Effect of breakfast omission and consumption on energy intake and physical activity in adolescent girls: a randomised controlled trial

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Abstract

It is not known if breakfast consumption is an effective intervention for altering daily energy balance in adolescents when compared with breakfast omission. This study examined the acute effect of breakfast consumption and omission on free-living energy intake (EI) and physical activity (PA) in adolescent girls. Using an acute randomised crossover design, forty girls (age 13.3 ± 0.8 y, body mass index 21.5 ± 5.0 $kg{\cdot}m^{-2}$) completed two, 3-day conditions in a randomised, counter-balanced order: no breakfast (NB) and standardised (~1962 kJ) breakfast (SB). Dietary intakes were assessed using food diaries combined with digital photographic records and PA was measured via accelerometry throughout each condition. Statistical analyses were completed using repeated measures analysis of variance. Post-breakfast EI was 483 ± 1309 kJ/d higher in NB vs. SB (P=0.025), but total daily EI was 1479 ± 1311 kJ/d higher in SB vs. NB (P<0.0005). Daily carbohydrate, fibre and protein intakes were higher in SB vs. NB (P<0.0005), whereas daily fat intake was not different (P=0.405). Effect sizes met the minimum important difference of ≥0.20 for all significant effects. Breakfast manipulation did not affect post-breakfast macronutrient intakes (P≥0.451) or time spent sedentary or in PA (P≥0.657). In this sample of adolescent girls, breakfast omission increased post-breakfast free-living EI, but total daily EI was greater when a standardised breakfast was consumed. We found no evidence that breakfast consumption induces compensatory changes in PA. Further experimental research is required to determine the effects of extended periods of breakfast manipulation in young people.

Introduction

There is a common belief that breakfast is the ‘most important meal of the day’(1). However, around one third of young people, including children (pre-pubertal and typically <11 in girls and <13 years in boys) and adolescents (between puberty and adulthood)(2), in many countries skip breakfast regularly(3,4). Cross-sectional reports that show infrequent breakfast consumption to be associated with overweight and obesity have led to premature assumptions that breakfast can be used as an intervention for weight loss(5). Indeed, the lower adiposity status in children who frequently consume breakfast was not observed uniformly across 12 countries(4). Thus, the strength, direction, and causal nature of associations between breakfast frequency and adiposity are questionable.

The mechanistic basis for a causal link between breakfast frequency and adiposity may be examined by assessing energy intake (EI) and expenditure. Indeed, a sustained positive energy balance where EI exceeds energy expenditure causes weight gain(6). Despite their higher adiposity, young people who skip breakfast have lower(7,8) or similar(9) daily EIs when compared to breakfast consumers. Interventions show that one day of breakfast omission did not increase subsequent EI to compensate for the energy deficit created by breakfast omission in children aged 8 to 10 years(10) and in adolescents aged 13 to 17 years(11). Increased lunchtime EI has, however, been reported in men in response to one day of breakfast omission(12). Under free-living conditions, adults generally show higher daily EIs when breakfast is consumed(13,14,15), even when reductions in EI at lunch(15) or between 12:00 and 18:00 h(13) are observed. However, daily EI was similar in obese adults assigned to daily breakfast omission or consumption for six weeks(16). In overweight and obese “breakfast-skipping” females aged 15 to 20 years, daily EI was increased with normal-protein breakfast consumption, but a high-protein breakfast reduced evening snacking and did not increase daily EI(17). In a similar mixed-sex sample, 12 weeks of high-protein breakfast consumption reduced free-living daily EI, whereas breakfast skipping and normal-protein breakfast consumption did not(18). However, these studies were based on young people accustomed to breakfast omission and only determined the impact of breakfast addition, not removal(17,18).

When determining free-living EI via self-report in adolescents, compliance and underreporting are major challenges(19). Adolescents report a preference for methods using technology, such as a disposable camera(19), which eliminate the need for participants to estimate portion size and are less burdensome than weighed food diaries(20,21). Digital photography methods have been validated against weighed food diaries and 24 hour recall in adults(21) and are reliable and valid when measuring children's food intake in cafeteria settings(22). However, understanding the individual variation in free-living EI assessed using digital photography requires investigation to determine clinically meaningful intervention effects(23).

In addition to EI, physical activity (PA) is a key determinant of energy balance, weight gain and health(6,24). Cross-sectional studies using objective measures of PA (e.g., accelerometry) have reported more frequent breakfast consumption to be associated with higher PA in girls but not boys(25), or in boys but not girls(26), or on weekends but not weekdays(27). In lean(14) and obese(16) adults assigned to six weeks of daily breakfast consumption or omission, higher PA energy expenditure in the morning was shown in the breakfast consumption groups, and this resulted in increased total daily PA energy expenditure in the lean adults(14). In support, an acute within-participant crossover study showed increased morning PA energy expenditure assessed via accelerometry when breakfast was consumed compared with when it was omitted in women(15). However, another study using pedometers and heart rate monitors showed no effect(28). Furthermore, it is not known whether consuming breakfast can increase PA in young people.

The adolescent period is a crucial time to promote dietary and PA behaviours for health, particularly in girls(29). Furthermore, breakfast skipping is highly prevalent in this population(30). Thus, the current study used a randomised, cross-over design to compare the effect of three consecutive weekdays of breakfast omission with standardised breakfast consumption on free-living EI and PA in girls aged 11 to 15 years. In a sub-sample, we examined the natural variability in free-living daily EI assessed using digital photography to determine the interindividual intervention response.

Methods

Participants

In this dual centre project, 49 girls aged 11 to 15 years were recruited from schools in the two locations in England. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects/patients were approved by the respective University Research Ethics Committees. Written informed parental consent and child assent were obtained 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 PA monitor on their wrist.

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, body mass index (BMI) was calculated as body mass divided by stature squared ($kg \cdot m^{-2}$). Using age and sex-specific BMI centiles(31), the girls were then classified as non-overweight (2nd to 85th centile) or overweight (85th to 95th centile). Waist circumference was measured to the nearest millimetre on exhalation at the midpoint between the last rib and top of the iliac crest using a non-elastic tape measure(32). To describe the pubertal status of the study sample, the girls were asked to provide a validated(33,34) self-assessment of their physical maturation using secondary sexual characteristics with the assistance of a primary home-based carer(35). Habitual breakfast frequency was assessed by asking participants the following question: "How often do you usually have breakfast?" Participants were asked to indicate their response separately for weekdays and for weekend days. Response categories were 'never' to 'five days' for the week, and 'never' to 'two days' for the weekend. To provide an indication of the composition and energy content of the participants' habitual breakfasts, they recorded their breakfast intakes across three days (Tuesday, Wednesday and Thursday, i.e., the weekdays selected for the intervention described below) using digital photography and a written food diary. Breakfast EI and macronutrient intakes were calculated using Dietplan 6.7 (Forestfield Software, Horsham, UK).

Experimental design

Using a within-measures cross-over design, participants completed two, 3-day conditions in a counter-balanced order: no breakfast (NB) and standardised breakfast (SB). The conditions were conducted across the same three weekdays (i.e., Tuesday, Wednesday and Thursday) with either a 4 or an 11 day washout between conditions. For the duration of each 3-day condition, participants were asked to record their diet and wear a wrist-worn accelerometer. The order of the conditions for each participant was produced using a computer-based random number generator by the principal investigator (JZF). All data was collected between December 2013 and July 2014.

On each morning of each 3-day condition, participants arrived at school in the fasted state (no food or drink consumed except water from 21:00 the previous day) and were asked not to eat breakfast (NB) or to consume the SB provided within 30 min (between 08:15-8:45). For NB, participants were provided with 375 mL of water. The participant's first opportunity to consume food or drink during the post-breakfast period was 10:30 (i.e., during school break time); thus, NB involved abstaining from energy-containing food and beverages between 21:00 the previous day and 10:30 the following morning. The participants were reminded on each day of the experimental conditions to refrain from snacking until 10:30 and reported that they complied with these instructions. The SB consisted of 56.3 g wheat biscuits (Weetabix, Kettering, UK), 188 mL semi-skimmed milk (Tesco Stores Ltd, Chestnut, UK) and 375 mL orange juice (Tesco Stores Ltd, Chestnut, UK). The breakfast was low glycaemic index (GI), with a calculated GI of 54(36,37). We chose a ready-to-eat cereal because this type of breakfast is associated with reduced obesity risk when compared with 'other breakfasts'(7). Recommendations suggest breakfast should be 20% of daily EI(38) and reviews define breakfast typically as containing 20% to 35% of total daily energy needs(39). Therefore, the SB contained 1994 kJ (500 kcal), equating to ~22-26% of daily energy requirements for 11-15 year old girls, which take into account total daily energy expenditure plus the deposited energy costs for growth (1935 to 2293 kcal/d)(40). The SB was consumed at school rather than home to monitor compliance to the breakfast intervention and record any leftovers. If the SB was not consumed completely, it had to represent at least 20% of recommended daily EI for the participant to be included in the final sample(38).

Dietary assessment

Participants recorded their daily diet using a digital camera (Vivitar, ViviCam 46, China) and food diary during each condition. A similar method has been validated previously in adults(21) and children(22). The participants were asked to photograph all foods and beverages consumed and use the photographs as a recall method when completing their food diaries each evening. The food diaries included a record of the day, time, type, brand name, preparation method, estimated portion size and any leftovers of all food and drink consumed. Before completing the main conditions, the girls received a tutorial and written instructions on using the digital camera and food diary. On the morning after each day of dietary recording, the research team checked the participants' food diaries for completeness and cross-referenced the food diaries with the corresponding photographs. For missing photographs, portion size was estimated by the participants using the Young Person's Food Atlas(41,42) with assistance from the research team; further details were added to the diary when appropriate. The mass of all foods and beverages consumed were estimated by comparing the digital photographs, taken by the participants, to the Young Person's Food Atlas(41,42); this method that has shown good agreement with weighed food diaries in children aged ≥11 years(43). Food diaries were analysed using Dietplan 6.7 (Forestfield Software, Horsham, UK) to estimate EI and macronutrient intakes, which were blocked into three time periods to separate breakfast, lunch and the evening meal and align with the school timetable: (i) 06:00 to 09:00 (including breakfast and early morning snacks), (ii) 10:30 to 14:00 (including school break time snacks and lunch), and (iii) 14:00 until 21:00 (including dinner and evening snacks). Percentage breakfast EI compensation was calculated for SB relative to NB (i.e., the difference in post-breakfast EI between SB and NB divided by SB breakfast EI multiplied by 100); values of 100% indicated complete compensation for breakfast EI. Portions of fruit and vegetable consumed were quantified using the National Health Service (NHS) guidelines for 5 portions/d(44). High-fat and sugary snacks were defined as sweet baked products, cookies, ice cream, cakes, desserts, jams, sugar, sweets, nuts, potato crisps, cheese products, popcorn and soft drinks(8).

Variability of daily EI

To determine the natural variability of daily EI, the primary outcome variable, a sub-sample of 10 girls completed two, 3-day free-living diet (FD) conditions on two consecutive weeks at least four weeks before commencing the main study. On each day, the girls were free to eat and drink as they pleased and were instructed to record their dietary intakes using the digital photography and food diary method described above (see 'Dietary assessment'). Thus, the data provided an indication of the variability in habitual dietary intakes between two 3-day periods rather than being an assessment of measurement reliability. The 95% Limits of Agreement (LoA) for daily EI were calculated by determining a 95% limit above and below the mean difference for FD trial 1 and FD trial 2 (systematic error ± (1.96 × random error)), as outlined by Bland and Altman(45). Student's paired t-tests were used to identify systematic change in the mean from trial one to two; whereas Pearson's product moment correlations between the paired residuals and the mean (proportional error check) and the absolute residuals and the mean (heteroscedasticity check) were examined to ensure the 95% LoA were representative of the whole sample. It has been estimated that excessive weight gain could be prevented in children and adolescents by reducing positive energy balance by 628 kJ/d (150 kcal/d)(46). Therefore, we deemed that LoA of ≤ ± 628 kJ/d (150 kcal/d) would be an acceptable test-retest error for daily FD EI.

The data on variability of EI was also used as a control arm to quantify the true interindividual differences in the EI response to the breakfast intervention(23). To determine a 'true' effect, Atkinson and Batterham(23) suggest comparing the standard deviation (SD) of changes in the intervention arm (i.e., the effect SD) with the SD of changes from the control arm (i.e., the control SD). The SD of the true individual response is: $\sqrt{(SD_e^2 - SD_c^2)}$, where SD_e is the effect SD and SD_c is the control SD(23). The magnitude of the SD of true individual responses is appraised in terms of clinical importance. As with our LoA analysis, we deemed that a difference of ≥ ± 628 kJ/d (150 kcal/d) would be clinically important when comparing the control and intervention SDs(46).

Physical activity assessment

Wrist-worn accelerometers that have been validated in 8 to 14 year olds (GENEActiv, ActivInsights Ltd., Colworth, UK) were used to assess PA for the duration of each 3-day condition(47). The accelerometers were set to record at 85.7 Hz using a 1-second epoch. The girls were asked to wear the accelerometers on their non-dominant wrist for three days at all times, removing only for bathing and water-based activities. To estimate daily time spent sedentary and in light PA (LPA) and moderate-to-vigorous PA (MVPA), GENEActiv cut-points specific to 8 to 14 year olds were applied and expressed as percentage of total daily wear time(47). The minimal amount of accelerometer data that was considered acceptable was 10 h/d of wear time on all three days of both breakfast conditions(48).

Statistical analyses

Statistical analyses were completed using IBM SPSS statistics software for Windows version 21 (IBM Corporation, New York, USA). Total daily EI, macronutient intakes and PA were compared between the two conditions using student's paired t-tests. For post-breakfast EI and macronutrient intakes, condition by time of day (2 x 2) repeated measures analysis of variance (ANOVA) were used to examine differences between the conditions across the two time periods (i.e., 10:30 to 14:00 and 14:00 to 21:00). Weekday habitual breakfast frequency and BMI were considered as covariates, but were not used because the data did not satisfy the assumptions for covariate analysis (i.e., they were not significantly associated with the dependent variables across all conditions). Homogeneity of covariances 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. Cohen's d effect sizes (d) were calculated to gauge the magnitude of differences between conditions for all significant effects. In the absence of published anchors, a $d \geq 0.20$ was considered the minimum important difference in all outcome measures, 0.50 to <0.80 moderate and ≥0.80 large(49). Values are presented as means ± SDs unless stated otherwise.

Justification of sample size

The calculated sample size was based on total daily EI (the primary outcome variable) and LPA (% wear time), as this PA intensity has been shown to be sensitive to breakfast manipulation in adults(14). A worthwhile difference in EI or energy expenditure between the two conditions was defined as 628 kJ/d (150 kcal/d)(46). Our variability study showed that the SD of the EI difference between two, 3-day FD conditions was 1147 kJ/d (274 kcal/d). A 628 kJ/d increase in energy expenditure requires ~45 minutes of LPA at 14.0 kJ/min in adolescent girls(47,50). This would equate to 5% of weekday waking hours and an SD of 6%(48,51). Using these figures, the number of participants estimated to detect a significant change at 90% power with a two-sided significance level of 0.05 was 35 for daily EI and 30 for LPA. To be included in the final sample, participants had to meet the following criteria: 1) attended the breakfast intervention club on all days; 2) abstain from all foods and beverages until 10:30 for NB; 3) consume at least 20% of recommended daily EI if they did not consume the SB completely(38); 4) record their diet and wear the accelerometer as specified. Thus, 49 participants were recruited to allow for a dropout of 10-30%.

Results

Participant characteristics

The final sample for dietary analysis included 40 participants (nine were excluded: three broke the fast before 10:30 during NB, one did not consume an adequate amount of the SB and five did not record their dietary intakes as specified). Three participants that were included in the final sample did not eat all of the SB, but consumed enough so that SB energy intake was at least 20% of recommended daily EI(38). Table 1 shows the anthropometric characteristics and habitual breakfast frequencies of the final sample. The nine girls who were excluded from the final analyses did not have significantly different physical characteristics or breakfast frequencies compared with the 40 who were included ($P \geq 0.10$).

INSERT TABLE 1

Variability of daily energy intake

At the group level (n=10), EI was similar between FD trial 1 and FD trial 2; 5063 ± 1332 vs. 5244 ± 1293 kJ/d (1211 ± 319 vs. 1255 ± 309 kcal/d; $t=-0.500$; $P=0.629$). The systematic bias ± random error were 181 ± 1147 kJ/d (43 ± 274 kcal/d). This resulted in 95% LoA of -2067 to 2428 kJ/d, (-494 to 580 kcal/d) (see Online Supplementary Document S1). Significant proportional bias was not evident ($r=-0.038$; $P=0.917$) and random errors were homoscedastic ($r=-0.040$, $P=0.912$). The LoA based on all 10 girls exceeded our *a priori* acceptable test-retest variability of ± 628 kJ/d (150 kcal/d). However, seven of the 10 participants had paired EI values across the repeat measurements that were within ± 628 kJ/d (150 kcal/d), suggesting the natural variation in FD may be small enough to detect subtle changes in EI that could prevent excessive weight gain(46). In the remaining three girls, one had a particularly large difference of 3141 kJ/d between the repeat measurements. When excluding this participant (n=9), the systematic error ± random error was reduced by -148 ± 512 kJ/d, and the 95% LoA were tightened to -1151 to 855 kJ/d, but still exceed the ± 628 kJ/d cut-off.

Breakfast energy and macronutrient intake

Accounting for leftovers, breakfast energy and macronutrient intakes for SB were: EI 1962 ± 121 kJ (469 ± 29 kcal), 88.3 ± 6.0 g CHO, 16.4 ± 1.3 g protein, 5.7 ± 0.7 g fat and 5.8 ± 0.6 g fibre. For comparison, the girls consumed 766 ± 439 kJ (183 ± 105 kcal), 29.4 ± 16.1 g CHO, 5.4 ± 3.7 g protein, 5.4 ± 4.5 g fat and 1.2 ± 1.0 g fibre for breakfast habitually. The energy, CHO, protein and fibre intake of the SB were higher than the girls habitual breakfasts ($P<0.005$; d=3.69 to 5.32), whereas fat intakes were similar ($P=0.672$; d=0.09).

Daily and post-breakfast energy intake

Fig. 1 shows daily and time-specific EIs for each breakfast condition. Daily EI was higher in SB than NB ($P<0.0005$). For daily EI, we quantified the true interindividual differences in the intervention responses using the control SD from the variability data described above and the SDs of the residuals from the breakfast conditions(23). The SD (95% confidence interval) of the true individual response was 636 (229 to 1042) kJ/d (152 [55 to 249] kcal/d) for SB vs. NB. Using our cut-off of ≥628 kJ/d (150 kcal/d), the large differences in the control and intervention SDs may be clinically important.

Post-breakfast (i.e., 10:30 to 21:00) EI was 483 ± 1309 kJ/d higher in NB compared with SB ($P=0.025$; d=0.37), independent of the time of day ($P=0.993$) (Fig. 1). The higher post-breakfast EI in NB accounted for 24 ± 66% of the standardised breakfast EI.

INSERT FIGURE 1

Daily and post-breakfast macronutrient intakes

Table 2 shows daily macronutrient intakes for each breakfast condition. Daily CHO, fibre and protein intakes were higher in SB compared with NB (d≥0.81 for all comparisons), whereas daily fat intake was not. The effect of condition was not significant for CHO, fat, protein and fibre intakes for the post-breakfast period ($P\geq0.451$; d≤0.14 for all comparisons) and there was no interaction with time of day ($P\geq0.329$). The time of day main effect showed that protein and fibre intakes were higher in the 14:00-21:00 period than the 10:30-14:00 period ($P\leq0.026$; d≥0.50), but this difference only approached significance for CHO with a small effect ($P=0.054$; d=0.40).

INSERT TABLE 2

Daily fruit & vegetable and high-fat & sugary snack consumption

The breakfast condition main effect for daily portions of fruit and vegetables consumed was not significant (1.1 ± 1.1 for NB vs. 1.1 ± 0.8 for SB; *P*=0.801). Although the mean number of high-fat and sugary snacks consumed per day tended to be higher for NB (3.0 ± 1.5) compared with SB (2.6 ± 1.3) (*P*=0.097), the effect was only small (d=0.26).

Daily physical activity

A total of 35 girls had valid accelerometer data and were included in PA analyses. Wear time was 14.2 ± 1.2 h/d for SB and 14.1 ± 1.3 h/d for NB (*P*=0.488). Daily time spent sedentary or in LPA or MVPA (% wear time) was not different between conditions (Table 3).

INSERT TABLE 3

Discussion

Using an experimental crossover design, this study showed that total daily EI was higher when adolescent girls consumed a ~1962 kJ standardised breakfast (SB) when compared with no breakfast (NB) over three consecutive weekdays. Although NB increased post-breakfast EI, the degree of EI compensation was small and only accounted for ~24% of the SB. In addition, breakfast manipulation did not affect time spent sedentary or in PA.

Our study supports previous research showing that breakfast consumption results in higher daily EIs in young people(10,17) and adults(12,13,14,15,52) when compared with breakfast omission. In addition to being statistically significant, random within-subject variation and measurement error did not explain the higher daily EI with breakfast consumption, which exceeded the natural variability in EI by more than 150 kcal/d and may thus have clinical importance for weight gain(23,46). The 483 kJ/d (115 kcal/d) increase in post-breakfast EI (i.e., between 10:30 and 21:00) when the girls omitted breakfast amounted to only a quarter of the SB. This incomplete EI compensation may be due to the large size of the SB, which contained 2.6 times more energy than the participants' habitual breakfasts. As CHO-based breakfasts containing ~1.3 times less energy than our SB also did not result in EI compensation in young people(10,17), examining the effects of smaller breakfasts similar in energy content to the habitual breakfasts of adolescent girls (~766 kJ in our sample) may enhance the ecological validity of the findings and likelihood EI compensation being complete. Although the increased EI with breakfast omission was distributed evenly across the day in our study, reports in adults indicate that these effects are specific to certain time periods(12,13,15). It has also been shown that such effects may depend on the sex and breakfast habits of the sample(28), whereas habitual breakfast frequency was not related to the outcome variables in our sample of adolescent girls. Nevertheless, the 95% confidence interval for the SD of the individual response (229 to 1042 kJ/d) indicates large interindividual variability in compensatory EI responses to breakfast omission. Thus, individual characteristics that may explain this variability, such as eating and PA habits, body composition, age and socioeconomic status warrant clarification.

Unlike most previous experimental studies in adults that involved unstandardised breakfast manipulation(13,14,16,28), we provided a standardised, wholegrain ready-to-eat cereal-based breakfast. This type of breakfast was chosen because it has strong association with lowered obesity risk in adolescents(7) and it is a convenient breakfast choice that requires minimal preparation time, which could be appealing for adolescents who skip breakfast due to a 'lack of time'(53). The small, but statistically significant increase in post-breakfast EI (i.e., between 10:30 and 21:00) with breakfast omission reported here is in contrast with research in "breakfast-skipping" adolescents showing that normal-protein breakfasts do not reduce subsequent EI(11,17,18). Although breakfast GI was not reported in these studies(11,17,18), it is possible that the low GI breakfast in our study promoted a slower release of glucose into the blood, which can reduce hunger and lunchtime EI(54) and prolong satiety(55) in young people and may explain our discrepant findings(11,17,18). However, the link between GI and EI is controversial(56,57), with the satiating effect of low GI foods possibly being due to their higher fibre content(56). Nevertheless, the 5.8 g of fibre in our SB was within the range of the breakfasts in previous studies (2.0 to 6.1 g)(11,17). Thus, differences in fibre content of the CHO-based breakfasts may not explain discrepancies between our results and previous work. Increased EI in response to breakfast omission may be due to a host of metabolic and behavioural responses induced by the appetite regulatory system, including reduced pre-dinnertime neural activation in brain regions controlling food motivation/reward in late adolescent girls(17). Such mechanisms require further research in young people.

Whilst weighed food records are often considered the criterion reference measure of free-living EI in adults, self-reported EI can be underestimated through poor compliance, participant selection bias, recording bias and changes to diet to facilitate recording(58). In adolescents, the reliability and validity of weighed food diaries is less certain and the participant burden is particularly high(59,60). In an attempt to increase compliance to recording dietary intakes in our study, we used a food diary accompanied by photographic evidence rather than a weighed food diary(19). Although previous research has indicated that the addition of photographs to a traditional diet diary can enhance the validity and reliability of dietary recording(61), our comparison of two 3-day records showed 95% LoA for EI of -494 to +580 kcal/d. This high variability of free-living EI, potentially resulting from environmental, biological and methodological factors(62), may limit the potential to detect clinically meaningful differences of 150 kcal/d(46). Previous literature on free-living EI variability using 3-day diet records has used varied statistical approaches and produced mixed findings(63,64). Interestingly, our LoA are narrower than studies reporting ‘acceptable’ agreement with a 3-day diet record in adults(65) and a food menu in free-living young people(66). Thus, the use of a clinically relevant anchor may have affected the interpretation of the LoA in these studies.

Consistent with cross-sectional reports(8,9,30), the higher daily EI with SB consumption was due to higher intakes of CHO, protein and fibre, whereas breakfast did not affect daily fat intakes. These differences in daily macronutrient intakes were a direct effect of the breakfast meal rather than post-breakfast intakes. Nevertheless, it is likely that the tendency for higher high-fat and sugary snack consumption contributed to the increased post-breakfast EI when breakfast was omitted. This finding also suggests that the nature of the cross sectional association between infrequent breakfast consumption and higher unhealthy snack consumption(8,9) may be causal. Overall, the girls consumed around one portion of fruit and vegetables a day, a concerning number considering that a minimum of five portions per day is recommended(44). Although breakfast consumption has been associated with higher fruit and vegetable consumption(67,68), the present study suggests that any such relations are not causal, at least in our sample over a 3-day intervention. As food groups other than fruit and vegetables contribute to micronutrient intakes, whether breakfast manipulation affects micronutrient intakes warrants examination using assessment periods of more than three days(69).

The small post-breakfast EI compensation in the present study suggests that a higher PA energy expenditure may be more important in contributing to the healthy weight status in frequent breakfast consumers(1,3,4,5,7). However, our finding that breakfast did not affect sedentary time or MVPA supports cross-sectional findings in girls aged 9-10 years when using accelerometry to quantify PA on weekdays and weekends(26) and experimental research in adults showing no effect of breakfast manipulation on PA assessed via pedometers and heart rate monitors during a working week(28). Although breakfast manipulation did not affect LPA in the girls in the present study, energy expenditure from LPA assessed over seven days was higher in lean adults who consumed breakfast daily compared with those who omitted breakfast daily(14). In the obese cohort of this six week intervention, total PA energy expenditure in the morning was higher in the breakfast group compared with the breakfast omission group(16). An acute randomised crossover trial using accelerometry also showed that consuming breakfast increased PA energy expenditure when compared with breakfast omission in women classified as habitual breakfast eaters(15). The adolescent girls in our study may have responded differently to the adults in previous studies(14,15,16) because the provision of breakfast at school meant that they had limited opportunity to engage in free-living PA directly after consuming breakfast. Thus, providing breakfast at home and including weekend days may increase the scope for detecting effects on PA.

The present study has several limitations. First, breakfast manipulation over three weekdays does not allow us to apply the findings to weekends, where diet and PA patterns are different(27,51,70), or to determine the effects of longer intervention periods. Second, similar to previous studies(17,18), we provided a fixed absolute breakfast portion. However, providing breakfast relative to daily energy requirements may be recommended to reduce between–participant variability in the response to breakfast manipulation. Similarly, methods that provide less variable measures EI would help support our findings, although this is challenging in free-living conditions(58,59.60). In addition, standardising pre-intervention diet and the duration of the washout period between participants would help to minimise the influence of these factors on the study outcomes. Third, future studies employing more sensitive measures to quantify free-living PA or energy expenditure (e.g. combined heart rate-accelerometry or doubly labelled water) over longer measurement periods (e.g. seven days) would be valuable in extending the findings reported here. In doing so, the possibility that breakfast consumption may affect PA through an interaction with wake time and sleeping patterns requires consideration. Differences in wake time are unlikely to have confounded the comparison between SB and NB in our study, as the provision of breakfast at school rather than at home meant that the participants were not required to wake up any earlier to consume the SB. Nevertheless, the independent effects of breakfast frequency, timing and composition warrant study. Finally, the generalisability of our findings to adolescent boys and to younger children requires investigation.

In conclusion, adolescent girls showed a small increase in post-breakfast EI of 483 kJ/d (115 kcal/d) that was not sufficient to compensate completely for three consecutive weekdays of breakfast omission when compared with standardised breakfast consumption (~1962 kJ/d). Thus, total daily EI remained greater when a standardised breakfast was consumed. We also report no evidence of breakfast affecting time spent sedentary or in PA. These findings require examination using extended periods of breakfast manipulation and more sensitive devices to quantify PA energy expenditure in young people.

Figure legends

Fig. 1. Energy intake during different times of the day for the no breakfast (NB) and the standardised breakfast (SB) conditions. Error bars represent standard deviation. *Significant main effect of condition for total daily energy intake using paired t-tests and for total energy intake between 10:30-21:00 using a condition by time of day ANOVA ($P \leq 0.025$). †Significant main effect of time of day using ANOVA ($P = 0.003$). n=40.

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Conflict of interest

None.

Authorship

JKZF and KT designed the study (project conception, development of overall research plan, and study oversight). All authors contributed to the data collection (hands-on conduct of the experiments and data collection). JKZF, TP and KT analysed the data and/or performed statistical analyses. JKZF and KT wrote the paper. JKZF had primary responsibility for final content. All authors have read and approved the final manuscript.

Supplementary material

S1. Bland-Altman plot of energy intake (kJ/d averaged across 3 days) for trials 1 and 2. Residual for energy intake is the energy intake in trial 1 minus energy intake in trial 2.The solid line indicates the systematic error. The dashed lines indicate the upper and lower 95% limits of agreement. n=10.

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Tables

Table 1. Participant characteristics

	Average	Variability
Age (y)[1]	13.3	0.8
Stature (m)[1]	1.60	0.08
Body mass (kg)[1]	55.2	15.4
Body fat %[1]	30.7	10.1
Waist circumference (cm)[1]	71.1	12.8
Body mass index ($kg \cdot m^{-2}$)[1]	21.5	5.0
Breast development[2]	4	1
Pubic hair[2]	4	1
Weekday habitual breakfast frequency (d/week)[1]	3.7	1.6
Weekend habitual breakfast frequency (d/week)[1]	1.7	0.5

[1] Values are mean and standard deviation.
[2] Values are median and interquartile range.

Table 2. Daily energy and macronutrient intakes during three days of no breakfast (NB) or standardised breakfast consumption (SB) using a randomised crossover design (n=40).

	SB		NB		*P*	d
	Mean	SD	Mean	SD		
Energy, kJ/d	6728	1234	5249	1419	<0.0005	1.11
Carbohydrate, g/d	243.1	50.6	158.4	50.0	<0.0005	1.68
Fat, g/d	51.3	18.3	48.3	17.2	0.405	0.17
Protein, g/d	61.4	18.6	47.6	15.4	<0.0005	0.81
Fibre, g/d	13.1	3.1	7.5	2.8	<0.0005	1.91

[1] SD, standard deviation; d, Cohen's d effect size.

[2] Paired t-tests and Cohen's d effect sizes were used to compare the SB and NB conditions.

Table 3. Daily time spent sedentary and in physical activity during three days of no breakfast (NB) or standardised breakfast consumption (SB) using a randomised crossover design (n=35).

	SB		NB		*P*	d
	Mean	SD	Mean	SD		
Sedentary, %WT	70.1	4.9	69.7	4.6	0.769	0.04
LPA, %WT	23.1	2.8	23.2	2.8	0.657	0.06
MVPA, %WT	6.8	2.8	7.1	2.5	0.936	0.01

[1] SD, standard deviation; d, Cohen's d effect size; %WT, percentage of total wear time; LPA, light physical activity; MVPA, moderate to vigorous physical activity.

[2] Paired t-tests and Cohen's d effect sizes were used to compare the SB and NB conditions.

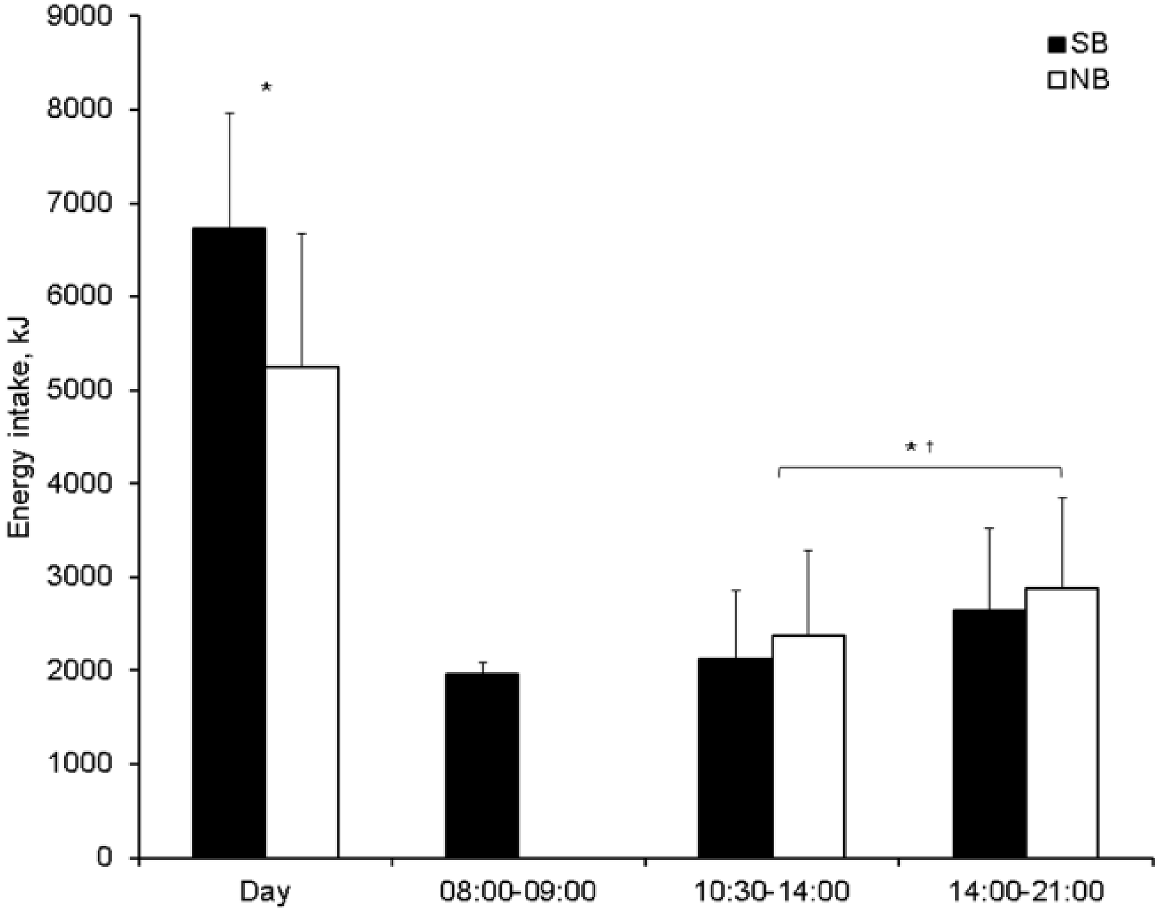

Fig. 1. Energy intake during different times of the day for the no breakfast (NB) and the standardised breakfast (SB) conditions. Error bars represent standard deviation. *Significant main effect of condition for total daily energy intake using paired t-tests and for total energy intake between 10:30-21:00 using a condition by time of day ANOVA ($P \leq 0.025$). †Significant main effect of time of day using ANOVA ($P=0.003$). n=40.