Breakfast glycemic index affects subsequent daily energy intake in free-living healthy children

Anette E Buyken, Karin Trauner, Anke LB Günther, Anja Kroke, and Thomas Remer

ABSTRACT

Background: Experimental studies have reported that the effect of a meal’s glycemic index (GI) on subsequent energy intake depends on the timing of the subsequent meal.

Objective: We examined whether the timing of the next meal after breakfast modifies the effect of the breakfast GI (GIbr) on subsequent daytime energy intake of healthy free-living children.

Design: Analyses included 381 participants of the DOrtmund Nutritional and Anthropometrical Longitudinally Designed (DONALD) Study who had provided weighed dietary records at ages 2, 4–5, and 7 y.

Results: At all ages, among children who consumed their next meal in the early postprandial phase (after 3–4 h), children with a lower GIbr consumed more calories throughout the remainder of the day than did children with a higher GIbr, independent of major dietary confounders. For the age groups 2, 4–5, and 7 y, energy intakes in tertiles 1 and 3 were 785 kcal (95% CI: 743–830 kcal) and 717 kcal (900–1000 kcal), P for trend = 0.2; 993 kcal (941–1047 kcal) and 949 kcal (900–1000 kcal), P for trend = 0.05; 1255 (1171–1344) and 1166 (1090–1247 kcal), P for trend = 0.03, respectively. Conversely, among children consuming their next meal in the late postprandial phase (>3–4 h), subsequent daytime energy intake was not associated with GIbr.

Conclusion: This study confirms differential early and late postprandial effects of the GIbr on subsequent daytime energy intake for free-living children at different ages. Interestingly, the apparent short-term satiating effect of a higher GIbr, in particular, persisted throughout the day, if a second breakfast was consumed midmorning.

KEY WORDS Glycemic index, glycemic load, children, satiety, energy intake, breakfast

INTRODUCTION

The regular consumption of carbohydrates that elicits higher relative postprandial blood glucose and insulin concentrations, ie, high–glycemic index (GI) foods, was proposed to contribute to the development of overweight, impaired insulin sensitivity, and other components of the metabolic syndrome (1, 2). This notion builds on the assumption that the downstream effects of early postprandial peaks in insulin and glucose concentrations persist into the middle postprandial phase, ie 2–4 h after nutrient absorption has declined, subsequently provoking reactive hypoglycemia in the late postprandial phase, which may in turn induce hunger and higher voluntary energy intakes (2).

For adolescents, 3 experimental studies lend support to this hypothesis, reporting remarkably higher subsequent voluntary energy intakes or shorter periods of satiety after the consumption of high-GI meals when compared with isocaloric low-GI meals (3–5). However, the satiating effects of lower GI foods may require >3 h to emerge (6). In fact, studies in healthy adults assessing the impact of the dietary GI on voluntary energy intake in the early postprandial phase suggest that high-GI foods may suppress short-term voluntary energy intake more effectively than do low-GI foods (7–11). Such opposing effects of a high-GI meal in the early and late postprandial phase can potentially be ascribed to a satiating effect of blood glucose spikes in the early postprandial phase (6), which ceases once glycemia drops to concentrations below baseline in the later postprandial phase (2). However, it remains to be clarified whether such opposing early and late postprandial effects of a high-GI meal on subsequent energy intake can also be observed in healthy children under “real life conditions” and, if so, whether such influences extend to the entire subsequent daily energy intake. These insights would also be of interest for early childhood and the time of the adiposity rebound, because these periods are proposed as being critical for the development of later overweight (12, 13).

Detailed dietary assessment conducted as part of the DOrtmund Nutritional and Anthropometrical Longitudinally Designed (DONALD) Study allowed us to determine the dietary GI and the carbohydrate content of meals, as well as the time between meals. From these repeatedly assessed data we first analyzed the association between the dietary GI at breakfast and the timing of the subsequent meal and second examined whether the timing of the next meal after breakfast modifies the effect of the breakfast GI (GIbr) on the subsequent daytime energy intake of 381 healthy free-living children at ages 2, 4–5, and 7 y.

SUBJECTS AND METHODS

DONALD Study

The DONALD Study is a longitudinal (open cohort) study collecting detailed data on diet, growth, development, and physical activity (12, 13).

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metabolism between infancy and adulthood. Details on the subject selection procedure and the study protocol are described elsewhere (14). Briefly, the study was initiated in 1985 with children and adolescents of different ages participating in ongoing anthropometric studies at the Research Institute of Child Nutrition in Dortmund, Germany. Since then, each year ≈40–50 healthy infants were recruited from the city of Dortmund and surrounding communities by personal contacts, maternity wards, or pediatric practices. The study, which is exclusively observational and noninvasive until age 18 y, was approved by the Ethics Committee of the University of Bonn, and all examinations were performed with parental consent.

Annual visits include a medical examination, anthropometric measurements, and the completion of a weighed 3-d dietary record. Standing height was measured to the nearest 0.1 cm with the use of a digital stadiometer. Weight was measured to the nearest 0.1 kg with the use of an electronic scale. Skinfold thickness measurements were taken on the right side of the body at the biceps, triceps, subscapular, and suprailliac sites to the nearest 0.1 mm with the use of a Holtain caliper (Holtain Ltd, Crymych, United Kingdom). Parents were interviewed, and their anthropometric measurements were obtained by the study nurses on their child’s admission to the study.

Nutrition assessment

Food consumption in the DONALD Study was assessed with the use of weighed 3-d dietary records as described previously (15). Parents of the children weighed and recorded all foods and beverages consumed, as well as leftovers, with the use of electronic food scales (±1 g) on 3 consecutive days. Recipes for meals prepared at home were recorded. The packaging of commercial food products was kept. Semiquantitative recording (eg, number of spoons, scoops) was allowed if weighing was not possible. At the end of the 3-d record period, a dietitian visited the family and checked the record for completeness and accuracy.

Energy and nutrient intakes were calculated with the use of the in-house nutrient database LEBTAB (16), which is continuously updated to include all recorded food items. LEBTAB is based on the German standard food tables (17) with complementary data from other national food tables (18–20) and data obtained from commercial food products. Because the labels of commercial products do not usually provide information on all the nutrients included in LEBTAB, the composition of these products was simulated. This simulation procedure included all ingredients declared on the label. The respective amount of each ingredient was then estimated to match the simulated nutrient data with the available declared nutrient data (16). From this simulation, data for all nutrients in LEBTAB could then be calculated. For all complex foods not included in the food tables, food composition was calculated with the use of the recipes provided by the study participants or with local recipes.

Glycemic index and glycemic load

Dietary GI is defined as the incremental area under the glucose response curve after the intake of 50 g carbohydrate from a test food compared with the area under the glucose curve induced by the same amount of carbohydrates from ingested glucose (21). The glycemic load (GL) has been proposed as an indicator of the absolute glucose response induced by a serving of a food (22) and corresponds to the amount of each carbohydrate multiplied by its respective GI.

For the present analysis each carbohydrate-containing food recorded in the dietary record was assigned a dietary GI according to a standardized procedure (23). In brief, foods were either assigned 1) a published GI (24–26) or 2) the GI of a close match, or 3) the GI was calculated from the GI values of the food’s ingredients with the recipes available from the in-house database. The carbohydrate content of the food was the principal consideration when matching a particular food with one listed in the tables. Foods providing mainly fat or protein with a carbohydrate content <5 g/100 g were assigned a GI of 0 (eg, cold meats). The mean GI and GL of each subject’s breakfast (GIbr and GLbr) was determined by multiplying the carbohydrate content (in g) of each food consumed by the food’s GI and dividing the sum of these products (which corresponds to the GLbr) by the total carbohydrates consumed at breakfast.

Study population

In the DONALD population a total of 395 children had provided 3-d dietary records at each of the following ages: 2, 4–5, and 7 y. To be eligible for the present analysis, children had to have at least 1 recording day, fulfilling the following criteria: 1) an 8-h overnight fasting period before breakfast (ie, only dietary records kept on the second and third day were eligible because information on fasting during the preceding night was not available for the first recording day), and 2) a minimum carbohydrate intake of 3, 4, or 5 g at breakfast at ages 2, 4–5, and 7 y, respectively, corresponding to ≈1% of total recommended energy at the respective age.

Meals that were consumed <30 min apart were considered as 1 meal. Overall, 381 children had at least one 1-d record, meeting these criteria at each of the following ages: 2, 4–5, and 7 y (number of eligible records: 721, 1451, and 748, respectively). Among these, one 1-d record was randomly selected for each child at each age.

Statistical analysis

Values of GIbr and GLbr were energy-adjusted with the use of the residual method (27) and then grouped into tertiles. Differences in general characteristics, nutritional intake, or carbohydrate intake from food groups between tertiles were analyzed with the Kruskal-Wallis tests for continuous data and the chi-square tests for categorical data. All data were presented separately for ages 2, 4–5, and 7 y because the relations of carbohydrate (percent of energy), fat (percent of energy), protein (percent of energy), and fiber (g/1000 kcal) intakes with tertiles of GIbr were found to differ between the age groups (P < 0.0001 to P = 0.0004, test for interaction in a full model).

Separate sets of multiple regression models were run to examine the association of the energy-adjusted residuals of GIbr or GLbr with both time to second meal and subsequent energy intake as outcome variables. Subsequent energy intakes (daily energy intake minus energy intake at breakfast) were log-transformed to improve homoscedasticity. Analyses, including energy-adjusted residuals of GLbr or GIbr as continuous variables, were performed to test for a continuous trend, whereas analyses with energy-adjusted tertiles of GIbr or GLbr yielded mean times to second meal and mean subsequent daily energy intakes for each tertile adjusted for potential confounders. The adjusted means were the values predicted by the model when the other variables were held at their mean value. Potential confounders considered in multiple
regression analyses were energy-adjusted residuals of carbohydrate, fiber, protein, fat, and sugar at breakfast, as well as the quantity of calorie beverages (milk, cocoa, fruit juices, and soft drinks) at breakfast. Initial analyses also considered non-dietary factors (sex, maternal overweight, maternal education, smoking in the household, current body mass index, body fat, and body weight), which did not, however, affect any estimate. All models for age 4–5 y included age as a covariate.

To test the assumption that the association between GIbr or GLbr and the subsequent energy intake may be modified by the time to second meal, we performed tests for interactions in non-adjusted models, categorizing time to the second meal as ≤1, 1–2, 2–3, 3–4, or >4 h. In case of a significant interaction, separate sets of linear regression models were run for each time category to distinguish time categories with a negative estimate from those with a positive estimate for GIbr or GLbr. Subsequently, multiple linear regression analyses stratified for the 2 resulting time strata (early compared with late consumption of a second meal) were performed with strata-specific energy-adjusted tertiles. Finally, a concluding test for interaction with age groups was conducted with the data from all age groups. In the full models testing for a 3-factor interaction (eg, age group × GIbr × time to second meal), all lower order 2-factor interactions and main effects were kept in the full model.

Because analyses indicated no interactions between sex and the relations of the GIbr or GLbr to time to the second meal or to subsequent energy intake, data from girls and boys were pooled for analyses. All statistical analyses were performed with the SAS program, version 8.2 (SAS Institute, Cary, NC). A P value < 0.05 was considered to indicate statistical significance.

### Power considerations

The data from 381 children were sufficient to detect a difference of 0.5 h in the time to second meal between the lowest and the highest tertiles of GIbr at the 0.05 level, with 80% power. For the effect on subsequent daytime energy intake we estimated the power for age 7 y as an example, assuming that two-thirds of the children will, as in a pilot analysis (28), report a second meal in the early postprandial phase. Should this assumption hold, the numbers of children consuming their meal either in the early postprandial phase (n = 250) or in the later postprandial phase (n = 130) would be sufficient to detect differences of 75 kcal and 105 kcal, respectively, in subsequent energy intake between the lowest and the highest tertiles of GIbr at the 0.05 level, with 80% power.

### RESULTS

The general characteristics (Table 1), nutritional intakes (Table 2), and carbohydrate intakes (Table 3) from different food groups of the 381 children at ages 2, 4–5, and 7 y are shown by the lowest and highest tertiles of energy-adjusted GIbr. For the general characteristics, few differences were observed between the tertiles (Table 1). When compared with their respective counterparts reporting the highest tertile of GIbr, at age 2 y children in tertile 1 had a slightly higher body mass index, at age 4–5 y frequency of maternal overweight was higher in children reporting the lowest tertile of GIbr, and at age 7 y smoking in the household was more frequent among children in tertile 1.

As expected, at all 3 ages, nutritional intakes of children reporting the highest tertiles of GIbr were characterized by a significantly higher GL (Table 2), resulting from both significantly higher GIbr values and higher carbohydrate intakes in children in tertile 3 than children in tertile 1. Furthermore, at all ages, a higher GIbr was associated with a higher relative intake of carbohydrates and sugar and a lower relative intake of fat and protein. At age 2 y, a lower GIbr reflected a high-fat, high-protein breakfast providing no fiber. By age 7 y, a lower GIbr reflected a breakfast with a relatively high-carbohydrate content accompanied by a higher fiber intake and a lower sugar intake. Overall, compared with age 2 y, GIbr values were higher at ages 4–5 and 7 y, with the difference between tertile 1 and tertile 3 becoming smaller.

At age 2, milk and dairy products constituted most of the carbohydrates consumed at breakfast by children reporting the lowest tertile of GIbr, whereas bread or rolls with sweet spread provided most of the carbohydrates among children reporting the highest tertile of GIbr (Table 3). By age 7 y, the difference in GIbr was mostly attributable to a difference in the consumption of milk and dairy products. Other foods such as fruit, fruit juices, or...
breakfast cereals made only minor or no contributions to carbohydrate intake at breakfast at all ages.

At all ages, lower values of GI<sub>br</sub> were independently associated with a shorter time to the second meal (P for continuous trends = 0.01–0.05, adjusted for intake of carbohydrate, protein, energy, and caloric beverages at breakfast) (Figure 1); however, the strength of this association differed between the age groups (P = 0.03 for interaction of age group × GI<sub>br</sub> tertiles in the full model). Further adjustment for intake of fibers, sugar, or fat at breakfast did not affect the results (data not shown).

In unadjusted models higher values of GI<sub>br</sub> were related to lower subsequent energy intake (P = 0.02, P = 0.01, and P = 0.06 at ages 2, 4–5, and 7 y, respectively). As hypothesized, at all ages, categories of time to second meal showed a significant interaction with GI<sub>br</sub> in its association with subsequent energy intake (P for interaction = 0.004, P < 0.0001, and P = 0.0001 at ages 2, 4–5, and 7 y, respectively). Time categories with a negative estimate for the association between GI<sub>br</sub> and subsequent energy intake were distinguished from those with a positive estimate, yielding 2 strata of consumption of the next meal in the early and late postprandial phase, ie, ≤4 h compared with >4 h at ages 2 and 4–5 y and ≤3 h compared with >3 h at age 7 y.

At all ages, among children consuming their next meal earlier (after 3 or 4 h), children reporting the lowest GI<sub>br</sub> tertile consumed more calories throughout the remainder of the day than did their counterparts in the higher GI<sub>br</sub> tertiles; however, the continuous trend was only significant at ages 4–5 and 7 y (Figure 2). Conversely, among children consuming their next meal >3 or 4 h after breakfast, subsequent daily energy intake was not associated with GI<sub>br</sub>, despite a nonsignificant suggestion of a higher energy intake among children in the highest GI<sub>br</sub> tertile at age 2 y. In the full model with data from all ages, the absence of a 3-factor interaction (P = 0.8 for age group × GI<sub>br</sub> tertiles × time to second meal strata) and the presence of a 2-factor interaction for GI<sub>br</sub> tertiles × time to second meal strata (P = 0.02) underpin that the time to second meal influences the association between GI<sub>br</sub> and subsequent energy intake in a similar way at all 3 ages. Our analysis adjusts for potential differences between the GI<sub>br</sub> tertiles in carbohydrate, fiber, energy, and caloric beverages at breakfast. Further adjustments for intake of protein, sugar, or fat at breakfast did not affect the results (data not shown).

When analyses were repeated with GI<sub>br</sub> in place of GI<sub>br</sub>, GI<sub>br</sub> was neither related to the time to the second meal (P = 0.3, P = 0.5, and P = 0.2 at ages 2, 4–5, and 7 y, respectively, adjusted for fat, energy, and caloric beverages at breakfast) nor to subsequent daytime energy intake (P = 1.0, P = 0.7, and P = 0.3, respectively, adjusted for fat, energy, and caloric beverages at breakfast). In addition, no interaction between GL<sub>br</sub> and time to next meal was observed (P = 0.9, P = 0.2, and P = 0.7 at ages 2, 4–5, and 7 y, respectively, unadjusted) in its association with subsequent daytime energy intake.

### Table 2

<table>
<thead>
<tr>
<th>Age</th>
<th>T1 (n = 127)</th>
<th>T3 (n = 127)</th>
<th>T1 (n = 127)</th>
<th>T3 (n = 127)</th>
<th>T1 (n = 127)</th>
<th>T3 (n = 127)</th>
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<tbody>
<tr>
<td>GI</td>
<td>30 (27–34)</td>
<td>56 (53–61)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>44 (35–47)</td>
<td>60 (58–63)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>47 (44–49)</td>
<td>62 (60–65)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>GL (g)</td>
<td>3.4 (2.6–5.3)</td>
<td>12.8 (8.6–16.7)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>10.7 (5.1–17.0)</td>
<td>18.9 (13.1–26.6)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>14.8 (10.0–22.2)</td>
<td>23.2 (16.2–30.3)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>11.8 (9.0–15.4)</td>
<td>22.1 (14.8–29.5)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>24.7 (15.1–37.2)</td>
<td>32.1 (21.2–43.6)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>32.2 (22.1–46.5)</td>
<td>35.6 (25.7–48.1)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Carbohydrate (% of energy)</td>
<td>31.1 (29.4–41.3)</td>
<td>55.3 (46.9–64.9)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>43.5 (36.7–51.5)</td>
<td>57.0 (48.0–67.0)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>48.2 (40.8–58.6)</td>
<td>58.9 (47.7–66.1)&lt;sup&gt;2&lt;/sup&gt;</td>
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</table>

<sup>1</sup> Values are medians; 25th–75th percentiles in parentheses. Tertiles of GI<sub>br</sub> were based on GI<sub>br</sub> values adjusted for energy consumed at breakfast with the use of the residual method (27).

<sup>2</sup> Significant difference between tertiles, P < 0.05 (Kruskal–Wallis test, including data from all 3 tertiles).

### Table 3

<table>
<thead>
<tr>
<th>Age</th>
<th>T1 (n = 127)</th>
<th>T3 (n = 127)</th>
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<th>T3 (n = 127)</th>
<th>T1 (n = 127)</th>
<th>T3 (n = 127)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk and dairy products (g)</td>
<td>10.0 (7.1–13.0)</td>
<td>2.2 (0.5–9.4)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>11.3 (7.6–15.9)</td>
<td>2.0 (0.5–9.4)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>10.4 (5.4–16.7)</td>
<td>3.8 (0–7.2)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Breakfast cereals (g)</td>
<td>0 (0–0)</td>
<td>0 (0–0)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0 (0–0)</td>
<td>0 (0–0)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0 (0–0)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0 (0–0)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bread and rolls (g)</td>
<td>0 (0–0)</td>
<td>8.9 (0–13.2)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>5.2 (0–13.0)</td>
<td>12.5 (0–22.0)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>9.6 (0–15.9)</td>
<td>11.7 (0–25.9)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fruit and fruit juices (g)</td>
<td>0 (0–0)</td>
<td>0 (0–3.3)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0 (0–3.6)</td>
<td>0 (0–3.9)</td>
<td>0 (0–7.7)</td>
<td>0 (0–9.0)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sugary foods (g)&lt;sup&gt;4&lt;/sup&gt;</td>
<td>0 (0–0)</td>
<td>2.5 (0–6.1)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0 (0–5.0)</td>
<td>4.9 (0–10.4)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0 (0–7.5)</td>
<td>0 (0–9.6)&lt;sup&gt;2&lt;/sup&gt;</td>
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<sup>1</sup> Values are medians; 25th–75th percentiles in parentheses. Tertiles of GI<sub>br</sub> were based on GI<sub>br</sub> values adjusted for energy consumed at breakfast with the use of the residual method (27).

<sup>2</sup> Significant difference between tertiles, P < 0.05 (Kruskal–Wallis test, including data from all 3 tertiles).

<sup>4</sup> Soft drinks, cakes, cookies, and sweet spreads.
This study also confirms differential early and late postprandial effects of the GIbr on subsequent daytime caloric intake for free-living children. Among free-living children who consumed a second meal at midmorning, a higher dietary GI at breakfast yielded significantly lower subsequent daily caloric intakes. Conversely, GIbr was not related to subsequent daytime energy intake among children who consumed a second meal in the late postprandial phase. These differential associations were consistently observed at ages 2, 4–5, and 7 y, despite different carbohydrate sources being responsible for a lower or higher GIbr, and were independent of major dietary factors known to influence satiety, ie, consumption of protein, fat, sugar, fiber, or caloric beverages at breakfast (31, 32).

Suppressed energy intakes 1–2 h after the consumption of high-GI carbohydrates were also reported by most (7–11) but not all (33, 34) short-term experimental studies in adults. Interestingly, in our study the potential short-term satiating effect of a high-GI meal appears to persist throughout the remainder of the day, an aspect not analyzed in the short-term experimental studies. Elevated blood glucose concentrations after consumption of a high-GI meal are generally accompanied by peaks in insulin concentrations (2), which could be involved in daytime satiety signaling (35). Appropriate insulin signaling is, in addition to peripheral and hypothalamic neuropeptides, required for effective anorectic action of the satiety signal leptin. Because high-GI meals may elicit both postprandial insulin peaks (36) and increases in leptin concentrations (37, 38), it could thus be speculated that it is the combination of these effects after the ingestion of a high-GI breakfast that results in a persistent reduction of energy intake throughout the remainder of the day, if a second meal is consumed midmorning. It remains to be further explained whether a habitual increase in insulin secretion on a morning-to-morning basis could contribute to the established involvement of insulin in the long-term regulation of energy balance (35).

The GI of a meal is only one characteristic of carbohydrates that influences satiety signaling. Carbohydrates also affect the stimulation of several hormones involved in food regulation (35). Our finding that subsequent energy intake was clearly related to GIbr (ie, the potential relative increase in glycemia) but not to GLbr (ie, the potential absolute increase in glycemia) is nonetheless in accordance with a review concluding that absolute glucose concentrations have no straightforward relation to appetite, whereas short-term dynamic changes in blood glucose concentration are strongly related to satiety (35), as originally proposed in the glucostatic theory (39).

In the present observational study, children who consumed their next meal in the later postprandial phase did not report higher energy intakes after a breakfast with a higher GI, as suggested by experimental studies in normal weight and obese adolescents (3, 4). This discrepancy may lie in the nature of our observational study in that the GI in the highest GI tertiles (GI ranging from 56 to 62, values considered a medium GI (24)) may not have been high enough for the described hunger-inducing drop in glycemia to values below baseline to occur. In addition, at least at age 2 y, the nonsignificance of the suggested direct association between GIbr and subsequent energy intake among children who consumed their next meal >4 h after breakfast may be due to lack of power in this group of children (n = 33).
FIGURE 2. Subsequent daily energy intake by tertile (T) of glycemic index (GI) at breakfast in 381 children at age 2 y, age 4–5 y, and age 7 y by strata of time to the second meal. Data are presented as mean and 95% CI, adjusted for energy, energy-adjusted residuals of carbohydrate and fiber, and consumption of caloric beverages (in g) at breakfast. Models at age 4–5 y also consider the age of the participants. $P$ for continuous trend refers to the $P$ values obtained in linear regression models with the GI at breakfast as a continuous variable.
Whether this effect exists, is, however, of little practical relevance, because only a few 2- to 6- y-old children appear to consume their next meal >4 h after breakfast. At age 7 y, we would have been sufficiently powered to detect a difference well below the 20–80% caloric difference suggested by experimental studies that compared subsequent voluntary energy intakes after the consumption of high-GI meals and isocaloric low-GI meals (3, 4). Alternatively, the experimental studies may have been confounded by concomitant differences in protein content between the low- and high-GI diets (3, 4) because protein is known to have notable satiating properties (31). In addition, the hunger-induced drop in glycemia several hours after consumption of a high-GI breakfast may, if present, have affected only the caloric intake at the subsequent meal and not the overall subsequent daytime energy intake.

In the present study, children who consumed a breakfast with a lower GI consumed their second meal earlier than children who consumed a breakfast with higher GI. Although this finding contradicts results reported from experimental studies in children and adolescents (3, 4), it is in accordance with the previously discussed short-term satiating properties of a high-GI meal, which were more relevant in this cohort, because most children consumed their second meal within 3–4 h after breakfast.

The main advantages of this observational study include its relatively large sample size with dietary data assessed at ages 2, 4–5, and 7 y with a prospective weighed 3- d dietary record, which allows the determination of the dietary GI of meals, as well as our ability to control for major nutritional factors known to influence satiety (31, 32). In addition, because the same children were analyzed at the 3 ages, potential bias otherwise introduced by differences in socioeconomic variables was controlled for. However, 2 limitations require specific attention when interpreting our findings. First, we had to calculate GI values from their ingredients for a large percentage of the carbohydrate-containing foods, a procedure which was controversially discussed (40–44). However, several investigative groups have shown that the GI of a whole diet or mixed meal can be accurately estimated from the GI value of the individual foods it contains (40, 42, 45). In the absence of GI values for all foods and meals recorded in observational studies, GI calculation thus appears the only valid and feasible approach for epidemiologic studies. Second, we were not able to adjust for physical activity. If a lower GI at breakfast would reflect a healthier lifestyle, a lack of adjustment for physical activity could have confounded our results in that children in the lowest GL tertile may have had higher energy intakes as a result of higher levels of physical activity.

Our findings may have implications for strategies to prevent overweight in children: among children consuming a second meal within 3 h after the first, a high GI of the first meal may, if present, have affected only the caloric intake at the subsequent meal. However, we should note that, although the GLs of the meals consumed by the children in the present study were confirmed by concomitant differences in protein content between the low- and high-GI diets (3, 4) because protein is known to have notable satiating properties (31). In addition, the hunger-induced drop in glycemia several hours after consumption of a high-GI breakfast may, if present, have affected only the caloric intake at the subsequent meal and not the overall subsequent daytime energy intake.

In the present study, children who consumed a breakfast with a lower GI consumed their second meal earlier than children who consumed a breakfast with higher GI. Although this finding contradicts results reported from experimental studies in children and adolescents (3, 4), it is in accordance with the previously discussed short-term satiating properties of a high-GI meal, which were more relevant in this cohort, because most children consumed their second meal within 3–4 h after breakfast.

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Our findings may have implications for strategies to prevent overweight in children: among children consuming a second meal within 3 h after the first, a high GI of the first meal may result in a lower subsequent daily energy intake. We can, however, not preclude adverse influences of a high-GI breakfast among persons who do not ingest a second breakfast or consume breakfasts with much higher GI values than in our study, which may be more frequently the case among adolescents (46). As a corollary, the differential effects of a meals’ GI on subsequent energy intake, depending on the timing of the subsequent meal, among healthy children may explain why strong associations between the dietary GI and body composition are rarely reported for children and adolescents (47–49). Clearly, our observational data in healthy children cannot be interpreted as a general argument against the usefulness of diets low in GI, GL, or both in the management of overweight in childhood or adolescence. Our data would at most suggest that children who habitually consume a second breakfast at midmorning are unlikely to benefit from a low-GI breakfast with respect to their satiety.

In conclusion, this study confirms differential early and late postprandial effects of the GI of on subsequent daytime energy intake for free-living children at different ages. Interestingly, the apparent short-term satiating effect of a higher GI meal, in particular, persisted throughout the day, if a second breakfast was consumed midmorning.

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REFERENCES


