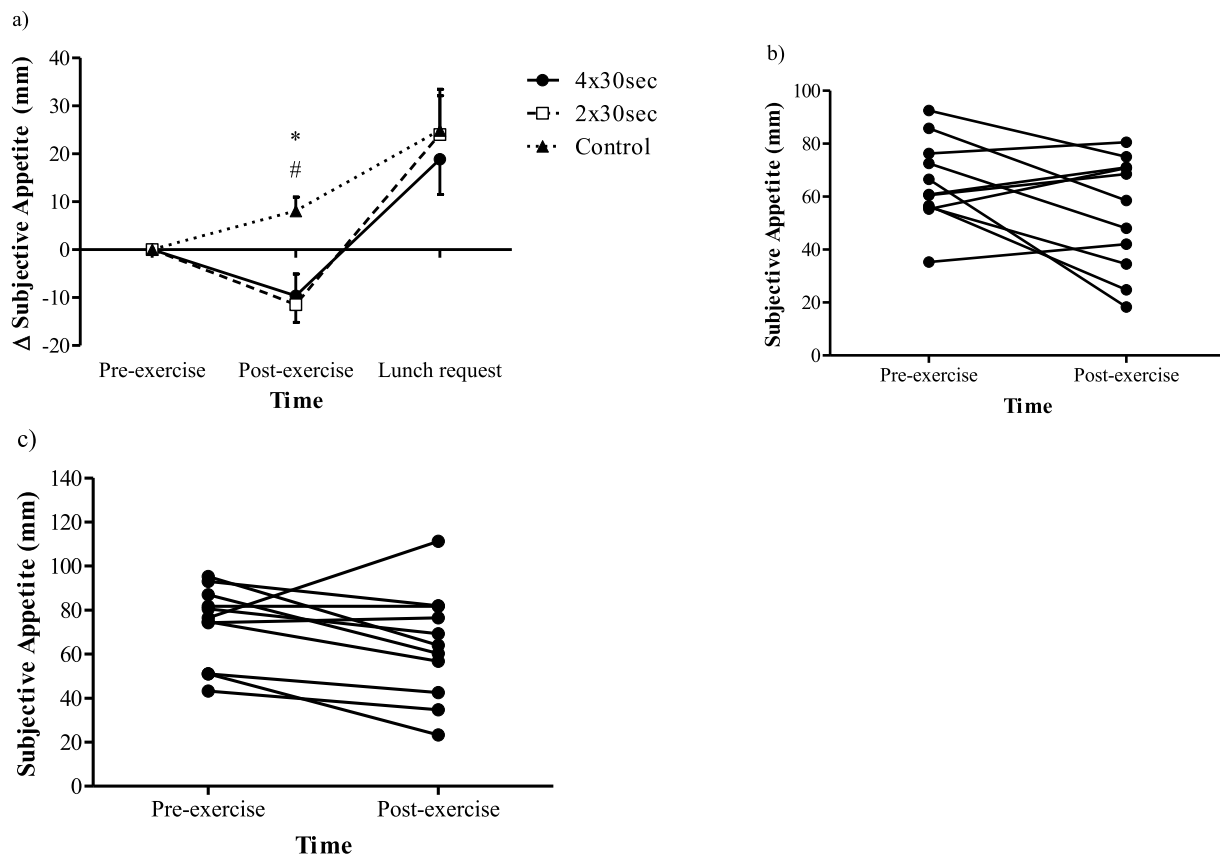


Fig. 2. (a): Change-from-baseline in subjective appetite for 4×30 (solid line, black circle symbols), 2×30 (dashed line, white square symbols) and CONT (dotted line, black triangle symbols); (b): Individual responses in subjective appetite to exercise in the 2×30 s condition; (c): Individual responses in subjective appetite to exercise in the 4×30 s condition. * = significantly different to 4×30 . # = significantly different to 2×30 .

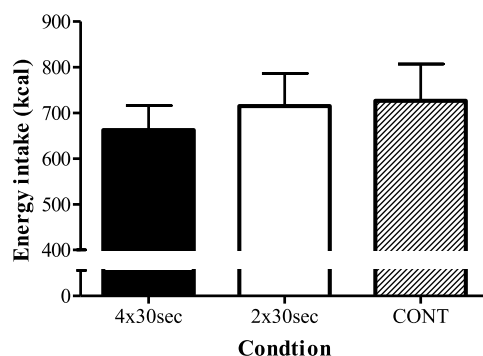


Fig. 3. Energy intake at the ad libitum lunch meal for 4×30 (black bar), 2×30 (white bar) and CONT (shaded bar).

trial day. Daily EE did not differ between conditions on any of these three days ($p > 0.05$ for each day). Consequently, mean EE across the three days was not different ($4 \times 30 = 2577 \pm 431$ kcal, $2 \times 30 = 2609 \pm 404$ kcal, CONT = 2598 ± 487 kcal, $p = 0.895$, $\eta_p^2 = 0.011$).

Energy balance did not differ between conditions on any of the three days following the trial ($p > 0.05$ for each day) Consequently, mean energy balance across these three days was not different ($4 \times 30 = -706 \pm 712$ kcal, $2 \times 30 = -593 \pm 705$ kcal, CONT = -679 ± 647 kcal, $p = 0.799$, $\eta_p^2 = 0.022$).

3.2.5. Blood glucose and lactate concentrations

Blood glucose and lactate concentrations are shown in Table 3. There was a significant main effect of condition for blood glucose concentration immediately after exercise ($p = 0.011$, $\eta_p^2 = 0.365$). However, when

correcting for change in plasma volume with exercise, this difference was no longer significant ($4 \times 30 = 3.90 \pm 0.41$ mmol·L⁻¹, $2 \times 30 = 3.64 \pm 0.49$ mmol·L⁻¹, CONT = 3.89 ± 0.42 mmol·L⁻¹; $p = 0.314$, $\eta_p^2 = 0.109$). There were no differences in blood glucose concentration between conditions at the point of lunch request ($p = 0.120$, $\eta_p^2 = 0.191$).

4. Discussion

The aim of the preliminary study was to determine the acute physiological responses to two apparatus-free, low-volume, “all-out” HIIE bouts versus a cycle ergometer-based HIIE bout, in inactive women of a healthy weight and with excess weight. Comparable HR_{peak} and plasma volume responses were achieved by 4×30 s of both JUMP and CYCLE. Additionally, 4×30 s of JUMP elicited blood lactate concentrations similar to previous literature reporting efficacious HIIE protocols and interventions [[2],[22],[23]]. Indeed, as little 2×30 s of JUMP was enough to elicit a mean blood lactate concentration of >4 mmol·L⁻¹, which is the value commonly used to determine the lactate threshold. Given that an elevated blood lactate concentration has been proposed as a potential stimulus for, or mediator of, exercise-induced appetite suppression [[32],[40],[48]], it may be hypothesised that both 4×30 s and 2×30 s of “all-out” star jumps could elicit a suppression of appetite.

In light of these findings, it was then of interest to explore the appetite and eating behaviour responses to 2×30 s and 4×30 s of “all-out” star jumps, given the potential time-efficiency and possible implications for energy balance, especially for those experiencing difficulties in weight management.

The aim of the main study was to elucidate responses of appetite and eating behaviour to an apparatus-free HIIE protocol of “all-out” star jumps of varying volumes (4×30 s vs. 2×30 s vs. rest) in inactive

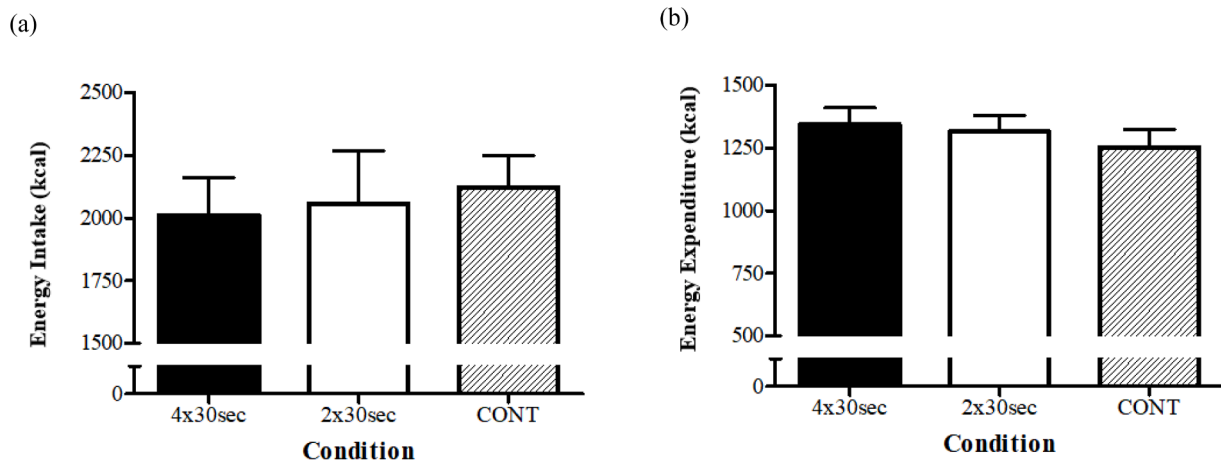


Fig. 4. . Trial day energy intake (a) and energy expenditure (b) for 4 × 30, 2 × 30 and CONT.

Table 2

Free-living energy intake (measured by 3-day food diary, see Section 2.2.6.3), expenditure (measured by Actiheart, see Section 2.2.6.4) and balance on the three days following the trial.

There was a significant main effect of condition for blood lactate concentration immediately after exercise ($p < 0.001$, $\eta_p^2 = 0.918$). Lactate concentration was significantly higher in 4 × 30 (6.50 ± 1.66 mmol·L ⁻¹) vs both 2 × 30 (4.11 ± 1.15 mmol·L ⁻¹) and CONT (1.13 ± 0.40 mmol·L ⁻¹ ; both $p < 0.001$). The difference between 2 × 30 and CONT was also statistically significant ($p < 0.001$). There was also a significant main effect at lunch request ($p = 0.006$, $\eta_p^2 = 0.493$), with lactate concentration remaining significantly higher in both 4 × 30 (4.22 ± 2.90 mmol·L ⁻¹) and 2 × 30 (2.51 ± 1.48 mmol·L ⁻¹) vs. CONT (1.18 ± 0.41 mmol·L ⁻¹ ; $p = 0.023$ and $p = 0.041$, respectively).	Day 1			Day 2			Day 3			3-day Mean		
	4 × 30	2 × 30	CONT	4 × 30	2 × 30	CONT	4 × 30	2 × 30	CONT	4 × 30	2 × 30	CONT
Energy intake (kcal)	1722 ± 567	1980 ± 507	2034 ± 757	1941 ± 960	2089 ± 1083	1943 ± 407	2071 ± 935	2023 ± 738	1779 ± 618	1871 ± 659	2016 ± 616	1919 ± 430
Energy expenditure (kcal)	2449 ± 465	2533 ± 559	2724 ± 690	2479 ± 253	2702 ± 516	2550 ± 497	2748 ± 534	2589 ± 363	2518 ± 428	2577 ± 431	2609 ± 404	2598 ± 487
Energy balance (kcal)	-727 ± 609	-553 ± 710	-690 ± 839	-538 ± 927	-613 ± 931	-607 ± 648	-677 ± 834	-565 ± 931	-739 ± 883	-706 ± 712	-593 ± 705	-679 ± 647

Table 3

Blood glucose and lactate concentrations. * = significantly different to CONT ($p < 0.05$); # = significantly different to 2 × 30 ($p < 0.05$).

	Pre-exercise			Post-exercise			Lunch request		
	4 × 30	2 × 30	CONT	4 × 30	2 × 30	CONT	4 × 30	2 × 30	CONT
Glucose (mmol·L ⁻¹)	4.00 ± 0.27	4.02 ± 0.25	3.98 ± 0.28	4.30 ± 0.37*	4.10 ± 0.32	3.87 ± 0.35	4.17 ± 0.51	3.94 ± 0.32	3.89 ± 0.32
Lactate (mmol·L ⁻¹)	1.20 ± 0.31	1.34 ± 0.55	1.10 ± 0.48	6.50 ± 1.66*#	4.11 ± 1.15*	1.13 ± 0.40	4.22 ± 2.90*	2.51 ± 1.48*	1.18 ± 0.41

women with excess weight. The main findings were that both exercise bouts induced a suppression of appetite, compared with the resting control condition. However, there were no differences in feeding latency nor absolute or relative energy intake at the ad libitum lunch meal following either 4 × 30 s or 2 × 30 s of “all-out” star jumps, or a resting control condition.

While previous studies have shown a suppression of appetite with as few as four 30 s intervals of high-intensity exercise [44,28], this is the first study to evidence a reduction in subjective appetite with just two 30 s intervals. These findings support the current perspective that the occurrence of a suppression of appetite after exercise appears to be exercise intensity-dependant [37,50,53], and may be somewhat independent of duration [28,29].

The exact mechanisms by which appetite is suppressed with high

intensity exercise are yet to be fully elucidated. It has been postulated that a reduction in splanchnic blood flow and consequent ischaemia of the gut in response to high-intensity exercise is the primary cause [10], while others have suggested that muscle-derived metabolites, such as lactate [32,40,48] and IL-6 [32], may play a role. A recent study by Vanderheyden et al. [54] demonstrated greater exercise-induced suppression of acylated ghrelin and increase in PYY when blood lactate concentration was further elevated during high-intensity interval exercise via the consumption of sodium bicarbonate. This was accompanied by a non-significantly greater exercise-induced suppression of appetite. In the present study, just 2 × 30 s of “all out” star jumps were enough to increase blood lactate concentration to 4 mmol·L⁻¹, which may explain the observed suppression of appetite. Of note, the findings of Study 1 show that blood lactate did not exceed 3 mmol·L⁻¹ after just

one 30-second bout of any of the three exercises, and as such it can be speculated that such a bout would not have elicited a suppression of appetite. It could be that the volume and intensity of exercise required to elicit an increase in blood lactate concentration provides the “threshold” for appetite suppression, and hence the response neither entirely intensity-dependant nor completely independent of duration. However, lactate remained significantly greater after both exercise bouts than the control condition at the point of lunch request, when no differences in subjective appetite – or food intake at lunch – were observed. Further experimental research is required to explore these potential mechanistic explanations for post-exercise appetite suppression.

Further, the present study demonstrated just such an appetite response with apparatus-free high-intensity interval exercise. This provides evidence for the potential for very low-volume exercise bouts, which can be done without having to access gym or exercise equipment, to suppress appetite. Indeed, if such bouts are used as snack replacements – to transiently suppress appetite at times of increased hunger between or before meals – this could reduce energy intake from snacking on energy-dense food. Given that energy consumed from snacking contributes to positive energy balance [13], [20] and weight gain [30], and poses a challenge to successful maintenance of weight-loss [42], this could prove an effective component of a weight management strategy.

However, the appetite suppression observed in the current study was of such a transient nature so as to not affect eating initiation, nor acute food intake. In all three conditions, the request for lunch was made approximately 30 min after exercise with no difference in energy intake at lunch. As appetite profiles had converged by the point of requesting lunch, it is perhaps unsurprising that intakes did not differ. The consistent timing of lunch request and the similarity in energy intake suggests that the suppression of appetite seen immediately after exercise was transient, lasting less than 30 min. This is commonly observed when subjective appetite is monitored over a period of time after exercise [37], [38], [53]; the present study confirms these observations when allowing participants to feed at a time of their choosing.

With one notable exception [48], previous studies have also shown no reduction in post-exercise energy intake when food was provided at a standardised time point after HIIE [4], [28], [39]. Few other studies have explored feeding latency as a measure of eating behaviour and have instead prescribed ad libitum meals at a pre-determined time point after exercise. In contrast to the current study, King, Wasse and Stensel [36] did observe a significant delay in eating initiation of ~35 min after 1 h of moderate-high-intensity continuous running, compared with resting control, in healthy-weight males. Subjective appetite responses immediately after exercise were similar between the study of King, Wasse and Stensel [36] and the current study, so the difference in the eating latency response is not easily explained. It is possible that the very short duration of exercise in the current study elicited a more transient suppression of appetite than that observed after the much longer bout of King, Wasse and Stensel [36] – while the presence or otherwise of an exercise-induced appetite suppression appears independent of duration, the longevity of a response may be somewhat duration dependant – or that differences in the weight-status of participants resulted in a different response.

However, in agreement with the study of King, Wasse and Stensel [36], the present study observed no difference in energy intake at the ad libitum lunch meal between conditions. While exercise did not acutely reduce energy intake, nor did it induce an acute compensatory increase in energy intake. This was the case for the remainder of the trial day. While energy balance could not be calculated for the entire 24 h period (as activity monitors were not worn until the participants arrived at the laboratory), relative energy intake for this day, calculated as total daily energy intake minus measured energy expenditure, was determined. Despite no significant condition effect, mean relative intake was 202 kcal lower in the 4 × 30 s condition, compared with the control condition. Given that accumulations of positive energy balance of as small

as ~24 kcal per day can lead to 1 kg weight gain over 3 years [25], this magnitude of difference may not be inconsequential. It is plausible to suggest that if a daily energy deficit of this extent (~200 kcal) can repeatedly be induced in this way, this may prevent small but meaningful magnitudes of positive energy balance, if not induce negative energy balance. With the short duration and low volume nature of the 4 × 30 s exercise bout in the present study, it would be of interest to explore the effects of repeating such a bout on a second occasion on the same day on relative energy intake and energy balance. A doubling of the observed effect with a second bout of exercise could result in a meaningful negative energy balance, approaching the recommended 500 kcal daily deficit for safe and sustainable weight-loss [33]. As such this may offer an effective strategy to not only increase physical activity behaviour in an inactive population, but also possibly lead to effective weight management for those with excess weight or obesity. Further, with no requirement of apparatus or equipment, such bouts of exercise could be completed quickly and conveniently in the home, with minimal time commitment or disruption to a daily routine. No study has yet explored the longer-term effects on energy intake and energy balance when HIIE is conducted within close proximity to a meal, in a free-living environment or on more than once occasion during a day. Such investigation would be of interest.

In turn, it is important to note the absence of compensatory increase in energy intake or decreases in energy expenditure during the three days following exercise. Indeed, there was a non-significant mean reduction in EI of 312 kcal on the day following 4 × 30, compared with the control condition. Previous work corroborates that acute exercise is able to induce short-term energy deficits without compensatory appetite or eating behaviour responses [31], [35]. Rocha et al. [44] found that, in inactive women only, energy intake was reduced by ~472 kcal on the day following 1 h of moderate-intensity cycling compared with active women. It can be speculated that this may be caused by a delayed eating behaviour response to exercise. Of note, similar findings were not seen when studied in inactive and active males [45], suggesting possible sex differences in delayed energy balance responses. In the present study, the observed reductions in EI with 4 × 30 s of exercise on the day following exercise was accompanied by a concurrent reduction in EE, resulting in very similar mean energy balance between the three conditions. However, energy balance values observed across the three days following exercise suggest a considerable energy deficit in all conditions. Given the weight-status of the participants, these values should be interpreted with caution, and suggest underreporting of food intake, non-habitually high activity, or both. The mean three-day EI of 1935 kcal is similar to the mean estimated TER of the study sample (1974 kcal), and as such suggest the error may lie in an overestimate of/un-habitual high activity and energy expenditure; it is plausible that some degree of measurement reactivity bias occurred, with participants increasing physical activity behaviour due to being monitored [6]. Nonetheless, our findings further support the value of future research exploring the promotion of low-volume, apparatus-free HIIE for initiating potentially meaningful energy deficit in a population of inactive females with excess weight, especially given the growing support for HIIE to be time-efficient, accessible and practical for inactive people [24], [26].

The present study is not without limitations. There were no measures of appetite-associated hormones to accompany measures of subjective appetite, eating latency and food intake. Such measures would have provided mechanistic insight. Given ghrelin’s potent role as a feeding initiator [17], measuring acylated ghrelin concentration would have been of particular interest alongside the measure of eating latency. Previous studies have observed the presence [51] and absence [1] of sex differences in acute appetite and eating behaviour responses to exercise. As such, it would be of interest to also explore the aims of the present study in men. Nonetheless, the present study focuses on women due to the lack of investigation in the field in female populations [14], and on women with excess weight in particular due to the application of the

findings for those seeking effective weight management strategies.

While the study design did allow for a measure of eating latency, the choice of when to consume lunch was somewhat restricted by the timing of the RMR measure two hours after exercise. However, we felt that this was timed sufficiently (~2.30pm) so as to be comfortably after lunch for participants. The meal could also have been requested after the RMR measurement. All participants did indeed request the meal comfortably in advance of the RMR measure (a minimum of 40 min in advance). Covertly measuring eating latency is not without challenges. Such measures could, in future study, be obtained in free-living settings, allowing the participant to leave the laboratory immediately after exercise and using ecological momentary assessment methods, such as the “Snap-N-Send” method [15].

It is acknowledged that different cohorts of participants were used in the preliminary and main studies. The participants in the preliminary study had markedly lower mean BMI compared to the main study group ($25.5 \pm 4.2 \text{ kg}\cdot\text{m}^{-2}$ vs $29.2 \pm 2.9 \text{ kg}\cdot\text{m}^{-2}$), including nine participants of healthy-weight and nine with excess weight. The aim of the preliminary study was to determine an appropriate apparatus-free exercise bout for non-obese inactive women, with the main study focussing specifically on those with excess weight due to the primary interest in appetite and food intake responses. We are nonetheless confident that the star jump exercise identified in the cohort of the preliminary study was appropriate for the aims of the main study in a cohort of exclusively inactive women with excess weight. There were no differences in any of the outcome measures between healthy-weight participants and those with excess weight during star jumping, suggesting no bodyweight-related differences in responses to the exercise. Further, the blood lactate concentration values after 2 and 4 intervals of star jumping in the preliminary the main trials were comparable ($4.6 \pm 1.4 \text{ mmol}\cdot\text{L}^{-1}$ vs. $4.1 \pm 1.2 \text{ mmol}\cdot\text{L}^{-1}$, and $7.3 \pm 2.4 \text{ mmol}\cdot\text{L}^{-1}$ vs. $6.5 \pm 1.7 \text{ mmol}\cdot\text{L}^{-1}$ after interval 2 and 4, respectively. Neither were significantly different).

A strength of the study includes controlling for stage of the menstrual cycle in a within-subject manner, as eating behaviour can differ across the menstrual cycle [9],[11],[19]. Additionally, EI over a 4-day period has been demonstrated to be increased in inactive women taking oral contraceptives compared with inactive women not taking oral contraceptives [46]. The present study did not control for contraceptive method in women. This was due to the likely restrictions this would have induced upon recruitment. However, the within-subject design in the present study discounts for this somewhat.

An ad libitum buffet format was selected for the laboratory measure of food intake. This allowed for measures of macronutrient intake and aimed to avoid premature cessation of eating due to boredom or limited food choice with single item ad libitum test meals [5]. Attempts were made to avoid overconsumption due to hedonic bias. EI and EE were then both assessed beyond the laboratory environment which are strengths of the present study; although, the inherent limitations with self-report food diaries are noted and future studies should look to use measures with greater objectivity.

5. Conclusion

“All out” star jumping can elicit important physiological responses indicating the potential effectiveness of apparatus-free HIIE for implementation into a physical activity strategy for inactive women. As little as 2×30 s of “all-out” apparatus-free HIIE induced an acute suppression of appetite but did not affect eating latency or acute energy intake in inactive women with excess weight. However, albeit not significant, potentially meaningful acute reductions in relative EI were observed with 4×30 s “all-out” star jumps. Future research should explore these responses in men, as well as exploring the chronic adoption of such apparatus-free HIIE, timed in very close proximity to meals and undertaken in a free-living setting, to elucidate longer-term energy balance responses for those with excess weight.

Author contributions

AB, AKB, DMP and AH conceived the research question and designed the study. AB collected the data. AB and AH analysed the data. AB and AH wrote the manuscript. AKB and DMP edited the manuscript. All authors approved the final version of the manuscript.

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Declaration of Competing Interest

None to declare.

Data Availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.physbeh.2022.113906](https://doi.org/10.1016/j.physbeh.2022.113906).

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