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

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

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Short title: Breakfast, diet and activity in girls

Key words: Breakfast, children, exercise, health, nutrition, youth.

## 1 **Abstract**

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

20

## 21 Introduction

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

30  
31 The mechanistic basis for a causal link between breakfast frequency and adiposity may be examined  
32 by assessing energy intake (EI) and expenditure. Indeed, a sustained positive energy balance where  
33 EI exceeds energy expenditure causes weight gain<sup>(6)</sup>. Despite their higher adiposity, young people  
34 who skip breakfast have lower<sup>(7,8)</sup> or similar<sup>(9)</sup> daily EIs when compared to breakfast consumers.  
35 Interventions show that one day of breakfast omission did not increase subsequent EI to compensate  
36 for the energy deficit created by breakfast omission in children aged 8 to 10 years<sup>(10)</sup> and in  
37 adolescents aged 13 to 17 years<sup>(11)</sup>. Increased lunchtime EI has, however, been reported in men in  
38 response to one day of breakfast omission<sup>(12)</sup>. Under free-living conditions, adults generally show  
39 higher daily EIs when breakfast is consumed<sup>(13,14,15)</sup>, even when reductions in EI at lunch<sup>(15)</sup> or  
40 between 12:00 and 18:00 h<sup>(13)</sup> are observed. However, daily EI was similar in obese adults assigned  
41 to daily breakfast omission or consumption for six weeks<sup>(16)</sup>. In overweight and obese “breakfast-  
42 skipping” females aged 15 to 20 years, daily EI was increased with normal-protein breakfast  
43 consumption, but a high-protein breakfast reduced evening snacking and did not increase daily  
44 EI<sup>(17)</sup>. In a similar mixed-sex sample, 12 weeks of high-protein breakfast consumption reduced free-  
45 living daily EI, whereas breakfast skipping and normal-protein breakfast consumption did not<sup>(18)</sup>.  
46 However, these studies were based on young people accustomed to breakfast omission and only  
47 determined the impact of breakfast addition, not removal<sup>(17,18)</sup>.

48  
49 When determining free-living EI via self-report in adolescents, compliance and underreporting are  
50 major challenges<sup>(19)</sup>. Adolescents report a preference for methods using technology, such as a  
51 disposable camera<sup>(19)</sup>, which eliminate the need for participants to estimate portion size and are less  
52 burdensome than weighed food diaries<sup>(20,21)</sup>. Digital photography methods have been validated  
53 against weighed food diaries and 24 hour recall in adults<sup>(21)</sup> and are reliable and valid when  
54 measuring children's food intake in cafeteria settings<sup>(22)</sup>. However, understanding the individual

55 variation in free-living EI assessed using digital photography requires investigation to determine  
56 clinically meaningful intervention effects<sup>(23)</sup>.

57

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

69

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

76

## 77 **Methods**

### 78 **Participants**

79 In this dual centre project, 49 girls aged 11 to 15 years were recruited from schools in the two  
80 locations in England. The study was conducted according to the guidelines laid down in the  
81 Declaration of Helsinki and all procedures involving human subjects/patients were approved by the  
82 respective University Research Ethics Committees. Written informed parental consent and child  
83 assent were obtained for all participants. Girls were excluded from the study if they had health  
84 related issues identified from a health screen questionnaire (e.g., allergies to the breakfast meals,  
85 fitted with a pacemaker) or were unable to walk or wear a PA monitor on their wrist.

86

### 87 **Preliminary measurements**

88 Stature was measured to the nearest 0.01 m using a portable Leicester height measure (SECA  
89 Corporation, Hamburg, Germany). Body mass was measured and percent body fat estimated to the

90 nearest 0.1 kg and 0.1% respectively using a Tanita Body Composition Analyser (BC-418 MA,  
91 Tanita Corporation, Tokyo, Japan); subsequently, body mass index (BMI) was calculated as body  
92 mass divided by stature squared ( $\text{kg}\cdot\text{m}^{-2}$ ). Using age and sex-specific BMI centiles<sup>(31)</sup>, the girls were  
93 then classified as non-overweight (2<sup>nd</sup> to 85th centile) or overweight (85th to 95th centile). Waist  
94 circumference was measured to the nearest millimetre on exhalation at the midpoint between the  
95 last rib and top of the iliac crest using a non-elastic tape measure<sup>(32)</sup>. To describe the pubertal status  
96 of the study sample, the girls were asked to provide a validated<sup>(33,34)</sup> self-assessment of their  
97 physical maturation using secondary sexual characteristics with the assistance of a primary home-  
98 based carer<sup>(35)</sup>. Habitual breakfast frequency was assessed by asking participants the following  
99 question: “How often do you usually have breakfast?” Participants were asked to indicate their  
100 response separately for weekdays and for weekend days. Response categories were ‘never’ to ‘five  
101 days’ for the week, and ‘never’ to ‘two days’ for the weekend. To provide an indication of the  
102 composition and energy content of the participants’ habitual breakfasts, they recorded their  
103 breakfast intakes across three days (Tuesday, Wednesday and Thursday, i.e., the weekdays selected  
104 for the intervention described below) using digital photography and a written food diary. Breakfast  
105 EI and macronutrient intakes were calculated using Dietplan 6.7 (Forestfield Software, Horsham,  
106 UK).

107

### 108 **Experimental design**

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

116

117 On each morning of each 3-day condition, participants arrived at school in the fasted state (no food  
118 or drink consumed except water from 21:00 the previous day) and were asked not to eat breakfast  
119 (NB) or to consume the SB provided within 30 min (between 08:15-8:45). For NB, participants  
120 were provided with 375 mL of water. The participant’s first opportunity to consume food or drink  
121 during the post-breakfast period was 10:30 (i.e., during school break time); thus, NB involved  
122 abstaining from energy-containing food and beverages between 21:00 the previous day and 10:30  
123 the following morning. The participants were reminded on each day of the experimental conditions  
124 to refrain from snacking until 10:30 and reported that they complied with these instructions. The SB

125 consisted of 56.3 g wheat biscuits (Weetabix, Kettering, UK), 188 mL semi-skimmed milk (Tesco  
126 Stores Ltd, Chestnut, UK) and 375 mL orange juice (Tesco Stores Ltd, Chestnut, UK). The  
127 breakfast was low glycaemic index (GI), with a calculated GI of 54<sup>(36,37)</sup>. We chose a ready-to-eat  
128 cereal because this type of breakfast is associated with reduced obesity risk when compared with  
129 ‘other breakfasts’<sup>(7)</sup>. Recommendations suggest breakfast should be 20% of daily EI<sup>(38)</sup> and reviews  
130 define breakfast typically as containing 20% to 35% of total daily energy needs<sup>(39)</sup>. Therefore, the  
131 SB contained 1994 kJ (500 kcal), equating to ~22-26% of daily energy requirements for 11-15 year  
132 old girls, which take into account total daily energy expenditure plus the deposited energy costs for  
133 growth (1935 to 2293 kcal/d)<sup>(40)</sup>. The SB was consumed at school rather than home to monitor  
134 compliance to the breakfast intervention and record any leftovers. If the SB was not consumed  
135 completely, it had to represent at least 20% of recommended daily EI for the participant to be  
136 included in the final sample<sup>(38)</sup>.

137

### 138 **Dietary assessment**

139 Participants recorded their daily diet using a digital camera (Vivitar, ViviCam 46, China) and food  
140 diary during each condition. A similar method has been validated previously in adults<sup>(21)</sup> and  
141 children<sup>(22)</sup>. The participants were asked to photograph all foods and beverages consumed and use  
142 the photographs as a recall method when completing their food diaries each evening. The food  
143 diaries included a record of the day, time, type, brand name, preparation method, estimated portion  
144 size and any leftovers of all food and drink consumed. Before completing the main conditions, the  
145 girls received a tutorial and written instructions on using the digital camera and food diary. On the  
146 morning after each day of dietary recording, the research team checked the participants’ food  
147 diaries for completeness and cross-referenced the food diaries with the corresponding photographs.  
148 For missing photographs, portion size was estimated by the participants using the Young Person’s  
149 Food Atlas<sup>(41,42)</sup> with assistance from the research team; further details were added to the diary  
150 when appropriate. The mass of all foods and beverages consumed were estimated by comparing the  
151 digital photographs, taken by the participants, to the Young Person’s Food Atlas<sup>(41,42)</sup>; this method  
152 that has shown good agreement with weighed food diaries in children aged  $\geq 11$  years<sup>(43)</sup>. Food  
153 diaries were analysed using Dietplan 6.7 (Forestfield Software, Horsham, UK) to estimate EI and  
154 macronutrient intakes, which were blocked into three time periods to separate breakfast, lunch and  
155 the evening meal and align with the school timetable: (i) 06:00 to 09:00 (including breakfast and  
156 early morning snacks), (ii) 10:30 to 14:00 (including school break time snacks and lunch), and (iii)  
157 14:00 until 21:00 (including dinner and evening snacks). Percentage breakfast EI compensation was  
158 calculated for SB relative to NB (i.e., the difference in post-breakfast EI between SB and NB  
159 divided by SB breakfast EI multiplied by 100); values of 100% indicated complete compensation

160 for breakfast EI. Portions of fruit and vegetable consumed were quantified using the National  
 161 Health Service (NHS) guidelines for 5 portions/d<sup>(44)</sup>. High-fat and sugary snacks were defined as  
 162 sweet baked products, cookies, ice cream, cakes, desserts, jams, sugar, sweets, nuts, potato crisps,  
 163 cheese products, popcorn and soft drinks<sup>(8)</sup>.

164

### 165 **Variability of daily EI**

166 To determine the natural variability of daily EI, the primary outcome variable, a sub-sample of 10  
 167 girls completed two, 3-day free-living diet (FD) conditions on two consecutive weeks at least four  
 168 weeks before commencing the main study. On each day, the girls were free to eat and drink as they  
 169 pleased and were instructed to record their dietary intakes using the digital photography and food  
 170 diary method described above (see ‘Dietary assessment’). Thus, the data provided an indication of  
 171 the variability in habitual dietary intakes between two 3-day periods rather than being an assessment  
 172 of measurement reliability. The 95% Limits of Agreement (LoA) for daily EI were calculated by  
 173 determining a 95% limit above and below the mean difference for FD trial 1 and FD trial 2  
 174 (systematic error  $\pm (1.96 \times \text{random error})$ ), as outlined by Bland and Altman<sup>(45)</sup>. Student’s paired t-  
 175 tests were used to identify systematic change in the mean from trial one to two; whereas Pearson’s  
 176 product moment correlations between the paired residuals and the mean (proportional error check)  
 177 and the absolute residuals and the mean (heteroscedasticity check) were examined to ensure the  
 178 95% LoA were representative of the whole sample. It has been estimated that excessive weight gain  
 179 could be prevented in children and adolescents by reducing positive energy balance by 628 kJ/d  
 180 (150 kcal/d)<sup>(46)</sup>. Therefore, we deemed that LoA of  $\leq \pm 628$  kJ/d (150 kcal/d) would be an  
 181 acceptable test-retest error for daily FD EI.

182

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

191

### 192 **Physical activity assessment**

193 Wrist-worn accelerometers that have been validated in 8 to 14 year olds (GENEActiv, ActivInsights  
 194 Ltd., Colworth, UK) were used to assess PA for the duration of each 3-day condition<sup>(47)</sup>. The



195 accelerometers were set to record at 85.7 Hz using a 1-second epoch. The girls were asked to wear  
196 the accelerometers on their non-dominant wrist for three days at all times, removing only for  
197 bathing and water-based activities. To estimate daily time spent sedentary and in light PA (LPA)  
198 and moderate-to-vigorous PA (MVPA), GENEActiv cut-points specific to 8 to 14 year olds were  
199 applied and expressed as percentage of total daily wear time<sup>(47)</sup>. The minimal amount of  
200 accelerometer data that was considered acceptable was 10 h/d of wear time on all three days of both  
201 breakfast conditions<sup>(48)</sup>.

202

### 203 **Statistical analyses**

204 Statistical analyses were completed using IBM SPSS statistics software for Windows version 21  
205 (IBM Corporation, New York, USA). Total daily EI, macronutrient intakes and PA were compared  
206 between the two conditions using student's paired t-tests. For post-breakfast EI and macronutrient  
207 intakes, condition by time of day (2 x 2) repeated measures analysis of variance (ANOVA) were  
208 used to examine differences between the conditions across the two time periods (i.e., 10:30 to 14:00  
209 and 14:00 to 21:00). Weekday habitual breakfast frequency and BMI were considered as covariates,  
210 but were not used because the data did not satisfy the assumptions for covariate analysis (i.e., they  
211 were not significantly associated with the dependent variables across all conditions). Homogeneity  
212 of covariances were examined by Mauchly's test of sphericity, and a Greenhouse–Geisser  
213 correction was applied to the degrees of freedom if the sphericity assumption was violated. Cohen's  
214 d effect sizes (d) were calculated to gauge the magnitude of differences between conditions for all  
215 significant effects. In the absence of published anchors, a  $d \geq 0.20$  was considered the minimum  
216 important difference in all outcome measures, 0.50 to  $< 0.80$  moderate and  $\geq 0.80$  large<sup>(49)</sup>. Values  
217 are presented as means  $\pm$  SDs unless stated otherwise.

218

### 219 **Justification of sample size**

220 The calculated sample size was based on total daily EI (the primary outcome variable) and LPA (%  
221 wear time), as this PA intensity has been shown to be sensitive to breakfast manipulation in  
222 adults<sup>(14)</sup>. A worthwhile difference in EI or energy expenditure between the two conditions was  
223 defined as 628 kJ/d (150 kcal/d)<sup>(46)</sup>. Our variability study showed that the SD of the EI difference  
224 between two, 3-day FD conditions was 1147 kJ/d (274 kcal/d). A 628 kJ/d increase in energy  
225 expenditure requires ~45 minutes of LPA at 14.0 kJ/min in adolescent girls<sup>(47,50)</sup>. This would equate  
226 to 5% of weekday waking hours and an SD of 6%<sup>(48,51)</sup>. Using these figures, the number of  
227 participants estimated to detect a significant change at 90% power with a two-sided significance  
228 level of 0.05 was 35 for daily EI and 30 for LPA. To be included in the final sample, participants  
229 had to meet the following criteria: 1) attended the breakfast intervention club on all days; 2) abstain

230 from all foods and beverages until 10:30 for NB; 3) consume at least 20% of recommended daily EI  
 231 if they did not consume the SB completely<sup>(38)</sup>; 4) record their diet and wear the accelerometer as  
 232 specified. Thus, 49 participants were recruited to allow for a dropout of 10-30%.

233

## 234 **Results**

### 235 **Participant characteristics**

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

244

245

INSERT TABLE 1

246

### 247 **Variability of daily energy intake**

248 At the group level ( $n=10$ ), EI was similar between FD trial 1 and FD trial 2;  $5063 \pm 1332$  vs.  $5244 \pm$   
 249  $1293$  kJ/d ( $1211 \pm 319$  vs.  $1255 \pm 309$  kcal/d;  $t=-0.500$ ;  $P=0.629$ ). The systematic bias  $\pm$  random  
 250 error were  $181 \pm 1147$  kJ/d ( $43 \pm 274$  kcal/d). This resulted in 95% LoA of -2067 to 2428 kJ/d, (-  
 251 494 to 580 kcal/d) (see Online Supplementary Document S1). Significant proportional bias was not  
 252 evident ( $r=-0.038$ ;  $P=0.917$ ) and random errors were homoscedastic ( $r=-0.040$ ,  $P=0.912$ ). The LoA  
 253 based on all 10 girls exceeded our *a priori* acceptable test-retest variability of  $\pm 628$  kJ/d (150  
 254 kcal/d). However, seven of the 10 participants had paired EI values across the repeat measurements  
 255 that were within  $\pm 628$  kJ/d (150 kcal/d), suggesting the natural variation in FD may be small  
 256 enough to detect subtle changes in EI that could prevent excessive weight gain<sup>(46)</sup>. In the remaining  
 257 three girls, one had a particularly large difference of 3141 kJ/d between the repeat measurements.  
 258 When excluding this participant ( $n=9$ ), the systematic error  $\pm$  random error was reduced by  $-148 \pm$   
 259  $512$  kJ/d, and the 95% LoA were tightened to -1151 to 855 kJ/d, but still exceed the  $\pm 628$  kJ/d cut-  
 260 off.

261 **Breakfast energy and macronutrient intake**

262 Accounting for leftovers, breakfast energy and macronutrient intakes for SB were: EI  $1962 \pm 121$  kJ  
 263 ( $469 \pm 29$  kcal),  $88.3 \pm 6.0$  g CHO,  $16.4 \pm 1.3$  g protein,  $5.7 \pm 0.7$  g fat and  $5.8 \pm 0.6$  g fibre. For  
 264 comparison, the girls consumed  $766 \pm 439$  kJ ( $183 \pm 105$  kcal),  $29.4 \pm 16.1$  g CHO,  $5.4 \pm 3.7$  g  
 265 protein,  $5.4 \pm 4.5$  g fat and  $1.2 \pm 1.0$  g fibre for breakfast habitually. The energy, CHO, protein and  
 266 fibre intake of the SB were higher than the girls habitual breakfasts ( $P < 0.005$ ;  $d = 3.69$  to  $5.32$ ),  
 267 whereas fat intakes were similar ( $P = 0.672$ ;  $d = 0.09$ ).

268

269 **Daily and post-breakfast energy intake**

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

277

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

281

282 INSERT FIGURE 1

283

284 **Daily and post-breakfast macronutrient intakes**

285 Table 2 shows daily macronutrient intakes for each breakfast condition. Daily CHO, fibre and  
 286 protein intakes were higher in SB compared with NB ( $d \geq 0.81$  for all comparisons), whereas daily  
 287 fat intake was not. The effect of condition was not significant for CHO, fat, protein and fibre intakes  
 288 for the post-breakfast period ( $P \geq 0.451$ ;  $d \leq 0.14$  for all comparisons) and there was no interaction  
 289 with time of day ( $P \geq 0.329$ ). The time of day main effect showed that protein and fibre intakes were  
 290 higher in the 14:00-21:00 period than the 10:30-14:00 period ( $P \leq 0.026$ ;  $d \geq 0.50$ ), but this difference  
 291 only approached significance for CHO with a small effect ( $P = 0.054$ ;  $d = 0.40$ ).

292

293 INSERT TABLE 2

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

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

299

300 **Daily physical activity**

301 A total of 35 girls had valid accelerometer data and were included in PA analyses. Wear time was  
 302  $14.2 \pm 1.2$  h/d for SB and  $14.1 \pm 1.3$  h/d for NB ( $P=0.488$ ). Daily time spent sedentary or in LPA or  
 303 MVPA (% wear time) was not different between conditions (Table 3).

304

305

INSERT TABLE 3

306

307 **Discussion**

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

313

314 Our study supports previous research showing that breakfast consumption results in higher daily EIs  
 315 in young people<sup>(10,17)</sup> and adults<sup>(12,13,14,15,52)</sup> when compared with breakfast omission. In addition to  
 316 being statistically significant, random within-subject variation and measurement error did not  
 317 explain the higher daily EI with breakfast consumption, which exceeded the natural variability in EI  
 318 by more than 150 kcal/d and may thus have clinical importance for weight gain<sup>(23,46)</sup>. The 483 kJ/d  
 319 (115 kcal/d) increase in post-breakfast EI (i.e., between 10:30 and 21:00) when the girls omitted  
 320 breakfast amounted to only a quarter of the SB. This incomplete EI compensation may be due to the  
 321 large size of the SB, which contained 2.6 times more energy than the participants' habitual  
 322 breakfasts. As CHO-based breakfasts containing ~1.3 times less energy than our SB also did not  
 323 result in EI compensation in young people<sup>(10,17)</sup>, examining the effects of smaller breakfasts similar  
 324 in energy content to the habitual breakfasts of adolescent girls (~766 kJ in our sample) may enhance  
 325 the ecological validity of the findings and likelihood EI compensation being complete. Although the  
 326 increased EI with breakfast omission was distributed evenly across the day in our study, reports in  
 327 adults indicate that these effects are specific to certain time periods<sup>(12,13,15)</sup>. It has also been shown  
 328 that such effects may depend on the sex and breakfast habits of the sample<sup>(28)</sup>, whereas habitual

329 breakfast frequency was not related to the outcome variables in our sample of adolescent girls.  
330 Nevertheless, the 95% confidence interval for the SD of the individual response (229 to 1042 kJ/d)  
331 indicates large interindividual variability in compensatory EI responses to breakfast omission.  
332 Thus, individual characteristics that may explain this variability, such as eating and PA habits, body  
333 composition, age and socioeconomic status warrant clarification.

334

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

354

355 Whilst weighed food records are often considered the criterion reference measure of free-living EI  
356 in adults, self-reported EI can be underestimated through poor compliance, participant selection  
357 bias, recording bias and changes to diet to facilitate recording<sup>(58)</sup>. In adolescents, the reliability and  
358 validity of weighed food diaries is less certain and the participant burden is particularly high<sup>(59,60)</sup>.  
359 In an attempt to increase compliance to recording dietary intakes in our study, we used a food diary  
360 accompanied by photographic evidence rather than a weighed food diary<sup>(19)</sup>. Although previous  
361 research has indicated that the addition of photographs to a traditional diet diary can enhance the  
362 validity and reliability of dietary recording<sup>(61)</sup>, our comparison of two 3-day records showed 95%  
363 LoA for EI of -494 to +580 kcal/d. This high variability of free-living EI, potentially resulting from

364 environmental, biological and methodological factors<sup>(62)</sup>, may limit the potential to detect clinically  
365 meaningful differences of 150 kcal/d<sup>(46)</sup>. Previous literature on free-living EI variability using 3-day  
366 diet records has used varied statistical approaches and produced mixed findings<sup>(63,64)</sup>. Interestingly,  
367 our LoA are narrower than studies reporting ‘acceptable’ agreement with a 3-day diet record in  
368 adults<sup>(65)</sup> and a food menu in free-living young people<sup>(66)</sup>. Thus, the use of a clinically relevant  
369 anchor may have affected the interpretation of the LoA in these studies.

370  
371 Consistent with cross-sectional reports<sup>(8,9,30)</sup>, the higher daily EI with SB consumption was due to  
372 higher intakes of CHO, protein and fibre, whereas breakfast did not affect daily fat intakes. These  
373 differences in daily macronutrient intakes were a direct effect of the breakfast meal rather than post-  
374 breakfast intakes. Nevertheless, it is likely that the tendency for higher high-fat and sugary snack  
375 consumption contributed to the increased post-breakfast EI when breakfast was omitted. This  
376 finding also suggests that the nature of the cross sectional association between infrequent breakfast  
377 consumption and higher unhealthy snack consumption<sup>(8,9)</sup> may be causal. Overall, the girls  
378 consumed around one portion of fruit and vegetables a day, a concerning number considering that a  
379 minimum of five portions per day is recommended<sup>(44)</sup>. Although breakfast consumption has been  
380 associated with higher fruit and vegetable consumption<sup>(67,68)</sup>, the present study suggests that any  
381 such relations are not causal, at least in our sample over a 3-day intervention. As food groups other  
382 than fruit and vegetables contribute to micronutrient intakes, whether breakfast manipulation affects  
383 micronutrient intakes warrants examination using assessment periods of more than three days<sup>(69)</sup>.

384  
385 The small post-breakfast EI compensation in the present study suggests that a higher PA energy  
386 expenditure may be more important in contributing to the healthy weight status in frequent  
387 breakfast consumers<sup>(1,3,4,5,7)</sup>. However, our finding that breakfast did not affect sedentary time or  
388 MVPA supports cross-sectional findings in girls aged 9-10 years when using accelerometry to  
389 quantify PA on weekdays and weekends<sup>(26)</sup> and experimental research in adults showing no effect  
390 of breakfast manipulation on PA assessed via pedometers and heart rate monitors during a working  
391 week<sup>(28)</sup>. Although breakfast manipulation did not affect LPA in the girls in the present study,  
392 energy expenditure from LPA assessed over seven days was higher in lean adults who consumed  
393 breakfast daily compared with those who omitted breakfast daily<sup>(14)</sup>. In the obese cohort of this six  
394 week intervention, total PA energy expenditure in the morning was higher in the breakfast group  
395 compared with the breakfast omission group<sup>(16)</sup>. An acute randomised crossover trial using  
396 accelerometry also showed that consuming breakfast increased PA energy expenditure when  
397 compared with breakfast omission in women classified as habitual breakfast eaters<sup>(15)</sup>. The  
398 adolescent girls in our study may have responded differently to the adults in previous studies<sup>(14,15,16)</sup>

399 because the provision of breakfast at school meant that they had limited opportunity to engage in  
400 free-living PA directly after consuming breakfast. Thus, providing breakfast at home and including  
401 weekend days may increase the scope for detecting effects on PA.

402

403 The present study has several limitations. First, breakfast manipulation over three weekdays does  
404 not allow us to apply the findings to weekends, where diet and PA patterns are different<sup>(27,51,70)</sup>, or  
405 to determine the effects of longer intervention periods. Second, similar to previous studies<sup>(17,18)</sup>, we  
406 provided a fixed absolute breakfast portion. However, providing breakfast relative to daily energy  
407 requirements may be recommended to reduce between-participant variability in the response to  
408 breakfast manipulation. Similarly, methods that provide less variable measures EI would help  
409 support our findings, although this is challenging in free-living conditions<sup>(58,59,60)</sup>. In addition,  
410 standardising pre-intervention diet and the duration of the washout period between participants  
411 would help to minimise the influence of these factors on the study outcomes. Third, future studies  
412 employing more sensitive measures to quantify free-living PA or energy expenditure (e.g. combined  
413 heart rate-accelerometry or doubly labelled water) over longer measurement periods (e.g. seven  
414 days) would be valuable in extending the findings reported here. In doing so, the possibility that  
415 breakfast consumption may affect PA through an interaction with wake time and sleeping patterns  
416 requires consideration. Differences in wake time are unlikely to have confounded the comparison  
417 between SB and NB in our study, as the provision of breakfast at school rather than at home meant  
418 that the participants were not required to wake up any earlier to consume the SB. Nevertheless, the  
419 independent effects of breakfast frequency, timing and composition warrant study. Finally, the  
420 generalisability of our findings to adolescent boys and to younger children requires investigation.

421

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

429

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433

434 **Figure legends**

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

440

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444

445 **Conflict of interest**

446 None.

447

448 **Authorship**

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

454

455 **Supplementary material**

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

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465 **References**

- 466 1. Rampersaud GC, Pereira MA, Girard BL *et al.* (2005) Breakfast habits, nutritional status,  
467 body weight, and academic performance in children and adolescents. *J Am Diet Assoc* **105**,  
468 743-760.
- 469 2. Tanner JM, Whitehouse RH, Marshall WA *et al.* (1975) Prediction of adult height, bone  
470 age, and occurrence of menarche, at age 4 to 16 with allowance for midparental height. *Arch*  
471 *Dis Child* **50**, 14–26.
- 472 3. Vereecken C, Dupuy M, Rasmussen M *et al.* (2009) Breakfast consumption and its socio-  
473 demographic and lifestyle correlates in schoolchildren in 41 countries participating in the  
474 HBSC study. *Int J Public Health* **54**, Suppl. 2, S180-S190.
- 475 4. Zakrzewski JK, Gillison FB, Cumming S *et al.* for the ISCOLE Research Group. (2015)  
476 Associations between breakfast frequency and adiposity indicators in children from 12  
477 countries. *Int J Obes* **5**, Suppl. 2, S80-S88.
- 478 5. Brown AW, Bohan Brown MM & Allison DB (2013) Belief beyond the evidence: using the  
479 proposed effect of breakfast on obesity to show 2 practices that distort scientific evidence.  
480 *Am J Clin Nutr* **98**, 1298-1308.
- 481 6. Hill JO (2006) Understanding and addressing the epidemic of obesity: an energy balance  
482 perspective. *Endocr Rev* **27**, 750-761.
- 483 7. Deshmukh-Taskar PR, Nicklas TA, O'Neil CE *et al.* (2010) The relationship of breakfast  
484 skipping and type of breakfast consumption with nutrient intake and weight status in  
485 children and adolescents: the National Health and Nutrition Examination Survey 1999-2006.  
486 *J Am Diet Assoc* **110**, 869-878.
- 487 8. Sjöberg A, Hallberg L, Höglund D *et al.* (2003) Meal pattern, food choice, nutrient intake  
488 and lifestyle factors in The Göteborg Adolescence Study. *Eur J Clin Nutr* **57**, 1569-1578.
- 489 9. Dubois L, Girard M, Potvin Kent M *et al.* (2009) Breakfast skipping is associated with  
490 differences in meal patterns, macronutrient intakes and overweight among pre-school  
491 children. *Public Health Nutr* **12**, 19-28.
- 492 10. Kral TV, Whiteford LM, Heo M *et al.* (2011) Effects of eating breakfast compared with  
493 skipping breakfast on ratings of appetite and intake at subsequent meals in 8- to 10-y-old  
494 children. *Am J Clin Nutr* **93**, 284-291.
- 495 11. Leidy HJ & Racki EM (2010) The addition of a protein-rich breakfast and its effects on  
496 acute appetite control and food intake in 'breakfast-skipping' adolescents. *Int J Obes (Lond)*  
497 **34**, 1125-1133.
- 498 12. Clayton DJ, Barutcu A, Machin C *et al.* (2015) Effect of breakfast omission on energy  
499 intake and evening exercise performance. *Med Sci Sports Exerc* **47**, 2645-2652.

- 500 13. Reeves S, Huber JW, Halsey LG *et al.* (2014) Experimental manipulation of breakfast in  
501 normal and overweight/obese participants is associated with changes to nutrient and energy  
502 intake consumption patterns. *Physiol Behav* **133**, 130-135.
- 503 14. Betts JA, Richardson JD, Chowdhury EA *et al.* (2014) The causal role of breakfast in energy  
504 balance and health: a randomized controlled trial in lean adults. *Am J Clin Nutr* **100**, 539-  
505 547.
- 506 15. Yoshimura E, Hatamoto Y, Yonekura S *et al.* (2017) Skipping breakfast reduces energy  
507 intake and physical activity in healthy women who are habitual breakfast eaters: A  
508 randomized crossover trial. *Physiol Behav* **174**, 89-94.
- 509 16. Chowdhury EA, Richardson JD, Holman GD *et al.* (2016) The causal role of breakfast in  
510 energy balance and health: a randomized controlled trial in obese adults. *Am J Clin Nutr*  
511 **103**, 747-756.
- 512 17. Leidy HJ, Ortinau LC, Douglas SM *et al.* (2013) Beneficial effects of a higher-protein  
513 breakfast on the appetitive, hormonal, and neural signals controlling energy intake  
514 regulation in overweight/obese, "breakfast-skipping," late-adolescent girls. *Am J Clin Nutr*  
515 **97**, 677-688.
- 516 18. Leidy HJ, Hoertel HA, Douglas SM *et al.* (2015) A high-protein breakfast prevents body fat  
517 gain, through reductions in daily intake and hunger, in "Breakfast skipping" adolescents.  
518 *Obesity (Silver Spring)* **23**, 1761-1764.
- 519 19. Boushey CJ, Kerr DA, Wright J *et al.* (2009) Use of technology in children's dietary  
520 assessment. *Eur J Clin Nutr* **63**, Suppl. 1, S50-S57.
- 521 20. Martin CK, Nicklas T, Gunturk B *et al.* (2014) Measuring food intake with digital  
522 photography. *J Hum Nutr Diet* **27**, Suppl. 1, S72-S81.
- 523 21. Wang DH, Kogashiwa M & Kira S (2006) Development of a new instrument for evaluating  
524 individuals' dietary intakes. *J Am Diet Assoc* **106**, 1588-1593.
- 525 22. Martin CK, Newton RL Jr, Anton SD *et al.* (2007) Measurement of children's food intake  
526 with digital photography and the effects of second servings upon food intake. *Eat Behav* **8**,  
527 148-156.
- 528 23. Atkinson G & Batterham AM (2015) True and false interindividual differences in the  
529 physiological response to an intervention. *Exp Physiol* **100**, 577-588.
- 530 24. Janssen I, Katzmarzyk PT, Boyce WF *et al.* for the Health Behaviour in School-Aged  
531 Children Obesity Working Group. (2005) Comparison of overweight and obesity prevalence  
532 in school-aged youth from 34 countries and their relationships with physical activity and  
533 dietary patterns. *Obes Rev* **6**, 123-132.

- 534 25. Corder K, van Sluijs EM, Steele RM *et al.* (2011) Breakfast consumption and physical  
535 activity in British adolescents. *Br J Nutr* **105**, 316-321.
- 536 26. Vissers PA, Jones AP, Corder K *et al.* (2013) Breakfast consumption and daily physical  
537 activity in 9-10-year-old British children. *Public Health Nutr* **16**, 1281-1290.
- 538 27. Corder K, van Sluijs EM, Ridgway CL *et al.* (2014) Breakfast consumption and physical  
539 activity in adolescents: daily associations and hourly patterns. *Am J Clin Nutr* **99**, 361-368.
- 540 28. Halsey LG, Huber JW, Low T *et al.* (2012) Does consuming breakfast influence activity  
541 levels? An experiment into the effect of breakfast consumption on eating habits and energy  
542 expenditure. *Public Health Nutr* **15**, 238-245.
- 543 29. Todd AS, Street SJ, Ziviani J *et al.* (2015) Overweight and obese adolescent girls: the  
544 importance of promoting sensible eating and activity behaviors from the start of the  
545 adolescent period. *Int J Environ Res Public Health* **12**, 2306-2329.
- 546 30. Timlin MT, Pereira MA, Story M *et al.* (2008) Breakfast eating and weight change in a 5-  
547 year prospective analysis of adolescents: project EAT (Eating Among Teens). *Pediatrics*  
548 **121**, 638-645.
- 549 31. Cole TJ, Freeman JV & Preece MA (1995) Body mass index reference curves for the UK,  
550 1990. *Arch Dis Child* **73**, 25-29.
- 551 32. McCarthy HD, Jarrett KV, Emmett PM *et al.* (2005) Trends in waist circumferences in  
552 young British children: a comparative study. *Int J Obes (Lond)* **29**, 157-162.
- 553 33. Brooks-Gunn J, Warren MP, Rosso J *et al.* (1987) Validity of self-report measures of girls'  
554 pubertal status. *Child Dev* **58**, 829-841.
- 555 34. Morris NM & Udry JR (1980) Validation of a self-administered instrument to assess stage  
556 of adolescent development. *J Youth Adolesc* **9**, 271-280.
- 557 35. Tanner JM (1962) *Growth at adolescents*. Oxford, UK: Blackwell Scientific.
- 558 36. Atkinson FS, Foster-Powell K & Brand-Miller JC (2008). International tables of glycemic  
559 index and glycemic load values: *Diabetes Care* **31**, 2281-2283
- 560 37. Wolever TM & Jenkins DJ (1986) The use of the glycemic index in predicting the blood  
561 glucose response to mixed meals. *Am J Clin Nutr* **43**, 167-172.
- 562 38. Food Standards Agency (2007) Nutrient and food based guidelines for UK institutions.  
563 <http://www.food.gov.uk/multimedia/pdfs/nutrientinstitution.pdf> (accessed March 2017).
- 564 39. Timlin MT & Pereira MA (2007) Breakfast frequency and quality in the etiology of adult  
565 obesity and chronic diseases. *Nutr Rev* **65**, 268-281.
- 566 40. Scientific Advisory Committee on Nutrition (2011) *Dietary Reference Values for Energy*.  
567 Public Health England. London: TSO.

- 568 41. Foster E, Adamson A, Hawkins A *et al.* (2010) *Young Person's Food Atlas - Secondary*.  
569 Food Standards Agency. Newcastle University, UK.
- 570 42. Foster E & Adamson AJ (2012) Development and validation of the Young Person's Food  
571 Atlas. *Proc Nutr Soc* **71**, 195.
- 572 43. Foster E, Hawkins A, Barton KL *et al.* (2017) Development of food photographs for use  
573 with children aged 18 months to 16 years: comparison against weighed food diaries - The  
574 Young Person's Food Atlas (UK). *PLoS One* **15**, 12:e0169084.
- 575 44. NHS Choices. 5 A DAY: portion guide.  
576 [www.nhs.uk/Livewell/5ADAY/Documents/Downloads/5ADAY\\_portion\\_guide.pdf](http://www.nhs.uk/Livewell/5ADAY/Documents/Downloads/5ADAY_portion_guide.pdf)  
577 (accessed March 2017).
- 578 45. Bland JM & Altman DG (1986) Statistical methods for assessing agreement between two  
579 methods of clinical measurement. *Lancet* **1**, 307-310.
- 580 46. Wang YC, Gortmaker SL, Sobol AM *et al.* (2006) Estimating the energy gap among US  
581 children: a counterfactual approach. *Pediatrics* **118**, 1721-1733.
- 582 47. Phillips LR, Parfitt G & Rowlands AV (2013) Calibration of the GENEActiv accelerometer for  
583 assessment of physical activity intensity in children. *J Sci Med Sport* **16**, 124-128.
- 584 48. Rowlands AV, Rennie K, Kozarski R *et al.* (2014) Children's physical activity assessed with  
585 wrist- and hip-worn accelerometers. *Med Sci Sports Exerc* **46**, 2308-2316.
- 586 49. Cohen J (1988) *Statistical power analysis for the behavioral sciences*. 2nd ed. Hillsdale, NJ:  
587 Lawrence Erlbaum Associates.
- 588 50. Schmitz K, Treuth MS, McMurray R, *et al.* (2005) Predicting energy expenditure from  
589 accelerometry counts in adolescent girls. *Med Sci Sport Exerc* **37**, 155-161.
- 590 51. Treuth MS, Catellier DJ, Schmitz KH *et al.* (2007) Weekend and weekday patterns of  
591 physical activity in overweight and normal-weight adolescent girls. *Obesity (Silver Spring)*  
592 **15**, 1782-1788.
- 593 52. Chowdhury EA, Richardson JD, Tsintzas K *et al.* (2015) Carbohydrate-rich breakfast  
594 attenuates glycaemic, insulinaemic and ghrelin response to ad libitum lunch relative to  
595 morning fasting in lean adults. *Br J Nutr* **114**, 98-107.
- 596 53. Shaw ME (1998) Adolescent breakfast skipping: an Australian study. *Adolescence* **33**, 851-  
597 861.
- 598 54. Warren JM, Henry CJ & Simonite V (2003) Low glycemic index breakfasts and reduced  
599 food intake in preadolescent children. *Pediatrics* **112**, 414-419.
- 600 55. Ball SD, Keller KR, Moyer-Mileur LJ *et al.* (2003) Prolongation of satiety after low versus  
601 moderately high glycemic index meals in obese adolescents. *Pediatrics* **111**, 488-494.

- 602 56. Bornet FR, Jardy-Gennetier AE, Jacquet N *et al.* (2007) Glycaemic response to foods:  
603 impact on satiety and long-term weight regulation. *Appetite* **49**, 535-553.
- 604 57. Sun FH, Li C, Zhang YJ *et al.* (2016) Effect of glycemic index of breakfast on energy intake  
605 at subsequent meal among healthy people: a meta-analysis. *Nutrients* **8**, 37-51.
- 606 58. Macdiarmid J & Blundell J (1998) Assessing dietary intake: who, what and why of under-  
607 reporting. *Nutr Res Rev* **11**, 231-253.
- 608 59. Burrows TL, Martin RJ & Collins CE (2010) A systematic review of the validity of dietary  
609 assessment methods in children when compared with the method of doubly labeled water. *J*  
610 *Am Diet Assoc* **110**, 1501-1510.
- 611 60. Livingstone MB, Robson PJ & Wallace JM (2004) Issues in dietary intake assessment of  
612 children and adolescents. *Br J Nutr* **92**, Suppl. 2, S213-S222.
- 613 61. Small L, Sidora-Arcoleo K, Vaughan L *et al.* (2009) Validity and reliability of photographic  
614 diet diaries for assessing dietary intake among young children. *ICAN* **1**, 27-36.
- 615 62. Tarasuk V & Beaton GH (1991) The nature and individuality of within-subject variation in  
616 energy intake. *Am J Clin Nutr* **54**, 464-470.
- 617 63. Carlsohn A, Fusch G & Scharhag-Rosenberger F (2011) Validity and reliability of athletes'  
618 self-recorded food intake determined by doubly-labelled water. *Med Sci Sports Exerc* **43**,  
619 503-504.
- 620 64. Tremblay A, Sévigny J, Leblanc C *et al.* (1983) The reproducibility of a three-day dietary  
621 record. *Nutr Res* **3**, 819-830.
- 622 65. Toeller M, Buyken A, Heitkamp G *et al.* (1997) Repeatability of three-day dietary records in  
623 the EURODIAB IDDM Complications Study. *Eur J Clin Nutr* **51**, 74-80.
- 624 66. Chaput JP, Jomphe-Tremblay S, Lafrenière J *et al.* (2016) Reliability of a food menu to  
625 measure energy and macronutrient intake in adolescents. *Eur J Clin Nutr* **70**, 104-108.
- 626 67. Arora M, Nazar GP, Gupta VK *et al.* (2012) Association of breakfast intake with obesity,  
627 dietary and physical activity behavior among urban school-aged adolescents in Delhi, India:  
628 results of a cross-sectional study. *BMC Public Health* **12**, 881-893.
- 629 68. Utter J, Scragg R, Mhurchu CN *et al.* (2007) At-home breakfast consumption among New  
630 Zealand children: associations with body mass index and related nutrition behaviors. *J Am*  
631 *Diet Assoc* **107**, 570-576.
- 632 69. Bingham S (1987) The dietary assessment of individuals; methods, accuracy, new  
633 techniques and recommendations *Nut Abstracts Rev* **57**, 705-42.
- 634 70. Hjorth MF, Damsgaard CT, Michaelsen KF *et al.* (2015) Markers of metabolic health in  
635 children differ between weekdays--the result of unhealthier weekend behavior. *Obesity*  
636 *(Silver Spring)* **23**, 733-736.

## Tables

**Table 1.** Participant characteristics

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

<sup>1</sup>Values are mean and standard deviation.

<sup>2</sup>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		<i>P</i>	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

<sup>1</sup>SD, standard deviation; d, Cohen's d effect size.

<sup>2</sup>Paired t-tests and Cohen's d effect sizes were used to compare the SB and NB conditions.

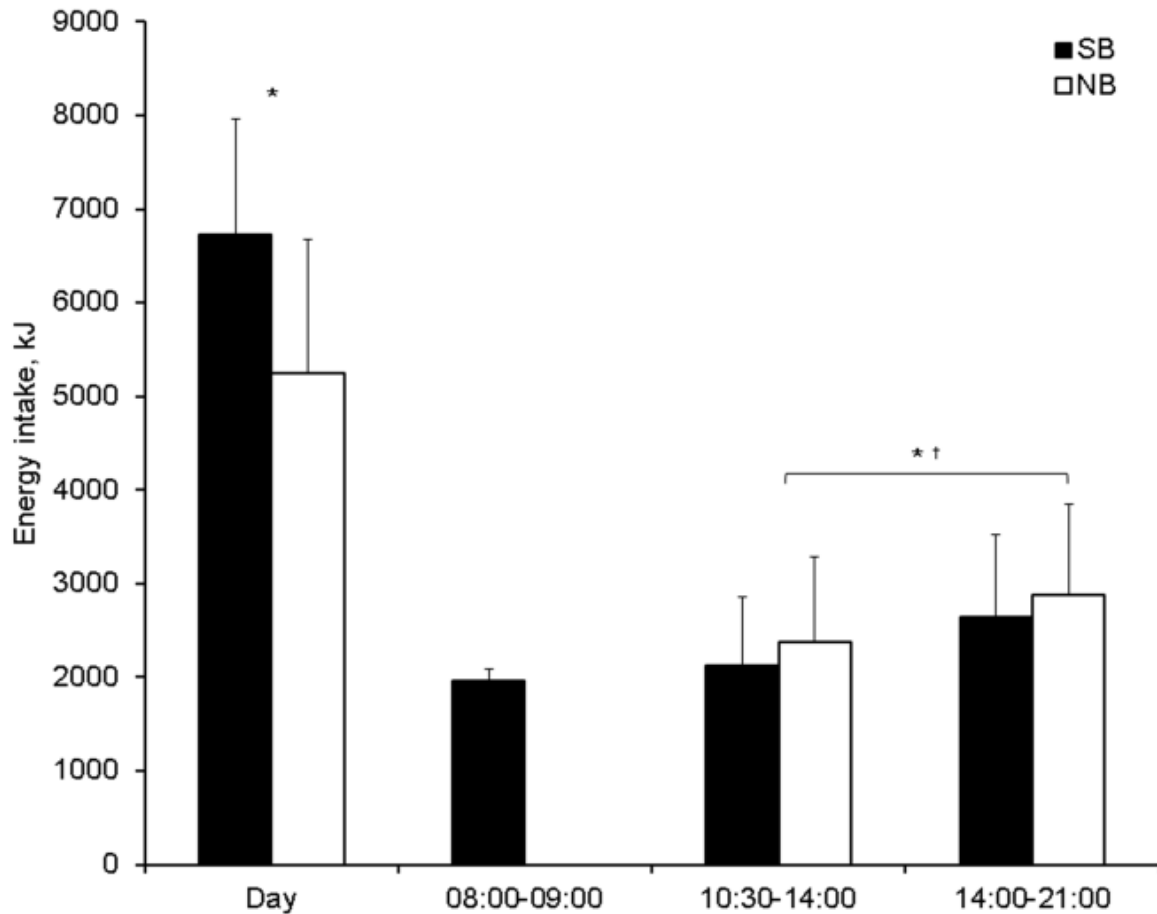
**Table 3.** Daily time spent sedentary and in physical activity during three days of no breakfast (NB) or standardised breakfast consumption (SB) using a randomised crossover design (n=35).

	SB		NB		<i>P</i>	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

<sup>1</sup>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.

<sup>2</sup>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 ( $P = 0.003$ ).  $n = 40$ .