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Physical activity duration but not energy expenditure differs between daily compared with intermittent breakfast consumption in adolescent girls: a randomized crossover trial

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CHO, carbohydrate; DBC, daily breakfast consumption; IBC, intermittent breakfast consumption; LPA, light physical activity; MET, metabolic equivalent; MVPA, moderate-to-vigorous physical activity; PA, physical activity; PAEE, physical activity energy expenditure; RMR, resting metabolic rate.

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Abstract

Background: It is not known whether breakfast frequency affects physical activity (PA) in children or adolescents. Objective: This study examined the effect of daily compared with intermittent breakfast consumption on estimated PA energy expenditure (PAEE) in adolescent girls. Methods: Using a randomized crossover design, 27 girls (age 12.4 ± 0.5 y, body mass index 19.3 ± 3.0 kg·m⁻²) completed two, 7-day conditions. A standardized breakfast (~1674 kJ) was consumed every day before 09:00 in the daily breakfast consumption (DBC) condition. The standardized breakfast was consumed on only three days before 09:00 in the intermittent breakfast consumption (IBC) condition alternating with breakfast omission on the remaining four days (i.e., only water consumed before 10:30). Combined heart rate-accelerometry was used to estimate PAEE throughout each condition. Statistical analyses were completed using condition by time of day repeated measures analysis of variance. The primary outcome was PAEE and the secondary outcome was time spent in PA. Results: Daily estimated PAEE from sedentary, light, moderate and vigorous intensities and total PAEE were not significantly different between the conditions. The condition by time of day interaction for sedentary time (P = 0.05) indicated that the girls spent 11.5 min/d more time sedentary in IBC compared with DBC during 15:30-bedtime (P = 0.04). Light PA was 19.8 min/d higher during DBC compared with IBC (P = 0.05), which was accumulated during wake-10:30 (P = 0.04) and 15:30-bedtime (P = 0.03). There were no significant differences in time spent in MPA or VPA between the conditions. Conclusions: Adolescent girls spent more time in light PA before 10:30 and after school and spent less time sedentary after school when a standardized breakfast was consumed daily compared with intermittently across seven days. However, breakfast manipulation did not affect estimated daily PAEE.

Clinical Trial Registry number: ISRCTN74579070

Keywords: Breakfast, children, adolescents, physical activity, exercise, health, nutrition.
Introduction

Infrequent breakfast consumption (1, 2) and physical inactivity (3) are global health concerns in children and adolescents (young people). The majority of cross-sectional reports show a positive association between breakfast frequency (i.e., days per week that breakfast is consumed) and self-reported physical activity (PA) in young people (4-6), with few showing no meaningful relationship (7, 8). When using objective measures of PA, frequent breakfast consumption was associated with higher counts/min in the morning compared with occasional breakfast consumption in girls, but not boys (9). In contrast, another report showed that more frequent breakfast consumption was associated with lower sedentary time and higher time in moderate to vigorous PA (MVPA) in boys, but not girls (10). Furthermore, a cross-sectional study where breakfast and PA were assessed simultaneously detected higher MVPA when breakfast was consumed compared with when it was omitted on weekend days, but not on weekdays, in girls and boys (11). However, the association between breakfast frequency and PA could be due to a clustering of healthy lifestyle behaviours. Thus, prospective interventions are required to determine whether consuming breakfast results in increased PA.

A randomized controlled trial reported higher PA energy expenditure (PAEE), particularly from light PA (LPA) during the morning, in lean adults (12) and higher total PAEE during the morning in obese adults (13) who consumed breakfast daily compared with those who omitted breakfast daily for six weeks. In these studies (12, 13), the difference in PAEE was of equal magnitude during the first and last weeks of breakfast manipulation. Similarly, an acute crossover trial reported that morning PAEE assessed via accelerometry was higher after breakfast consumption compared with omission in women classified as habitual breakfast eaters (14). However, studies using pedometers and accelerometers in adults have generally shown no effect of breakfast on PA (15-17). Likewise, the only experimental study available
in young people found no effect of breakfast consumption compared with omission on PA when using wrist-worn accelerometers in adolescent girls (18). In contrast, combined heart rate-accelerometry is particularly sensitive to low-to-moderate intensity, spontaneous PA (12, 19) and provides a more valid estimation of PAEE than movement or heart rate alone (20).

The influence of breakfast consumption and omission on PA may be more pronounced in young people than adults due to their increased energy demands for growth (21), higher PAEE (22) and higher reliance on exogenous carbohydrate (CHO) as a fuel (23). In girls particularly, breakfast frequency (24) and PA (25) decline during adolescence, which is a crucial time to promote healthy dietary and PA behaviours (26). Thus, this study used a randomized, cross-over design to examine the effect of daily compared with intermittent breakfast consumption on free-living PAEE over seven days in 11 to 13 year old girls.

Methods

Participants

This dual centre study was registered at www.isrctn.com (ISRCTN74579070) and conducted in accordance with the ethical standards of the respective University Research Ethics Committees. Data collection was completed between December 2015 and September 2016. Forty girls aged 11 to 13 years were recruited from schools in the two locations in England. Parental informed consent and child assent were gained for all participants. Girls were excluded from the study if they had health related issues identified from a health screen questionnaire (e.g., allergies to the breakfast meals, fitted with a pacemaker) or were unable to walk or wear a combined heart rate-accelerometer on their chest.

Sample size calculations
A positive energy balance of at least 628 kJ/d in excess of normal growth requirements (27) may explain the higher adiposity in infrequent breakfast consumers (1, 2). Post-breakfast energy intake compensation would be expected to account for ~24% of breakfast in adolescent girls (18), which equates to ~402 kJ of the 1674 kJ standardized breakfast used here. Therefore, energy intake would be expected to be 1272 kJ/d higher on the breakfast consumption days compared with the breakfast omission days in the present study. To achieve energy balance, PAEE would need to be 5088 kJ higher in total across the seven days, equating to a daily average of 727 kJ/d during daily compared with intermittent breakfast consumption. Therefore, we deemed that the smallest worthwhile difference in estimated PAEE between the conditions would be 1355 kJ/d. The expected SD for free-living PAEE in adolescents is ~1883 kJ/d (28, 29). Using these figures, a sample size of 23 participants was estimated to detect a significant difference in estimated PAEE at 90% power with an α of 0.05 and an effect size of 0.72 in this two-treatment within-participant crossover design. Forty participants were recruited to allow for a dropout of ~30%.

Preliminary measurements

Stature was measured to the nearest 0.01 m using a portable Leicester height measure (SECA Corporation, Hamburg, Germany). Body mass was measured and percent body fat estimated to the nearest 0.1 kg and 0.1%, respectively, using a Tanita Body Composition Analyser (BC-418 MA, Tanita Corporation, Tokyo, Japan). Subsequently, BMI was calculated as body mass divided by stature squared (kg·m⁻²). Waist circumference was measured to the nearest millimetre, as described elsewhere (30). To describe the pubertal status of the study sample, the girls were asked to provide a validated (31, 32) self-assessment of their physical maturation using secondary sexual characteristics with the assistance of a primary home-based carer (33). A questionnaire was used to assess habitual breakfast patterns for weekdays...
and weekend days separately. Habitual breakfast frequency was assessed using the question “how often do you usually have breakfast?” Response categories ranged from ‘never’ to ‘five days’ for the week, and ‘never’ to ‘two days’ for the weekend. Participants were also asked to indicate what they normally eat and drink for breakfast and the time that they usually consume breakfast on weekdays and weekend days. Participants who consumed breakfast (≥~418 kJ based on the girls written descriptions of their habitual breakfasts) before 10:30 on at least five d/week were classified as habitual breakfast consumers; those who did not were classified as non-habitual breakfast consumers (9, 15).

The participants then completed two tests on a treadmill: 1) a submaximal test consisting of 4 x 4 min stages to determine the relation between heart rate and estimated energy expenditure, and 2) a maximal test to determine peak oxygen uptake. On a separate occasion, a 10 min resting expired air sample was collected after 20 min of quiet rest in the fasted state (34); resting metabolic rate (RMR) was computed using the Weir equation (35). Expired air was sampled continuously during the treadmill and RMR tests using online gas analysis with the same equipment used at both sites (Metalyzer 3b, Cortex, Leipzig, Germany).

**Experimental design**

Using a within-participants cross-over design, participants completed two, 7-day conditions in a counter-balanced order: daily breakfast consumption (DBC) and intermittent breakfast consumption (IBC). There was a seven to ten day washout between conditions. The order of the conditions for each participant was produced using a computer-based random number generator by the principal investigator (JZF). During the DBC condition, participants were asked to consume a standardized breakfast every day for seven consecutive days. During the IBC condition, the participants consumed no food or drink except for water until 10:30 on
days 1, 3, 5 and 7 (breakfast omission days) and consumed the standardized breakfast on days 2, 4 and 6 (breakfast consumption days). The participants were allowed to eat as and when they pleased from 10:30 onwards. The 4:3 breakfast omission:breakfast consumption ratio in IBC ensured the majority of days were breakfast omission and aligns with research showing that occasional breakfast consumption (1-4 d/week) is associated with lower PA in girls (9).

Throughout each 7-day condition, free-living PAEE was estimated using combined heart rate-accelerometry (Actiheart, CamNtech, Cambridge, UK). The experimental conditions did not coincide with anticipated changes in PA habits (e.g., holidays, school sports days).

In an attempt to enhance compliance to study procedures (i.e., wearing the Actiheart monitor continuously and adhering to the breakfast protocol), the participants and parents received telephone reminders during each 7-day condition. The parents were also asked to ensure the girls consumed or omitted breakfast on the specified days. To confirm compliance to the breakfast intervention, the participants were asked to take photographic evidence of all food and drink consumed before 10:30 using a digital camera (ViviCam 46, Vivitar Shenzhen, China) and complete a daily breakfast log that included the time breakfast was consumed.

**Breakfast meals**

The standardized breakfasts contained 1674 kJ (400 kcal), which equated to 18-25% of daily energy requirements for girls aged 11-13 years (36). Thus, breakfast energy intake was in line with recommendations that breakfast should contribute to ~20% of daily energy intake (37). Based on findings from preliminary focus groups on the breakfast preferences of 12 to 13 year old girls, the participants were provided with a limited selection of wholegrain, CHO-based ready-to-eat cereals, fruit and juice to taste before the experimental conditions. Ready-to-eat cereal was chosen because it is associated with reduced BMI z-scores and waist
circumference when compared with ‘other breakfasts’ in adolescents (38). Furthermore, CHO-based breakfasts would be expected to increase exogenous glucose availability, which may act as a physiological mechanism to increase PA (12). The girls selected one cereal and had the option of adding one fruit and one drink item to consume on all breakfast days (i.e., 10 days across the two trials) (see Supplemental Table 1). Thus, the breakfast meal was standardized within participants, but not between participants to account for individual breakfast preferences. With the exception of the milk, all breakfast items were provided to the participants to take home prior to each condition. The cereal and fruit were weighed and provided in pre-packaged containers and the girls were provided with marked beakers to accurately measure the amount of juice and milk to consume each morning. All parents stated that they could provide semi-skimmed (1.8% fat) milk for their daughter’s breakfasts. The girls and their parents were told that sugar should not be added to the cereal or drink.

The standardized breakfasts were consumed at home before 09:00. For IBC, breakfast omission was defined as abstaining from energy-containing food and beverages until 10:30 on days 1, 3, 5 and 7. The breakfast consumption and omission cut-off times were in line with a proposed definition of breakfast being ‘the first meal of the day, eaten before or at the start of daily activities (e.g., errands, travel, work), within 2 hours of waking, typically no later than 10:00 am’ (39). The breakfast omission cut-off time also coincided with the school day, as the participants’ first opportunity to consume food or drink during the post-breakfast period was during school break time at ~10:30.

**Physical activity energy expenditure assessment**

Throughout each 7-day trial, free-living PAEE was estimated using combined heart rate-accelerometry (Actiheart, CamNtech, Cambridge, UK). This method provides a more valid
estimation of PAEE in 12 to 13 year olds than the use of accelerometry or heart rate
monitoring alone (20). The monitor was fitted the day before and removed the day after each
7-day condition, as described previously (11, 20). Individual calibration was performed using
the measured RMR, peak oxygen uptake, and energy expenditure values corresponding to the
four different exercise intensities (expressed as heart rate) performed during preliminary
testing. This calibration method ensured greater accuracy of the PAEE estimations during the
experimental conditions than using group regression equations, as it accounted for individual
differences in the heart rate-PAEE relationship (20). The Actiheart was set to record in 15-s
epochs. At the point when the Actiheart monitor was fitted, participants were provided the
following message both verbally and in writing to ensure that only genuinely meaningful
behavioural responses were recorded: “Your lifestyle choices during this monitoring period
are very important to this study. We are interested in any natural changes in your physical
activity habits, which you may or may not make in response to the breakfast intervention.
This monitoring period has been carefully scheduled to avoid any pre-planned changes in
these habits, such as a holiday, sports days or exercise plans. You should inform us
immediately if unexpected factors influence your lifestyle.”

To complement the Actiheart data, participants were required to record their answers to the
following questions using a daily log: “what time did you wake up?” and “what time did you
turn off the light and go to bed?” Due to a lack of compliance in completing these logs, wake
and bed times were identified via visual inspection of the Actiheart data using a standardized
protocol. The same researcher viewed all of the 24-hour data files and, if available, used self-
reported wake and bed times to provide a region of interest. Objective markers were then used
to identify bed time (i.e., the beginning of prolonged minimal movement accompanied by a
A decline in heart rate) and wake time (i.e., the beginning of prolonged increased movement accompanied by an increase in heart rate) (40). Only data during waking hours were analyzed.

Actiheart recordings were classified by the Actiheart software as being ‘OK’, ‘recovered’, ‘interpolated’, ‘lost’ or ‘not worn’. The ‘lost’ and ‘not worn’ data were excluded from analyses, as this suggested non-wear time or signal failure. Thus, minutes of useable data for each day were the sum of the ‘OK’, ‘recovered’ and ‘interpolated’ data. A valid day was defined as having at least 10 h of useable data, as used previously (11, 41). The minimal amount of useable data that was considered acceptable within each condition was four valid days, including one weekend day (41). For the IBC condition, breakfast must have been omitted for ≥50% of the valid days. Branched equation modelling was used to estimate PAEE, with metabolic equivalent (MET) values used to define sedentary (<1.5 METs), light (1.5-2.9 METs), moderate (3.0-5.9 METs) and vigorous (>5.9 METs) activity. For each valid dataset, time spent and estimated PAEE for each intensity were calculated for three time segments of the day: wake time to <10:30, 10:30 to <15:30 and 15:30 until bed time. These times were chosen to coincide with the breakfast omission cut-off (i.e., 10:30) and end of the school day (i.e., 15:30), as school is a particularly sedentary setting in adolescent girls (42).

**Statistical analyses**

Statistical analyses were completed using IBM SPSS statistics software for Windows version 21 (IBM Corporation, New York, USA). The primary outcome was PAEE and the secondary outcome was time spent in PA. Condition by time of day (2 x 3) ANOVA were used to examine differences between conditions across the three time segments (i.e., wake time to <10:30; 10:30 to <15:30; 15:30 until bed time). The difference in hours of useable data between the conditions, the difference in wake time between the conditions, habitual breakfast
frequency and BMI were included as covariates. Homogeneity of variances were examined by Mauchly’s test of sphericity, and a Greenhouse–Geisser correction was applied to the degrees of freedom if the sphericity assumption was violated. For significant ($P \leq 0.05$) breakfast condition by time interactions, each individual time segment was compared between the two conditions. Cohen’s $d$ effects sizes were checked to gauge the magnitude of the significant between-condition differences ($P \leq 0.05$) and trends ($P > 0.05$ and $\leq 0.09$) (43). To determine whether between-condition differences were a driven by the breakfast omission days or a uniform effect across the week in IBC, the breakfast omission and consumption days within IBC were also compared. Values are presented as means ± SDs unless stated otherwise.

Results

Participant characteristics

The final sample included 27 participants (Figure 1). The physical characteristics of the participants are shown in Table 1. Habitual self-reported weekday breakfast frequency was $3.7 \pm 1.9$ d/week, weekend breakfast frequency was $1.7 \pm 0.5$ d/week and weekly breakfast frequency was $5.4 \pm 2.0$ d/week; 81% of the participants were classified as habitual breakfast consumers (9, 15). Ready-to-eat cereal was consumed habitually for breakfast in 59% of the participants on weekdays and in 33% of the participants on weekend days. The participants consumed breakfast habitually at $07:39 \pm 00:49$ on weekdays and $09:32 \pm 00:56$ on weekend days. There were no significant differences in the physical characteristics or breakfast frequencies of the 13 girls who were excluded from the final analyses compared with the 27 who were included.
Breakfast meals

The energy and macronutrient composition of the breakfasts were: 1674 ± 0 kJ (400 ± 0 kcal), 63.0 ± 6.3 g CHO, 5.6 ± 0.8 g fat, 14.7 ± 1.8 g protein and 8.6 ± 4.9 g fibre. Thus, the experimental breakfasts were 63.0 ± 6.3 % CHO, 12.5 ± 1.9 % fat and 14.7 ± 1.8 % protein. There was only a small amount of between-participant variation in the number of breakfast consumption days (2.8 ± 0.4 days) and breakfast omission days (3.9 ± 0.4 days) within IBC in the final dataset. Only four of the 27 girls in the final sample reported their breakfast times on all breakfast consumption days; in these girls, breakfast was consumed at 07:38 ± 00:32 in DBC and 07:38 ± 00:24 in IBC.

Wake time and useable data

There were no significant differences in the hours of useable data (DBC 15.5 ± 1.7 h vs. IBC 15.4 ± 1.1 h), wake times (DBC 07:02 ± 00:42 vs. IBC 07:07 ± 00:44) or bed times (DBC 22:56 ± 00:37 vs. IBC 22:47 ± 00:35) between the conditions.

Time spent in physical activity

Figure 2 shows the time spent in each PA intensity stratified by time of day for each condition. The overall effect of condition or time of day on sedentary time was not significant, but there was a significant crossover interaction (P = 0.05). Individual time segment analyses showed no significant difference in sedentary time between conditions for wake-10:30 and 10:30-15:30, but sedentary time was 11.5 min higher in IBC compared with DBC during 15:30-bedtime (P = 0.04) (Figure 2). There was a trend towards an interaction with time of day when comparing sedentary time between the breakfast omission and consumption days within IBC (P = 0.07), but no significant differences were found for the
individual time segments. Time spent in LPA was 19.8 min/d higher in DBC compared with IBC \((P = 0.05)\). There was a trend for a main effect of time of day for LPA \((P = 0.06)\) and the condition by time of day interaction was significant \((P = 0.04)\). Time spent in LPA was significantly higher in DBC compared with IBC by 5.0 min/d during wake-10:30 \((P = 0.04)\) and by 12.7 min/d during 15:30-bedtime \((P = 0.03)\), but not during 10:30-15:30 (Figure 2).

Within IBC, time spent in LPA tended to be higher (by 2.3 min/d) on the breakfast consumption compared with the omission days \((P = 0.07)\) and there was a significant interaction with time of day \((P = 0.03)\), but no significant differences were found for the individual time segments. Cohen’s \(d\) values indicated that the magnitude of the differences in time spent sedentary and in LPA were small at best \((d \leq 0.31)\). All main effects and interactions were non-significant for time spent in MPA and VPA.

**Physical activity energy expenditure**

Estimated daily PAEE for each intensity and total estimated daily PAEE are shown in Figure 3 and Figure 4, respectively. All main effects for condition and time of day and the condition by time of day interactions were non-significant for estimated PAEE from sedentary, moderate and vigorous activities and for total estimated PAEE. The condition main effect for estimated light intensity PAEE was not significant, but the main effect of time was significant \((P = 0.01)\) and the condition by time interaction indicated that this effect depended on the condition \((P = 0.05)\). When each condition was analyzed separately, estimated light intensity PAEE differed significantly between the daily time segments for IBC \((P = 0.01)\), but not for DBC. For IBC, estimated light intensity PAEE increased across the day, being higher during
Discussion

This randomized crossover trial reported for the first time that adolescent girls spent more time in LPA in the morning and after school and less time sedentary after school when a standardized breakfast was consumed daily compared with intermittently over seven days. However, estimated PAEE was not affected.

It has been proposed that changes in PA after breakfast consumption compared with omission may be characterized by the replacement of sedentary behaviors with spontaneous LPA, as supported by a randomized controlled trial in lean adults (12). In line with this notion, the girls in our study engaged in 19.8 min/d more LPA during DBC compared with IBC. This finding complements the higher counts/min in the morning in girls classified as frequent compared with occasional breakfast consumers (9). Although sedentary time was lower after school during DBC compared with IBC, past research showed no association between breakfast frequency and sedentary time in girls when the after-school period was not analyzed specifically (10). Similar to previous reports in girls (10) and in adults (12, 13), we found no evidence of a link between breakfast frequency and moderate or vigorous PA. Nevertheless, girls and boys spent more time in MVPA when they consumed breakfast on weekends, but not weekdays (11). Hence, it has been proposed that the school timetable limits opportunities to engage in PA on weekdays, whereas structured MVPA on weekends may cause breakfast
to be consumed in preparation (11). Indeed, glucose ingestion delays time to exhaustion (44) and reduces ratings of perceived exertion (45) during MVPA in boys, although data in girls are not available. Collectively, these findings suggest that the direction of the breakfast-PA relationship may depend on PA intensity and intentions, which requires further investigation.

Morning PA has been shown to be particularly sensitive to breakfast omission in adults (12-14), perhaps due to low exogenous glucose availability and high perceptions of lethargy (12, 46). Although we did not measure blood glucose concentrations, it is plausible that the ~63 g of CHO consumed at breakfast underpinned the higher time in LPA between waking and 10:30 (i.e., before the breakfast omission cut-off) during DBC. It might also explain why PAEE from light activities was lower earlier in the day during IBC, but not DBC. In support, time in LPA tended to be lower on the breakfast omission compared with consumption days within the IBC condition. School timetable restrictions may explain why differences in PA did not emerge during 10:30-15:30, whereas the girls engaged in more LPA and less sedentary time after school during DBC. Similarly, total work done during evening exercise was reduced when men omitted breakfast (47), possibly due to the lower daily CHO intake limiting glucose availability throughout the day. Likewise, daily CHO intake is lower when adolescent girls omit breakfast (18). As the higher after-school sedentary time was a uniform effect across IBC rather than specific to the breakfast omission days, it may have also been an attempt to conserve energy in preparation for breakfast omission the next morning.

The 19.8 min/d difference in LPA in may be meaningful given that breakfast is a single factor that can be incorporated into multi-disciplinary PA promotion interventions (48, 49). Furthermore, LPA is associated with favourable adiposity (50) and cardiometabolic health in young people, although higher PA intensities may evoke greater benefits (51). Thus, breakfast
consumption may have a dual-effect on health involving direct benefits (e.g., reduced
glycemic excursions to subsequent meals) (12, 52) and indirect benefits through increased
PA. However, the duration and intensity of the additional LPA in our study was not sufficient
to elicit meaningful changes in estimated total daily PAEE. Thus, the role of PAEE in
mediating the inverse association between breakfast frequency and adiposity in girls is
questionable (1, 2). In fact, the current findings and the incomplete energy intake
compensation reported previously (18) suggest that energy balance is more likely to be
positive during acute periods of breakfast consumption compared with omission in adolescent
girls. Importantly, it is unlikely that our measurement device explained why PAEE was
unaffected in the current study. Indeed, heart rate-accelerometry has been sensitive to
breakfast manipulation previously (12, 13), whereas accelerometers (16, 18), pedometers and
heart rate monitors (15) and pedometers alone (17) have generally not.

Possible reasons for the lack of difference in estimated PAEE may be related to the
participant characteristics and study design. First, the standardized school timetable may have
limited the opportunity for the girls to modify their PA. This would counteract the expectation
that breakfast omission may have more pronounced effects in young people than adults due to
their higher reliance on exogenous CHO as a fuel (23). Additionally, the majority of our
sample were mid-pubertal, whereas the higher reliance on exogenous CHO is more apparent
during early puberty boys (23) and data in females are not consistent (53-55). Second, studies
in adults employed a later cut-off for breakfast omission (e.g., 12:00 (12-15) and 11:30 (16))
and compared daily breakfast consumption with daily breakfast omission (12-17) rather than
with intermittent breakfast consumption. However, ethical restrictions pose challenges in
asking young people to omit breakfast for seven consecutive days or to extend the overnight
fast beyond school break time. Although total PAEE was similar to previously reported values
in adolescent girls (56), time spent in MVPA was ~2.4 times the UK Government guidelines (57) and higher than previous reports (25, 56, 58, 59). The high MVPA may be partly explained by the use of a MET cut-point of 3.0 (12, 13, 60, 61) rather than 4.0 (62, 63) to distinguish between LPA and MPA. However, using a cut-point of 4.0 may only reduce MVPA to ~107 min/d (61), which is still high and suggests a strong self-selection bias with limited scope for change. Including non-habitual breakfast consumers only may have also increased the scope for detecting differences in PAEE (11). However, others propose that habitual breakfast consumers are more sensitive to breakfast omission (16). Thus, the impact of breakfast and PA habits on the response to breakfast manipulation requires further study.

Limitations of the present study include the seven day manipulation of breakfast, which does not allow for the examination of longer intervention periods. Studies employing longer fasting periods and continuous rather than intermittent periods of breakfast omission in young people would also be valuable in extending our findings. As the current study and previous work in adults did not provide precise first eating occasion timings (12-17), future work should ensure compliance in the reporting of these data. In the four girls with complete breakfast logs, breakfast was consumed at ~07:38 during the experimental conditions. In the full sample, breakfast was consumed at ~08:02 across the week habitually. Additionally, unpublished data from our previous study showed that the first eating occasion occurred at 11:33 ± 00:58 when adolescent girls were asked to omit breakfast (18). Thus, the first eating occasion would be expected to differ by ~3.5 h between the breakfast consumption and omission days in the present study, although this may have varied considerably between participants. Finally, our findings based on adolescent girls may not translate to boys. Indeed, the association between breakfast frequency and PA (9, 10) and other healthy behaviors (64) may depend on sex.
In conclusion, PAEE was not different when adolescent girls consumed breakfast daily compared with intermittently over seven days. Nevertheless, the girls spent more time in LPA in the morning and after school and less time sedentary after school when consuming breakfast daily. Due to the limited evidence base, additional interventions on the use of breakfast to promote PA in adolescents would be useful to inform PA promotion practices.

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Conflicts of interest

The authors declare no conflicts of interest.

Authors’ contributions to the manuscript

The authors’ responsibilities were as follows: JKZF and KT: designed the research (project conception, development of overall research plan, and study oversight); EKW, NSGC and SAOA: conducted the research (hands-on conduct of the experiments and data collection); JKZF and EKW: analyzed data or performed statistical analysis; JKZF and KT: wrote the paper; JKZF: had primary responsibility for final content. All authors have read and approved the final manuscript.
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Tables

Table 1. Characteristics of adolescent girls who participated in randomized crossover trial comparing seven days of daily breakfast consumption (DBC) with seven days of intermittent breakfast consumption (IBC)\(^1\)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>12.4 ± 0.5</td>
</tr>
<tr>
<td>Stature (m)</td>
<td>1.55 ± 0.06</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>46.7 ± 8.5</td>
</tr>
<tr>
<td>Body fat %</td>
<td>24.0 ± 4.1</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>66.7 ± 5.1</td>
</tr>
<tr>
<td>BMI (kg·m(^{-2}))</td>
<td>19.3 ± 3.0</td>
</tr>
<tr>
<td>Breast development (stage(^2))</td>
<td>3 (1)</td>
</tr>
<tr>
<td>Pubic hair (stage(^2))</td>
<td>3 (1)</td>
</tr>
<tr>
<td>Peak oxygen uptake (mL·kg(^{-1})·min(^{-1}))</td>
<td>47.1 ± 9.0</td>
</tr>
<tr>
<td>RMR (kJ/d)</td>
<td>5207 ± 1095</td>
</tr>
<tr>
<td>RMR (kcal/d)</td>
<td>1244 ± 262</td>
</tr>
</tbody>
</table>

\(^1\)Values are mean ± SDs or medians (IQRs), \(n=27\). DBC was the consumption of a standardized 1674 kJ (400 kcal) breakfast for seven consecutive days; IBC was the abstinence from all energy-providing nutrients until at least 10:30 on days 1, 3, 5 and 7 and the consumption of the standardized breakfast on days 2, 4 and 6.

\(^2\)Five stages of breast and pubic hair development described by Tanner (33).
Figure legends

Figure 1. Schematic representation of recruitment, enrollment, and follow-up of adolescent girls who participated in randomized crossover trial comparing seven days of daily breakfast consumption (DBC) with seven days of intermittent breakfast consumption (IBC). DBC was the consumption of a standardized 1674 kJ (400 kcal) breakfast for seven consecutive days; IBC was the abstinence from all energy-providing nutrients until at least 10:30 on days 1, 3, 5 and 7 and the consumption of the standardized breakfast on days 2, 4 and 6.

Figure 2. Time spent in each physical activity intensity partitioned by the time of day in adolescent girls who participated in randomized crossover trial comparing seven days of daily breakfast consumption (DBC) with seven days of intermittent breakfast consumption (IBC). DBC was the consumption of a standardized 1674 kJ (400 kcal) breakfast for seven consecutive days; IBC was the abstinence from all energy-providing nutrients until at least 10:30 on days 1, 3, 5 and 7 and the consumption of the standardized breakfast on days 2, 4 and 6. Data are means with SD bars. *Difference between conditions, P ≤ 0.05. n=27 for all outcome variables. MET, metabolic equivalent.

Figure 3. Physical activity energy expenditure for each physical activity intensity partitioned by the time of day in adolescent girls who participated in randomized crossover trial comparing seven days of daily breakfast consumption (DBC) with seven days of intermittent breakfast consumption (IBC). DBC was the consumption of a standardized 1674 kJ (400 kcal) breakfast for seven consecutive days; IBC was the abstinence from all energy-providing nutrients until at least 10:30 on days 1, 3, 5 and 7 and the consumption of the standardized breakfast on days 2, 4 and 6. Data are means with SD bars. *15:30-bed>10:30-15:30>wake-10:30, P ≤ 0.03. n=27 for all outcome variables. MET, metabolic equivalent.
Figure 4. Total physical activity energy expenditure partitioned by the time of day in adolescent girls who participated in randomized crossover trial comparing seven days of daily breakfast consumption (DBC) with seven days of intermittent breakfast consumption (IBC). DBC was the consumption of a standardized 1674 kJ (400 kcal) breakfast for seven consecutive days; IBC was the abstinence from all energy-providing nutrients until at least 10:30 on days 1, 3, 5 and 7 and the consumption of the standardized breakfast on days 2, 4 and 6. Data are means with SD bars. n=27 for all outcome variables. MET, metabolic equivalent.
Figure 1

Enrollment
- Assessed for eligibility (n=85)
- Excluded (n=45)
  - Declined to participate (n=45)

Allocation
- Random assignment to main conditions (n=40)

Follow-up
- Condition order: DEC and then IBC (n=20)
- Condition order: IBC and then DBC (n=20)
- Lost to follow-up (n=0)

Analysis
- Analyzed (n=27)
  - Reasons excluded: did not meet the minimum requirements for useable Actiheart data (n=10); did not comply with the breakfast intervention (n=3)
Figure 4

Total physical activity energy expenditure (kJ/d)

- Total
- Wake-10:30
- 10:30-15:30
- 15:30-bed

DBC vs IBC
Supplemental Table 1. Breakfast choices of adolescent girls who participated in randomized crossover trial comparing seven days of daily breakfast consumption (DBC) with seven days of intermittent breakfast consumption (IBC)\(^1\)

<table>
<thead>
<tr>
<th>Breakfast options</th>
<th>(n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breakfast cereal with semi-skimmed (1.8% fat) milk (compulsory)</td>
<td></td>
</tr>
<tr>
<td>Swiss Style Muesli (no added sugar)(^2)</td>
<td>3</td>
</tr>
<tr>
<td>Weetabix(^3)</td>
<td>8</td>
</tr>
<tr>
<td>All-Bran Original(^4)</td>
<td>16</td>
</tr>
<tr>
<td>Apple</td>
<td>6</td>
</tr>
<tr>
<td>Fruit (optional)</td>
<td></td>
</tr>
<tr>
<td>Banana</td>
<td>13</td>
</tr>
<tr>
<td>Raisins</td>
<td>6</td>
</tr>
<tr>
<td>Orange juice(^2)</td>
<td>14</td>
</tr>
<tr>
<td>Beverage (optional)</td>
<td></td>
</tr>
<tr>
<td>Apple juice(^2)</td>
<td>9</td>
</tr>
<tr>
<td>Tea with semi-skimmed (1.8% fat) milk (no sugar)</td>
<td>1</td>
</tr>
</tbody>
</table>

\(^1\) \(n=27\). DBC was the consumption of a standardized 1674 kJ (400 kcal) breakfast for seven consecutive days; IBC was the abstinence from all energy-providing nutrients until at least 10:30 on days 1, 3, 5 and 7 and the consumption of the standardized breakfast on days 2, 4 and 6.

\(^2\) Tesco, UK.

\(^3\) Weetabix Limited, UK.

\(^4\) Kelloggs, UK.