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## Effect of breakfast glycemic index on metabolic responses during rest and exercise in overweight and non-overweight adolescent girls

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1 Effect of breakfast glycemic index on metabolic responses during rest and exercise in  
2 overweight and non-overweight adolescent girls

3

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23

24 **Abstract**

25 **Background/Objectives:** The metabolic responses to mixed breakfast meals with different  
26 glycemic indexes (GI) and their effects on substrate metabolism during exercise in adolescent  
27 girls have not been examined. The interaction with weight status also warrants investigation.  
28 The present study investigated the effect of mixed breakfast meals containing high GI (HGI)  
29 or low GI (LGI) carbohydrates on metabolic responses and fat oxidation during rest and  
30 exercise in overweight (OW) and non-overweight (NO) adolescent girls.

31 **Subjects/Methods:** Eight OW and 12 NO adolescent girls consumed an isoenergetic HGI  
32 (GI=73) or LGI (GI=44) breakfast 120 min before completing a 30-min treadmill walk at 50%  
33  $\dot{V}O_{2\text{peak}}$ .

34 **Results:** Peak blood glucose concentration was higher for HGI compared with LGI in OW  
35 (P=0.023), but not NO (P>0.05) girls. Blood glucose total area under the curve (TAUC) was  
36 13% higher in HGI compared with LGI in OW (P=0.006), but only 4% higher in NO  
37 (P=0.072) girls. Plasma insulin data were log<sub>e</sub> transformed (lninsulin). Plasma lninsulin  
38 concentrations were not different between HGI and LGI (P>0.05). Peak plasma lninsulin  
39 concentration (P=0.016) and TAUC (P=0.001) were greater in OW than NO girls. Fat  
40 oxidation during postprandial rest and exercise was not different between breakfasts (P>0.05).

41 **Conclusions:** The elevated glycemic response in HGI compared with LGI was more  
42 pronounced in OW girls, suggesting a reduced ability to cope with the metabolic demands of  
43 the HGI, but not LGI, breakfast. Manipulation of breakfast GI did not alter fat oxidation  
44 during rest or subsequent moderate intensity exercise in OW and NO adolescent girls.

45 **Keywords:** glycemic index, overweight, adolescents, females, metabolism, exercise

## 46 **Introduction**

47 Several lines of evidence have demonstrated benefits associated with regular breakfast  
48 consumption in children and adolescents, relating to academic performance (Lien, 2007),  
49 nutrition (Barton *et al.*, 2005; Song *et al.*, 2006), cardiorespiratory fitness and obesity  
50 (Sandercock *et al.*, 2010). However, the relationship between breakfast and health benefits  
51 may not be due to consumption *per se*, but rather breakfast composition (Cho *et al.*, 2003).  
52 There are concerns that ready-to-eat cereals commonly eaten by children and adolescents  
53 (Song *et al.*, 2006) fail to meet national nutrition recommendations (Schwartz *et al.*, 2008). In  
54 contrast, there has been considerable interest in potential health benefits of breakfasts  
55 containing low glycemic index (LGI) carbohydrates (Ludwig *et al.*, 1999; Willet *et al.*, 2002).  
56  
57 Manipulation of the GI of a mixed breakfast meal affects postprandial glycemic and  
58 insulinemic responses (Ludwig *et al.*, 1999; Stevenson *et al.*, 2009). Evidence that breakfasts  
59 rich in LGI carbohydrates promote satiety in obese adolescents (Ball *et al.*, 2003; Ludwig *et*  
60 *al.*, 1999) suggest that LGI breakfast consumption could have direct implications for pediatric  
61 weight management. In adults, the reduced glucose and insulin response to a LGI compared  
62 with HGI breakfast has also been shown to result in increased fat oxidation during rest  
63 (Stevenson *et al.*, 2009) and subsequent exercise (Stevenson *et al.*, 2006; 2009; Wee *et al.*,  
64 2005). However, breakfast GI does not affect fat oxidation during rest or exercise when  
65 comparing a moderate GI and HGI breakfast (Backhouse *et al.*, 2007) or when exercise is  
66 preceded by two LGI meals rather than breakfast alone (Stevenson *et al.*, 2005). A recent  
67 study even reported higher fat oxidation during a cycling time trial following a HGI compared  
68 with LGI breakfast (Moore *et al.*, 2010). Therefore, the influence of carbohydrate GI on  
69 postprandial fat oxidation remains unclear.

70

71 Reductions in fat oxidation (Zunquin *et al.*, 2009), glucose tolerance (Sinha *et al.*, 2002), and  
72 insulin sensitivity (Weiss *et al.*, 2004) have been shown in overweight and obese young  
73 people. Substituting a HGI breakfast for a LGI breakfast may, therefore, be particularly  
74 beneficial for overweight individuals through increased glycemic control (Willet *et al.*, 2002),  
75 fat oxidation (Stevenson *et al.*, 2009) and satiety (Ludwig *et al.*, 1999). However, the majority  
76 of studies investigating the impact of GI on fat oxidation have included endurance trained or  
77 recreationally active adults as participants (Stevenson *et al.*, 2006; Wu *et al.*, 2003) and we  
78 are unaware of similar studies including overweight individuals or young people, despite well  
79 recognised differences in metabolism between adolescents and adults (Riddell *et al.*, 2008).  
80 Therefore, we examined the effect of mixed breakfast meals providing HGI or LGI  
81 carbohydrates on metabolic responses and substrate utilization during rest and exercise in  
82 overweight and non-overweight adolescent girls.

83

## 84 **Subjects and Methods**

### 85 **Subjects**

86 After gaining approval from the University Ethical Advisory sub-Committee, eight  
87 overweight (OW) and twelve non-overweight (NO) girls aged 11-13 y participated in the  
88 study. Overweight status was defined using age and sex specific body mass index (BMI)  
89 reference points (Cole *et al.*, 2000). Written informed consent was obtained from the primary  
90 carer and the subjects provided their “willingness to participate”. Subjects were screened  
91 using a health history questionnaire. Exclusion criteria included: known congenital heart  
92 disease, musculoskeletal problems, uncontrolled exercise-induced asthma, diabetes and  
93 epilepsy. Stature was measured to the nearest 0.01 m using a stadiometer (Holtain, Holtain  
94 Limited, Dyfed, UK) and body mass (BM) to the nearest 0.1 kg using a beam balance scale  
95 (Seca Model 888, Hamburg, Germany). Skinfold thickness was measured over the triceps,  
96 subscapular and medial calf sites to the nearest 0.2 mm (Harpenden, Baty International,  
97 England). Each site was measured three times and median values were used to estimate  
98 percentage body fat (Slaughter *et al.*, 1988); fat free mass (FFM) was estimated subsequently.  
99 Waist circumference was measured midway between the 10th rib and the iliac crest  
100 (McCarthy *et al.*, 2005) using a Gulick tape measure (Creative Health Products, Plymouth,  
101 MI). With the assistance of a primary home-based carer, the girls provided a self-assessment  
102 of their physical maturation using pubic hair (Tanner, 1962).

103

### 104 **Preliminary measurements**

105 Subjects completed two preliminary tests on a treadmill (RunRace, TechnoGym, Gambettola,  
106 Italy) to determine 1) the relation between running speed and oxygen uptake ( $\dot{V}O_2$ ) and 2)  
107 peak oxygen uptake ( $\dot{V}O_{2\text{ peak}}$ ). The speed eliciting 50% of each subject's  $\dot{V}O_{2\text{ peak}}$  was  
108 determined subsequently.

109

**110 Test breakfasts**

111 Subjects were provided with a breakfast consisting of either HGI or LGI foods and containing  
112 1.5 g CHO·kg BM<sup>-1</sup> (Table 1). The breakfasts were matched for energy, macronutrients and  
113 fluid, but the LGI breakfast contained more fibre. The GI values for individual foods were  
114 taken from the International Table of GI and Glycemic Load Values (Atkinson *et al.*, 2008)  
115 and breakfast GI was calculated from the weighted means of the GI values for the component  
116 foods (Wolever and Jenkins, 1986). The calculated GI for the breakfasts were 73 (HGI) and  
117 44 (LGI).

118

**119 Experimental protocol**

120 Subjects completed two experimental trials (HGI and LGI) in a counter-balanced order. Trials  
121 were conducted a maximum 48 h apart for the girls who had irregular menstruation to  
122 minimise the potential influence of menstrual cycle phase on within-subject comparisons  
123 (Oosthuyse and Bosch, 2010). Due to the sporadic nature of the menstrual cycle in young  
124 adolescent girls, other studies have not accounted for menstrual cycle phase (Timmons *et al.*,  
125 2007). The girls consumed the same diet and minimised physical activity in the 24 h prior to  
126 experimental trials.

127

128 Subjects reported to the laboratory at 08:00 following a 12 h fast. Following fasted measures,  
129 the girls consumed a HGI or LGI breakfast (Table 1) within 15 min. Blood, expired air  
130 samples and subjective ratings of hunger were collected at regular intervals during the 120  
131 min postprandial period. Subsequently, the girls completed a 30 min treadmill walk at 50%  
132  $\dot{V}O_{2\text{peak}}$ . Water was available ad libitum throughout the first trial and the girls drank the same  
133 volume during the second trial.

134

**135 Blood sampling and analysis**

136 Capillary blood samples were obtained from a pre-warmed hand by finger prick (Unistik 2,  
137 Owen Mumford, UK) into collection tubes (Microvette CB300 EDTA, Sarstedt Ltd, UK).  
138 Capillary rather than venous blood sampling is preferred for reliable GI testing (Wolever *et*  
139 *al.*, 2003). Duplicate 25  $\mu$ l aliquots of whole blood were deproteinised in 250  $\mu$ l of ice cooled  
140 perchloric acid (PCA; 2.5%), centrifuged for 4 min at 2415 x g and stored at -20°C for blood  
141 glucose analysis. The remaining whole blood was centrifuged for 4 min at 2415 x g. Plasma  
142 was extracted and stored at -20°C for insulin analysis.

143

144 Blood glucose concentration was determined spectrophotometrically using the glucose  
145 oxidase method (GOD-PAP, Randox, Ireland). Plasma insulin was measured using an  
146 enzyme-linked immunosorbent assay (ELISA, Mercodia, Sweden). Total 2-h area under the  
147 curve (TAUC) for blood glucose and plasma insulin was calculated using the trapezium rule  
148 (Wolever and Jenkins, 1986). Homeostasis model assessment-insulin resistance (HOMA-IR)  
149 was calculated (Mathews *et al.*, 1985). The intra-assay coefficient of variation was 2.4% for  
150 blood glucose and 6.3% for plasma insulin.

151

**152 Expired air and indirect calorimetry**

153 Expired air was sampled continuously during exercise tests and for 10 min periods for resting  
154 measurements. Breath-by-breath data were displayed online using a portable metabolic cart  
155 (K4 b<sup>2</sup>, Cosmed, Rome, Italy) and interpolated into 1 sec intervals for subsequent analyses.  
156 Calibration procedures were carried out prior to each experimental test, as described  
157 previously (Zakrzewski and Tolfrey, 2011). Fat oxidation rates were calculated using  
158 stoichiometric equations, with the assumption that the urinary nitrogen excretion rate was



159 negligible and a physiological steady-state had been attained (Frayn, 1983). The total area  
160 under the fat oxidation versus time curve (TAUC) for the 120 min rest period was calculated  
161 using the trapezium rule and included in subsequent analyses.

162

### 163 **Perceived hunger**

164 Perceptions of hunger, satisfaction, fullness, prospective food consumption and breakfast  
165 palatability were assessed using 100 mm visual analogue scales.

166

### 167 **Statistical analyses**

168 Statistical analyses were completed using SPSS (v16 SPSS Inc, Chicago, IL, USA). The  
169 insulin data were transformed using a natural logarithm ( $\ln$ insulin) to normalise them and  
170 homogenize the variances between the groups. Breakfast by time (2 x 7) repeated measures  
171 ANOVA were used to examine differences between HGI and LGI over time for glucose and  
172  $\ln$ insulin; these were conducted separately for OW and NO girls. Breakfast by group (2 x 2)  
173 mixed measures ANOVA with breakfast as the repeated factor were used to compare the two  
174 groups directly for glucose and  $\ln$ insulin TAUC. For resting and exercise fat oxidation,  
175 breakfast by group (2 x 2) mixed measures ANCOVA with estimated FFM as the covariate  
176 were used. Homogeneity of regression slopes was confirmed prior to each ANCOVA. Paired  
177 sample t-tests with Bonferroni correction were used to compare glucose and  $\ln$ insulin  
178 concentrations at different time points and to follow-up significant two-way interactions.  
179 Values are expressed as mean(SD), unless stated otherwise, and effect sizes (ES) were  
180 calculated. Statistical significance was accepted at  $P \leq 0.05$ .

181

## 182 **Results**

### 183 **Subject characteristics**

184 Complete data for 8 OW and 12 NO girls were available for analyses. Body fat, BMI, body  
185 mass, fat free mass, waist circumference and hip circumference were higher in OW compared  
186 with NO girls ( $P \leq 0.05$ ), whereas  $\dot{V}O_{2\text{ peak}}$  ( $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) was higher in NO girls ( $P \leq 0.0005$ )  
187 (Table 2).

188

### 189 **Blood glucose concentration**

190 Following breakfast, blood glucose concentrations increased and peaked at a median  
191 (interquartile range) time of 30(0) min for all trials, except in the OW HGI trial where it  
192 peaked at 45 min in 4 girls (median 37.5(15) min) (Figure 1). Breakfast by time interactions  
193 were found for OW ( $P \leq 0.001$ ) and NO ( $P = 0.001$ ); concentrations were higher in HGI  
194 compared with LGI at 45 ( $P = 0.004$ ) and 60 ( $P \leq 0.001$ ) min in OW girls and at 90 ( $P = 0.006$ )  
195 and 120 ( $P = 0.001$ ) min in NO girls.

196

197 There were no differences in fasting or postprandial glucose between OW and NO girls at any  
198 time points ( $P > 0.05$ ). However, breakfast by group interactions for peak blood glucose  
199 ( $P = 0.053$ , ES: 0.44) and TAUC ( $P = 0.026$ , ES: 0.50) were found. Peak blood glucose was  
200 higher for HGI compared with LGI in OW ( $6.1$  vs.  $5.5$   $\text{mmol} \cdot \text{L}^{-1}$ ;  $P = 0.023$ , ES: 0.74), but  
201 similar between breakfasts in NO ( $5.8$  vs.  $5.9$   $\text{mmol} \cdot \text{L}^{-1}$ ;  $P = 0.741$ ). There were no between  
202 group differences in peak blood glucose after the HGI ( $P = 0.404$ ) or LGI ( $P = 0.122$ ) breakfasts.  
203 Blood glucose TAUC was 13% higher in HGI compared with LGI in OW ( $P = 0.006$ , ES: 0.82)  
204 but only 4% higher in NO ( $P = 0.072$ , ES: 0.51). Moreover, HGI TAUC was 9% higher in OW  
205 compared with NO ( $P = 0.070$ , ES: 0.41), but LGI TAUC was similar between the groups

206 (P=0.831, ES: 0.05). Similarly, the pattern of blood glucose over time differed between the  
207 OW and NO girls for HGI (P=0.047, ES: 0.24), but not LGI (P=0.119).

208

### 209 **Plasma insulin concentration**

210 Following breakfast, plasma lninsulin concentration increased and peaked at a median  
211 (interquartile range) time of 30(15) and 30(0) min for HGI and LGI in NO and 30(15) min in  
212 the OW LGI trial, but 45(15) min in the OW HGI trial (Figure 2). Breakfast by time  
213 interactions were found for OW (P=0.012) and NO (P≤0.005); however, pairwise  
214 comparisons only revealed a single significant difference in NO girls at 120 min (P=0.001).  
215 Furthermore, neither the main effect for breakfast nor the breakfast by group interaction for  
216 lninsulin TAUC were significant (P>0.05).

217

218 Although a strong statistical trend in fasting lninsulin between the OW and NO girls was  
219 found (P=0.054, ES: 0.45), pairwise analyses were not significant (P>0.025). Peak lninsulin  
220 (P=0.016) and TAUC (P=0.001) were higher in OW than NO. Whilst Bonferroni follow-up  
221 indicated that peak lninsulin was only significantly different following the HGI breakfast  
222 (P≤0.025), it was clear that both breakfasts led to significant differences in TAUC (P≤0.025)  
223 between OW and NO. HOMA-IR was higher in OW compared with NO (3.2 vs. 2.9,  
224 P=0.054).

225

### 226 **Fat oxidation**

227 The resting and exercise fat oxidation results by group and breakfast are in Table 3. During  
228 both postprandial rest and subsequent exercise, absolute and ANCOVA FFM adjusted fat  
229 oxidation were not different between HGI and LGI breakfast conditions in either group of  
230 girls (P>0.05).

231

232 During the postprandial rest period, absolute fat oxidation was higher in the OW compared  
233 with NO girls in HGI ( $P=0.004$ , ES: 0.61) and LGI ( $P=0.005$ , ES: 0.60). However, once  
234 between group differences in FFM were accounted for, resting fat oxidation was similar in the  
235 two groups of girls ( $P>0.05$ ). During subsequent exercise, absolute and ANCOVA FFM  
236 adjusted total fat oxidation were not different when comparing the OW and NO girls for the  
237 HGI and LGI conditions ( $P>0.05$ ).

238

### 239 **Hunger**

240 Perceptions of hunger, satisfaction, fullness, prospective food consumption and breakfast  
241 palatability were similar between trials ( $P>0.05$ ).

242

**243 Discussion**

244 The main finding of the present study was that the higher glycemic response in HGI compared  
245 with LGI was more pronounced in OW than NO girls, possibly reflecting a reduced ability to  
246 cope with the metabolic demands of a HGI breakfast in OW girls. Breakfast GI did not affect  
247 fat oxidation during the 120 min postprandial rest period or subsequent moderate intensity  
248 exercise in OW and NO adolescent girls.

249

250 A novel finding was that the higher glycemic response in HGI compared with LGI was  
251 exaggerated in the OW girls, mainly due to the delayed decline in blood glucose following the  
252 postprandial peak. This may indicate a delayed blood glucose uptake up to 60 min following  
253 HGI breakfast consumption in OW girls. Previous work has reported higher glycemic  
254 responses to HGI compared with LGI breakfasts in obese adolescents, but these studies did  
255 not include non-overweight participants for direct comparison (Ball *et al.*, 2003; Ludwig *et*  
256 *al.*, 1999). Furthermore, higher and more sustained postprandial glucose responses have been  
257 reported in obese compared with non-obese children (Sinha *et al.*, 2002). However, we were  
258 unable to locate another study that has investigated whether these differences between OW  
259 and NO young people are dependent on the GI of the consumed carbohydrate. Perälä *et al.*  
260 (2011) recently reported that the higher glycemic response to a HGI compared with LGI meal  
261 was similar in OW and NO 62 to 72 year olds. However, the meals only contained 50 g CHO  
262 and were not scaled to body mass. It is, therefore, difficult to compare our findings directly  
263 with those of Perälä *et al.* (2011) due to differences in study design and participants.

264

265 It is possible that the combination of readily absorbed glucose from the HGI (but not LGI)  
266 breakfast and higher insulin resistance (HOMA-IR) in the OW girls contributed to the larger  
267 glycemic response in the OW HGI trial. Furthermore, plasma insulin peaked earlier and

268 returned towards baseline values for LGI, but remained elevated for HGI in the OW girls. The  
269 earlier peak in plasma insulin may have contributed to the more rapid decline in blood glucose  
270 in LGI, as suggested previously in adults (Schenk *et al.*, 2003).

271

272 Collectively, these findings indicate that LGI breakfasts may be beneficial for blood glucose  
273 control in OW girls. Furthermore, the elevated glyceemic response in the OW HGI trial may  
274 also increase voluntary food intake later in the day (Ludwig *et al.*, 1999). Encouragingly,  
275 adults with higher postprandial glyceemic responses have a greater postprandial reduction  
276 when changing from HGI to LGI foods (Høstmark, 2007) and lowering breakfast GI for 21  
277 days reduced fasting glucose and satiety in obese adults (Pal *et al.*, 2008). Moreover, the  
278 similar palatability between breakfasts in our study indicates LGI breakfast promotion for  
279 OW girls may be feasible. As the higher fibre content in the LGI breakfast may have  
280 contributed to the lower glyceemic response to this breakfast (Pi-Sunyer, 2002), it may be  
281 more appropriate to recommend LGI high-fibre breakfasts (rather than LGI breakfasts) for  
282 OW girls. This is feasible since LGI foods typically contain more fibre than HGI foods.  
283 Nevertheless, confirmation of these results in larger groups of young people, including boys,  
284 is required.

285

286 Breakfast GI did not affect postprandial fat oxidation during rest or exercise in either group of  
287 girls. However, it is noteworthy that LGI resulted in 12% higher exercise fat oxidation  
288 (ANCOVA adjusted for FFM) in both groups on average, a finding that may have meaningful  
289 health-related implications since higher rates of fat oxidation may ameliorate the development  
290 of obesity and type 2 diabetes (Holloway *et al.*, 2009). During exercise, studies in adults have  
291 reported higher fat oxidation following LGI breakfasts (Stevenson *et al.*, 2009; Wee *et al.*,  
292 2005), no effect of GI (Backhouse *et al.*, 2007; Stevenson *et al.*, 2005) or even higher fat

293 oxidation following a HGI breakfast (Moore *et al.*, 2010). During rest, most have reported no  
294 effect of breakfast GI on fat oxidation (Díaz *et al.*, 2005; Stevenson *et al.*, 2005; Wee *et al.*,  
295 2005), although higher fat oxidation following LGI breakfasts has been shown (Stevenson *et*  
296 *al.*, 2009). Discrepancies between studies may be due to differences in breakfast size or  
297 composition, exercise mode, intensity and duration, postprandial time period and subject  
298 characteristics. However, higher exercise fat oxidation following LGI breakfasts has been  
299 reported 45 min to 3 h (Sparks *et al.*, 1998; Stevenson *et al.*, 2009) following breakfasts  
300 containing 1 to 2.5 g CHO·kg BM<sup>-1</sup> during exercise lasting 60 or 30 min at 50-71%  $\dot{V}O_{2\text{peak}}$   
301 (Stevenson *et al.*, 2009; Wee *et al.*, 2005). It is, therefore, difficult to ascertain which factors  
302 contribute specifically to the higher fat oxidation following LGI breakfasts in some adult  
303 studies. It is possible that the 1.5 g CHO·kg BM<sup>-1</sup> breakfast, 120 min postprandial period and  
304 30 min exercise duration at 50%  $\dot{V}O_{2\text{peak}}$  used in the present study was a sub-optimal  
305 combination to induce differences in fat oxidation between HGI and LGI. Furthermore,  
306 differences in fat metabolism between adolescents and adults (Riddell *et al.*, 2008) may have  
307 resulted in discrepancies between our study and some of the adult literature. Therefore, further  
308 examination of the relationship between breakfast GI and fat oxidation in young people is  
309 warranted.

310

311 The similar insulin response between HGI and LGI in our study may have underpinned the  
312 similarity in fat oxidation (Horowitz *et al.*, 1997). Furthermore, fructose has a lower GI than  
313 glucose, but results in higher blood lactate concentrations (Moore *et al.*, 2000). It is possible  
314 that higher lactate concentrations compromised fat oxidation following the LGI breakfast  
315 through direct inhibition of adipose tissue free fatty acid release (Boyd *et al.*, 1974). Indeed,  
316 resting fat oxidation was lower after high fructose compared with high glucose meals in obese  
317 adults, despite lower glycemic and insulinemic responses to the high fructose meal (Tittelbach

318 *et al.*, 2000). Although we did not measure blood lactate, higher postprandial lactate  
319 concentrations have been reported following LGI compared with HGI breakfasts (Stevenson  
320 *et al.*, 2006). In addition, blood lactate can affect the validity of indirect calorimetry for fat  
321 oxidation estimations (Rowlands, 2005). However, it is unlikely that this was a factor in the  
322 present study since the girls exercised at a moderate intensity (50%  $\dot{V}O_{2\text{peak}}$ ) and additional  
323 steps were taken to increase the validity of indirect calorimetry (e.g. removing individual  $\dot{V}O_2$   
324 and  $\dot{V}CO_2$  values  $\geq 3$  SD's from the mean and verifying a steady state in  $\dot{V}O_2$  and  $\dot{V}CO_2$ ).

325

326 Although we found no difference in perceptions of hunger between breakfasts, the 120 min  
327 postprandial period may have been too short for differences to emerge (Anderson and  
328 Woodend, 2003; Stevenson *et al.*, 2009). Furthermore, prolongation of satiety based on time  
329 to request food was found  $>3$  h following LGI compared with HGI foods in obese  
330 adolescents, despite no difference using hunger scales (Ball *et al.*, 2003).

331

332 In summary, the higher glycaemic response in HGI compared with LGI was more pronounced  
333 in OW girls, suggesting a reduced ability to cope with the metabolic demands of a HGI  
334 breakfast in this population. This provides further evidence for potential health benefits of  
335 LGI foods and suggests LGI breakfast promotion for OW girls is warranted. Breakfast GI did  
336 not affect fat oxidation during rest or exercise in OW and NO adolescent girls, although  
337 further examination of this relationship young people is required.

338



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344

345 **Conflict of interest**

346 The authors declare no conflict of interest.

347

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- 469

470 **Figure legends**

471 **Figure 1** Blood glucose concentration response to the HGI and LGI breakfasts for the  
472 overweight (OW; figure 1a) and non-overweight (NO; figure 1b) girls.  
473 Breakfast was consumed between 0 and 15 min. Breakfast x time interactions  
474 were significant for OW ( $P \leq 0.001$ ) and NO ( $P = 0.001$ ) girls.

475 <sup>a</sup> significant difference between HGI and LGI (Bonferroni correction;  
476 significance was  $P \leq 0.025$ ).

477 **Figure 2** Plasma insulin concentration response to the HGI and LGI breakfasts for the  
478 overweight (OW) and non-overweight (NO) girls. Breakfast was consumed  
479 between 0 and 15 min. Breakfast x time interactions were significant for OW  
480 ( $P = 0.012$ ) and NO ( $P \leq 0.005$ ) girls.

481 <sup>a</sup> significant difference between HGI and LGI in NO girls (Bonferroni  
482 correction; significance was  $P \leq 0.025$ ).

483

484

485 **Table 1** Composition of test breakfasts for a 45 kg girl

Breakfasts	Description	Macronutrient content
HGI	45 g Cornflakes <sup>a</sup> + 135 g skimmed milk, 44 g white bread, 4 g jam, 5 g margarine <sup>a</sup> , 124 g water (total weight = 356 g)	1498 kJ energy, 68 g CHO, 4.2 g fat, 11.6 g protein, 2.7 g fibre GI = 73 <sup>b</sup>
LGI	41 g muesli <sup>a</sup> + 90 g skimmed milk, 107 g apple, 169 g apple juice, 87 g yoghurt (total weight = 493 g <sup>c</sup> )	1498 kJ energy, 67 g CHO, 4.3 g fat, 11.7 g protein, 5.3 g fibre GI = 44 <sup>b</sup>

486 CHO - carbohydrate

487 <sup>a</sup> Cornflakes, Kellogg's; Flora original margarine spread, Unilever; Alpen no added sugar,  
488 Weetabix Ltd.489 <sup>b</sup> Calculated according to Wolever and Jenkins (1986) with GI values taken from Atkinson et  
490 al. (2008).491 <sup>c</sup> Total weight of LGI breakfast higher than HGI breakfast ( $P \leq 0.005$ ).

492



493 **Table 2** Subject characteristics

	OW <i>n</i> =8	NO <i>n</i> =12
Age (y)	12.6(0.5)	13.1(0.4)
Body mass (kg) <sup>a</sup>	70.9(19.4)	45.5(8.4)
Stature (m)	1.61(0.08)	1.56(0.09)
Body mass index (kg·m <sup>-2</sup> ) <sup>a</sup>	27.0(5.8)	18.5(2.0)
Body fat (%) <sup>a</sup>	35.7(6.0)	19.2(3.9)
Fat free mass (kg) <sup>a</sup>	45(9)	37(6)
Waist circumference (cm) <sup>a</sup>	84.6(13.5)	63.0(4.7)
Hip circumference (cm) <sup>a</sup>	99.5(12.3)	82.1(8.2)
Tanner Stage (pubic hair) <sup>b</sup>	3(1)	3(1)
Treadmill $\dot{V}O_{2\text{ peak}}$ (mL·kg <sup>-1</sup> ·min <sup>-1</sup> ) <sup>a</sup>	32(7)	45(6)

494 Tanner stage is an estimation of secondary sexual characteristics (Tanner, 1962).

495  $\dot{V}O_{2\text{ peak}}$  – peak oxygen uptake.

496 <sup>a</sup> significantly different between OW and NO.

497 <sup>b</sup> median (interquartile range).

498

499

**Table 3** Resting and exercise fat oxidation (area under curve over time): comparisons between breakfasts and groups

Group	Breakfast	Rest (g·120 min <sup>-1</sup> )		Exercise (g·30 min <sup>-1</sup> )	
		Absolute	FFM <sup>1</sup>	Absolute	FFM <sup>1</sup>
OW	HGI	0.25(0.10) <sup>a</sup>	0.20(0.05)	5.05(1.53)	4.49(1.71)
	LGI	0.26(0.13) <sup>b</sup>	0.18(0.07)	6.03(3.49)	5.08(2.38)
NO	HGI	0.15(0.04)	0.16(0.09)	4.76(1.83)	5.14(1.66)
	LGI	0.13(0.05)	0.14(0.07)	5.23(1.63)	5.86(2.31)

All values are mean(SD)

OW – overweight girls; NO – non-overweight girls; HGI – high glycemic index; LGI – low glycemic index

<sup>1</sup>ANCOVA adjusted values with FFM (fat free mass) as the covariate

<sup>a</sup>Significantly higher in OW compared with NO girls after consuming the HGI breakfast (P=0.004)

<sup>b</sup>Significantly higher in OW compared with NO girls after consuming the LGI breakfast (P=0.005)





