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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_e 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

Subjects and Methods

Subjects

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

Preliminary measurements

Subjects completed two preliminary tests on a treadmill (RunRace, TechnoGym, Gambettola, Italy) to determine 1) the relation between running speed and oxygen uptake ($\dot{V}O_2$) and 2) peak oxygen uptake ($\dot{V}O_{2\text{ peak}}$). The speed eliciting 50% of each subject's $\dot{V}O_{2\text{ peak}}$ was 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⁻¹ (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 µl aliquots of whole blood were deproteinised in 250 µl 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 b², 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

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

Perceived hunger

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

Statistical analyses

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

Results

Subject characteristics

Complete data for 8 OW and 12 NO girls were available for analyses. Body fat, BMI, body mass, fat free mass, waist circumference and hip circumference were higher in OW compared 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 ($P \leq 0.0005$) (Table 2).

Blood glucose concentration

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

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

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

Plasma insulin concentration

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

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

Fat oxidation

The resting and exercise fat oxidation results by group and breakfast are in Table 3. During both postprandial rest and subsequent exercise, absolute and ANCOVA FFM adjusted fat oxidation were not different between HGI and LGI breakfast conditions in either group of 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

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

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

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

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

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

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

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

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

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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 ^a 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 ^a 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 ^a + 135 g skimmed milk, 44 g white bread, 4 g jam, 5 g margarine ^a , 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 ^b
LGI	41 g muesli ^a + 90 g skimmed milk, 107 g apple, 169 g apple juice, 87 g yoghurt (total weight = 493 g ^c)	1498 kJ energy, 67 g CHO, 4.3 g fat, 11.7 g protein, 5.3 g fibre GI = 44 ^b

486 CHO - carbohydrate

487 ^a Cornflakes, Kellogg's; Flora original margarine spread, Unilever; Alpen no added sugar,
488 Weetabix Ltd.

489 ^b Calculated according to Wolever and Jenkins (1986) with GI values taken from Atkinson et
490 al. (2008).

491 ^c 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) ^a	70.9(19.4)	45.5(8.4)
Stature (m)	1.61(0.08)	1.56(0.09)
Body mass index (kg·m ⁻²) ^a	27.0(5.8)	18.5(2.0)
Body fat (%) ^a	35.7(6.0)	19.2(3.9)
Fat free mass (kg) ^a	45(9)	37(6)
Waist circumference (cm) ^a	84.6(13.5)	63.0(4.7)
Hip circumference (cm) ^a	99.5(12.3)	82.1(8.2)
Tanner Stage (pubic hair) ^b	3(1)	3(1)
Treadmill $\dot{V}O_{2\text{ peak}}$ (mL·kg ⁻¹ ·min ⁻¹) ^a	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 ^a significantly different between OW and NO.

497 ^b 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 ($\text{g} \cdot 120 \text{ min}^{-1}$)		Exercise ($\text{g} \cdot 30 \text{ min}^{-1}$)	
		Absolute	FFM ¹	Absolute	FFM ¹
OW	HGI	0.25(0.10) ^a	0.20(0.05)	5.05(1.53)	4.49(1.71)
	LGI	0.26(0.13) ^b	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

¹ANCOVA adjusted values with FFM (fat free mass) as the covariate

^aSignificantly higher in OW compared with NO girls after consuming the HGI breakfast (P=0.004)

^bSignificantly higher in OW compared with NO girls after consuming the LGI breakfast (P=0.005)





