Impact of energy density on liking for sweet beverages and caloric-adjustment conditioning in children

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ABSTRACT

Background: The contribution of sweet beverages to weight gain in children is controversial; the impact of these beverages on caloric adjustment needs clarification.

Objective: We studied the influence of energy-density (ED) conditioning on the liking for sweet beverages and caloric adjustment after their consumption in children.

Design: We used a within-subject design. Forty-four 8–11-yr-old children were exposed to the following 2 distinctly flavored, sweetened beverages: a high-energy (HE) version (150 kcal) and a no-energy (NE) version (0 kcal). During a 4-wk initial conditioning period, children were exposed either 2 or 7 times to each beverage. After a 3-wk stability period (without exposure), children were exposed 3 times to both beverages with a reversed association between the ED and flavor (4-wk reversed-conditioning period). Flavor liking and food intake during meals after the consumption of each beverage were assessed before and after each period.

Results: After the initial conditioning, the liking for both beverages increased ($P < 0.001$). After the stability period, the liking for the HE flavor was higher than for the NE flavor ($P = 0.024$). After the reversed conditioning, the liking for the flavor initially paired with the HE beverage tended to remain higher than for the NE flavor ($P = 0.089$). Initially, energy intakes during the meal did not differ after the consumption of NE or HE beverages. After the initial conditioning and up until the end of the reversed conditioning, energy intakes were lower after the HE beverage than after the NE beverage regardless of the beverage flavor (eg, after reversal; caloric compensation score: $29\%$). The number of exposures did not influence liking or energy intake.

Conclusion: After the association between a flavor and ED and reversal of this association, liking may be first guided by ED and then the flavor firstly associated with ED, whereas the partial caloric compensation may consistently be guided by ED. This trial was registered at clinicaltrials.gov as NCT02070185.


INTRODUCTION

A worldwide rise in sweet beverage consumption has been observed (1–4). The contribution of sugar-sweetened beverages to energy intake and weight gain in children and adolescents remains controversial (5–10), and the impact of nonnutritive sweeteners on these outcomes has not been fully characterized (11, 12). The energy density (ED) of a beverage is likely to induce learning of a novel flavor when the new flavor is paired repeatedly with nutrients (13, 14). This mechanism is generally named “flavor-nutrient learning” but was also referred as “flavor-nutrient hedonic learning” (15). When a new flavor is paired repeatedly with nutrients, humans also learn how filling the food bearing this flavor will be; this mechanism named “flavor-nutrient satiety learning” may lead to a better adjustment of energy intake from a liquid preload during a meal offered shortly after its consumption (16, 17). However, the caloric adjustment is generally partial and may be improved by repeated exposure to preloads (14, 18–22). Two studies used a conditioning and extinction paradigm by first offering twice one flavored-drink preload associated with a high ED and another flavored-drink preload with a low ED and exposed the children 2 times to the 2 preloads served in an isocaloric version (19, 22). During the extinction period, children initially ate more during the meal after the flavored preload that was previously associated with the low ED. However, after the second exposure to isocaloric preloads, no difference in meal intakes was observed between the 2 preloads, which suggested that the caloric adjustment may have been be adapted to the effective ED of the preload after 2 exposures. In adults, it has been shown that the liking for a new flavor increased after only 1 or 2 exposures (23, 24), whereas in children, the number of exposures ranged from 6 to 8 (13, 14, 20, 25). To our knowledge, the effect of a lower number of exposures on liking has never been tested in children.

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2 ER and CD contributed equally to this work.

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6 Abbreviations used: COMPX, caloric compensation; ED, energy density; HE, high energy; NE, no energy; T1, after the last exposure of the initial conditioning period; T2, after the stability period; T3, before (liking) and after (intake) the first exposure to the reversed energy density-flavor association; T4, after the third exposure to the reversed energy density-flavor association.

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The current study was conducted in school children to study the influence of ED conditioning on the liking for sweetened beverages and caloric adjustment after 2 or 7 exposures to the following 2 unfamiliar, flavored, sweetened beverages: a high-energy (HE) version (150 kcal) and a no-energy (NE) version (0 kcal). The stability of the initial conditioning effects was studied after a 3-wk without-exposure period and a 4-wk reversed conditioning period. This method mimics children’s alternative consumption of regular and diet soft drinks. If both types of learning occur, the following hypotheses can be stated: 1) caloric adjustment after the HE compared with NE beverages would be observed after the initial conditioning, 2) liking for the flavor associated with the HE beverage would be higher than for the NE beverage, and 3) more exposures to target beverages would strengthen the association between the beverage flavor and its ED and result in a better caloric adjustment and higher liking for the HE flavor. After the period without exposure, the caloric adjustment and liking were expected to remain stable. At the first exposure to the reversed ED-flavor association, the caloric adjustment was expected to decrease, but after learning of this reversed association, the caloric adjustment was expected to reincrease, and the liking for the flavor newly associated with the HE beverage was expected to increase.

**SUBJECTS AND METHODS**

**Overview: study design**

In the current study, we used a within-subject design divided into the following 3 periods: a 4-wk initial conditioning, a 3-wk stability period, and a 4-wk reversed conditioning period (Figure 1). During the initial conditioning period, 8–11-y-old children were alternatively exposed to an HE beverage and NE beverage. Each type of beverage was associated with a specific flavor. Both flavors were individually chosen to be initially neutrally liked by each child. Children were divided into 2 groups as follows: the 2-exposure group and 7-exposure group, wherein children were exposed 2 or 7 times to each beverage, respectively. The initial conditioning period was followed by a stability period of 3 wk, during which children were not exposed to the beverages. The reversed conditioning period consisted of switching the association between the flavor and ED of beverages. During this period, children were exposed 3 times to each beverage with this new ED-flavor association.

At baseline, after the initial conditioning period (T1), after the stability period (T2), before the reversed conditioning period (T3), and after the reversed conditioning period (T4), the liking for the flavor associated with each beverage (HE and NE flavors) was assessed. During these measurements, both flavors were presented in the NE version to evaluate the liking for the flavors independently of the ED and assess flavor-nutrient learning (15). Food intake was measured during meals after the consumption of the beverage at baseline, T1, T2, T3, and T4. Children were not informed that EDs of both beverages differed.

Participants

Participants were enrolled in 3 grade levels (third, fourth, and fifth grades) during the first semester of 2013 in the same private school located in Dijon, France. Eligible participants regularly ate at the school canteen and did not present with health problems, food restrictions, or food allergies. This study was conducted according to the guidelines established in the Declaration of Helsinki; the study protocol was approved by the local ethics committee (Comité de Protection de Personnes Est I Bourgogne, no. 2013/12). Written and informed consent was obtained from both parents, and oral assent was obtained from the child. At the end of the study, parents received a €10 voucher, and books were offered to the school.

The power calculation for intake data indicated that 17 subjects were necessary to show a difference in energy intake (±SD) of 60 ± 60 kcal with a power of 0.80 (13). For liking, the power calculation indicated that 23 subjects were necessary to show a difference in liking (±SD) of 21 ± 25 with a power of 0.80 (26). It was difficult to predict difference in outcomes for the 2 experimental groups, and thus, the aim was to constitute 2 groups of ~23 children. Consent was obtained for 45 children.

**Flavored beverages**

Twelve unfamiliar, sweetened, flavored beverages were developed. Beverages contained mineral water (Evian), a flavor (Meilleur du Chef), and 0.05% (vol:vol) sucralose (Sucrpharm; Codephyrama) composed of 7.5% sucralose in water for NE beverages (0 kcal/100 mL) or 15% (wt:vol) of sucrose (Carrefour Discount; Carrefour) for HE beverages (60 kcal/100 mL). The portion size was fixed at 250 mL, which resulted in an energy difference of 150 kcal between NE and HE beverages. Flavors (mango, cactus, cardamom, litchi, orange blossom, and violet) were pretested in 14 children from the same age range who did not participate in the main study to ensure that the flavors were colorless, neutrally and equally liked, and unfamiliar. Flavor...
concentrations ranged from 0.15% to 0.35% to obtain similar flavor intensities according to the manufacturer’s recommendations. A panel of 22 adults assessed the sweetness intensity of the 12 drinks. Results showed no impact of flavor on the sweet taste intensity. Triangular tests were conducted in children of a similar age who were not involved in the main study (n = 51). These children were not able to differentiate sucralose from sucrose in a flavored beverage (31 wrong answers; α = 22.7%; β25 = 4.6%).

Liking and preference measurements

These measurements took place in the children’s usual classrooms, approximately 1 h before lunchtime. Before the beginning of the study, experimenters met with children in school to train them in the liking and preference tasks by using pictures of common food items.

Children were presented with 6 plastic cups that contained 20 mL of each of the 6 flavored NE beverages. Beverages were presented according to a William’s Latin square design balanced for the order of presentation and first-order carryover effects. Children were instructed to taste each beverage and categorize it on a 5-point scale. Each point was illustrated by cartoon faces (27) and corresponded to the following different levels of liking: “I really do not like it” (1), “I do not like it” (2), “I cannot tell if I like it or not” (3), “I like it” (4), and “I really like it” (5).

After evaluating each beverage, children were asked to rank order them from 1 (least liked) to 6 (most liked), to obtain a preference rank for each beverage. Moreover, on the first test, children were asked to indicate if the beverage was familiar or not (yes or no).

Individual flavor choice

For each child, flavors ranked 3 and 4 in the preference task were selected to be paired with NE or HE beverages during the conditioning period. Additional verification attested that these individually chosen flavors were unfamiliar for each child. The 2 flavors were referred to as an HE flavor (flavor associated with the HE beverage) and NE flavor (flavor associated with the NE beverage). Children were assigned to the 2- or 7-exposure group. Compositions of groups were counterbalanced depending on the children’s assigned flavors, and each flavor was associated with as many HE as NE beverages.

Beverage exposures

The exposure sessions took place 4 times/wk for 8 wk in the children’s usual classrooms ~50 min before lunchtime. On a given day, children received 250 mL of their corresponding beverage (HE or NE) in a white plastic cup. The exposure to NE and HE beverages was always conducted on 2 successive days. Children in the 2-exposure group received their beverages on the first and last 2 d of the conditioning period; they received 250 mL mineral water (Evian) on all other days. At each exposure trial, experimenters carefully checked that children consumed their entire beverages.

Test meals

To measure caloric adjustment, 2 slightly different menus, which were supplied by the usual school canteen supplier (Compass Group), were served for the ad libitum meal after the consumption of HE or NE beverages. Menu 1 was composed of grated carrots with dressing (39 kcal/95 g; Servirest), turkey (191 kcal/80 g; Grupo Sada), plain pasta (179 kcal/125 g), green beans (26 kcal/80 g; Gelagri), processed cheese (41 kcal/17 g; Vache qui Rit), apple-strawberry purée (67 kcal/100 g; Faraud), and white bread (52 kcal/20 g) for a total caloric content of 615 kcal. Menu 2 was composed of red beetroot with dressing (68 kcal/100 g; Bonduelle), chicken (194 kcal/90 g; Grupo Sada), rice (169 kcal/125 g), zucchini (26 kcal/80 g; d’Arta), double-cream fresh cheese (66 kcal/21 g; Samos), apple-strawberry purée (67 kcal/100 g; Faraud), and white bread (52 kcal/20 g) for a total caloric content of 642 kcal. To ensure that children could eat ad libitum, amounts served were above the recommended portions for children of this age (28). In addition, extra helpings could be served when requested by the children. The ED of each food item was determined by using the Cijual table (29) or caloric composition from the manufacturers. The association between the composition of the meal (menus 1 and 2) and energy content of the beverage was counterbalanced. For any given child, the meal after the NE or HE beverage was identical throughout the experiment. Consumption data were obtained by individual prelunch and postlunch weighing of all foods served and all leftovers to the nearest gram by using electronic kitchen weighing scales (Soehnle). Weighing scales were out of the children’s sight. At each time, a caloric compensation (COMPX) score was calculated by dividing the difference in energy intake at the lunches after the NE and the HE beverage consumption by the energy from the preload (150 kcal) transformed to a percentage (30).

Other measurements

Hunger ratings

Just before lunch, an experimenter asked each child how hungry he or she felt by using an adapted version of a 5-point silhouette satiety scale (31) from “I am really hungry” (scored 1) to “I am not hungry at all” (scored 5).

Anthropometric measurements

Children were measured without shoes by trained experimenters. Height (cm) was measured to the nearest 0.5 cm by using a stadiometer (Leicester), and weight (kg) was measured to the nearest 0.1 kg by using a digital balance (Soehnle). BMI (in kg/m²) was calculated and transformed into age- and sex-standardized z scores on the basis of French reference data (32).

Statistical analysis

The SAS System for Windows version 9.3 software (SAS Institute) was used to perform analyses. Results are expressed as means (±SEMs) and variables (±SEs). Significance was set at $P < 0.05$, and $P$-trend was set at $<0.10$.

To compare children’s characteristics between the 2 experimental groups (2- compared with 7-exposure groups), $t$ tests were calculated for quantitative variables, and chi-square tests were calculated for qualitative variables.

ANOVAAs on repeated measurements were performed to determine whether liking (scored from 1 to 5), energy intake (kcal), or hunger ratings (1–5) differed according to the beverage (NE or HE), time of measurement (from baseline to T1, from T1 to T2, from T2 to T3, or from T3 to T4), and the experimental group (2-exposure or 7-exposure group), and their interactions. The child effect was considered as random. These models were estimated with the SAS MIXED procedure (SAS Institute), which
enabled taking into account the autocorrelation structure of data when needed. The delay between the beverage consumption and beginning of the meal was entered as a covariate in models concerning energy intake and hunger rating. A post hoc comparison (Student’s t tests) was used to compare means when relevant.

RESULTS

Children’s characteristics

This study included 45 children; one child was excluded from the analyses because of extensive absences. The remaining 44 children (26 girls; 18 boys) ranged in age from 8.3 to 11.1 y (mean ± SEM age; 9.9 ± 0.13 y). Children’s mean height was 141.9 ± 1.2 cm, their mean weight was 35.1 ± 1.2 kg, their mean BMI was 17.5 ± 0.4, and their mean BMI was 0.56 ± 0.20 (from −1.5 to 3.7). According to French cutoffs, 3 children were considered overweight (BMI > 2), and 3 children were considered obese (BMI > 3) (33). Children’s characteristics are summarized in Table 1. The 2 experimental groups did not differ in terms of age, BMI, or sex.

Liking measurements

Children’s liking scores at each measurement are represented in Figure 2.

Initial conditioning period (from baseline to T1)

At T1, the liking for both flavors had increased compared with at baseline (P < 0.001). The beverage effect was not significant (P = 0.74). No beverage × time interaction was observed (P = 0.95). No experimental group effect was observed (P = 0.55), and no interactions of group with time (P = 0.63) or beverage (P = 0.26) were observed. See Supplemental Figure 1 under “Supplemental data” in the online issue for mean likings for HE and NE beverages at T0 and T1 for both groups.

Stability period (from T1 to T2 and from T2 to T3)

The beverage × time interaction was significant (P = 0.027); after 3 wk without exposure, children’s liking for the NE flavor tended to decrease (P = 0.073), whereas the liking for the HE flavor remained constant (P = 0.58). At T2, children’s liking for the HE flavor was higher than that for the NE flavor [t(42) = 2.28, P = 0.024]. Neither experimental group effects nor interactions were observed.

Between T2 and T3, children received each beverage once. Children’s liking for the HE flavor was higher than their liking for the NE flavor (beverage effect, P = 0.009); the time effect was not significant (P = 0.32) nor was the beverage × time interaction (P = 0.81). Neither experimental group effects nor interactions were significant. At T3, children’s liking for the HE flavor was higher than that for the NE flavor [t(43) = 2.34, P = 0.021].

Reversed conditioning period (from T3 to T4)

The ANOVA showed a significant beverage × time interaction (P = 0.026). At T3, the flavor associated with HE was preferred to the flavor associated with NE (P = 0.021). At T4, the flavor associated with NE (and previously with HE) tended to be preferred to the flavor associated with HE (and previously with NE [t(43) = 1.71, P = 0.089]).

<p>| TABLE 1  |
| Children’s characteristics for each experimental group (2-exposure group compared with 7-exposure group) and for the whole sample1 |</p>
<table>
<thead>
<tr>
<th>n</th>
<th>2-exposure group</th>
<th>7-exposure group</th>
<th>Total</th>
<th>P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>23</td>
<td>21</td>
<td>44</td>
<td>—</td>
</tr>
<tr>
<td>F (n)</td>
<td>13</td>
<td>13</td>
<td>26</td>
<td>0.72</td>
</tr>
<tr>
<td>M (n)</td>
<td>10</td>
<td>8</td>
<td>18</td>
<td>—</td>
</tr>
<tr>
<td>Age (y)</td>
<td>9.8 ± 0.2a</td>
<td>10.0 ± 0.2</td>
<td>9.9 ± 0.1</td>
<td>0.46</td>
</tr>
<tr>
<td>Minimum</td>
<td>8.3</td>
<td>8.5</td>
<td>8.3</td>
<td>—</td>
</tr>
<tr>
<td>Maximum</td>
<td>10.9</td>
<td>11.1</td>
<td>11.1</td>
<td>—</td>
</tr>
<tr>
<td>z BMI</td>
<td>0.57 ± 0.31</td>
<td>0.55 ± 0.25</td>
<td>0.56 ± 0.20</td>
<td>0.41</td>
</tr>
<tr>
<td>Normal weight (n)</td>
<td>19</td>
<td>19</td>
<td>38</td>
<td>—</td>
</tr>
<tr>
<td>Overweight or obese (n)</td>
<td>4</td>
<td>2</td>
<td>6</td>
<td>—</td>
</tr>
</tbody>
</table>

12-exposure group, experimental group in which children were exposed 2 times to the beverages during the initial conditioning period; 7-exposure group, experimental group in which children were exposed 7 times to the beverages during the initial conditioning period.

2For each characteristic, the group difference was tested by using Student’s t test (quantitative variables) or the chi-square test (qualitative variables).

3Mean ± SEM (all such values).
Hunger ratings and energy intake after beverage consumption

The mean delay between the beverage ingestion and meals was 52 ± 0.5 min. Children’s energy intakes at each time of measurement are represented in Figure 3.

Initial conditioning period (from baseline to T1)

As concerned energy intake, the time effect ($P < 0.001$) and beverage effect were significant ($P = 0.018$). Children ate less at T1 than at baseline and less after the HE beverage than after the NE beverage. The beverage × time interaction was significant ($P = 0.028$); at baseline, energy intake at lunch did not depend on the ED of the preload ($P = 0.85$); at T1, children’s energy intakes at lunch were significantly lower after the HE beverage than after the NE beverage ($-56 ± 18$ kcal; $P = 0.002$). At baseline, the difference in intake after HE and NE beverages was not significant ($t(39) = 0.18$, $P = 0.86$), but it was significant at T1 ($t(40) = 3.17$, $P = 0.002$). No interaction with the experimental group was observed (beverage × time × group, $P = 0.40$). Mean COMPX scores were $9 ± 13\%$ at baseline and $40 ± 13\%$ at T1.

Mean hunger ratings did not vary with time, group, or their interactions. Hunger ratings tended to vary with the beverage ($P = 0.071$), which indicated a trend for a lower hunger rating after the consumption of the HE beverage than after the LE beverage. See Supplemental Figure 2 under “Supplemental data” in the online issue for mean energy intakes per time, beverage, and group; see Supplemental Figure 3 under “Supplemental data” in the online issue for mean hunger ratings.

Stability period (from T1 to T2)

The time effect was significant ($P < 0.001$); children ate more at T2 than at T1 ($P < 0.001$). The beverage effect was significant ($P < 0.001$); children ate significantly less after the HE beverage than after the NE beverage. No significant beverage × time interaction was observed ($P = 0.32$); nevertheless, at T2, the difference in intake after the HE and NE beverages was not significant ($t(37) = 1.38$, $P = 0.17$). All other effects were not significant. The COMPX score was $14 ± 15\%$ at T2. Mean hunger ratings did not vary with beverage, time, group, or their interactions.

Reversed conditioning period (from T2 to T3 and T3 to T4)

The ANCOVA between T2 and T3 showed a significant time effect ($P < 0.001$) and a trend for the beverage effect ($P = 0.056$); children ate more at T3 than T2 and tended to eat less after the HE beverage than after the NE beverage even though the HE beverage contained the flavor associated with NE during the initial conditioning. No significant beverage × time interaction was observed ($P = 0.71$).

The ANCOVA between T3 and T4 showed a significant beverage effect ($P = 0.007$) but no time effect ($P = 0.42$) and no beverage × time interaction ($P = 0.57$). Children ate significantly less after the consumption of the HE beverage than after the NE beverage, more specifically at T4 [$t(41) = 2.78$, $P = 0.006$]. At T3, the difference was marginally significant [$t(38) = 1.87$, $P = 0.06$]. Mean COMPX scores were $29 ± 13\%$ at T3 and $29 ± 11\%$ at T4. Mean hunger ratings did not vary with the version, time, group, or their interactions between T2 and T3 and between T3 and T4.

As shown in Figure 3, energy intake significantly increased over time when modeled as a linear effect regardless of the flavor or of the ED ($P < 0.001$). An analysis of the time effect considered as a factor showed, in particular, that energy intake was higher at T4 (454 ± 9 kcal) than at T0 (396 ± 9 kcal; $P < 0.001$).

DISCUSSION

To the best of our knowledge, this study is the first study to examine, with the same group of children, the impact of ED on changes both in flavor liking and caloric adjustment at the lunch after beverage consumption as well as the impact of changes in ED on the stability of flavor liking and caloric adjustment. Our first hypothesis was confirmed, whereby after the initial conditioning, caloric adjustment after the consumption of the HE beverage compared with NE beverage was observed. Contrary to our hypotheses, the liking for the HE flavor did not increase more than for the NE flavor, and a higher number of exposures did not lead to a higher liking or a better caloric adjustment. After the period without exposure, liking remained stable for the HE flavor but decreased for the NE flavor, and the effect of conditioning on the caloric adjustment weakened over time. After the reversed conditioning, the liking for the flavor initially associated with HE remained higher than for the flavor initially associated with NE, which suggested that the initial positive effect of ED on liking was resistant to relearning. Unexpectedly, a caloric adjustment was observed at the first exposure to the reversed flavor-ED association, but the compensation was lower (29%) than after the initial learning and did not increase after 2 supplementary reversed flavor-ED associations. These results suggested that flavor-nutrient hedonic learning as well as flavor-nutrient satiety learning occurred in the children, and flavor-nutrient hedonic learning was more resistant to relearning than flavor-nutrient satiety learning. However, the caloric adjustment was always partial throughout the study and weakened over time, and a reversed conditioning was not as effective as the initial conditioning.
After the initial conditioning, a similar increase in the liking for both flavors (NE and HE) was observed and confirmed the effectiveness of repeated exposures in increasing the liking for new foods in children (13, 14, 20, 25). Moreover, liking conditioned through flavor-nutrient learning was robust over time as previously shown (25) even after a reversed association. This last result was in line with the fact that the novelty of the flavor is a key point to observe flavor-nutrient hedonic learning and suggested that latent inhibition may have limited the increase in liking for the flavor initially associated with NE, which was a flavor that was no longer novel at the beginning of the reversed conditioning period (15). This result underlines the importance of first exposures to a food and how ED can affect its liking.

Regarding caloric adjustment, children were not able to immediately adjust for the ED of beverages, probably because the beverages were unfamiliar, had a similar sweetness intensity, and were not differentiated in a triangular test performed by another group of children. As observed in previous studies (19, 21), the caloric adjustment for liquid calories was learned after a conditioning period. After the reversed conditioning, children still ate more after the NE beverage than after the HE beverage even though the ED-flavor association had been switched. However, contrary to what was observed in a previous study with children exposed to 2 versions (high and low energy) of yogurts (22), in the current study, as soon as the first exposure to the switched beverages, children adjusted their energy intakes at the meal according to the actual EDs of beverages, thereby disregarding the flavor cues. These results suggested that, during the initial conditioning period, children may have learned to detect another sensory signal than the flavor that helped them differentiate sucrose from sucralse. This study could not provide a clear indication on the type of signal involved; however, it was possible that sucralose brought specific sensory properties to the NE beverage that children learned to perceive. In mice, it has been shown that artificial sweeteners and sucrose bind differently or with a different affinity to sweet receptors (34, 35). In an fMRI study conducted in adults, brain activations differed in response to caloric (sucrose) compared with noncaloric (sucralose) sweeteners, despite the subjects’ inability to consciously discern both stimuli (35). These physiologic and unconscious responses could have allowed the brain to immediately anticipate the postingestive effects of the 2 beverages especially after learning.

However, regardless of the signal involved, the caloric adjustment remained partial, and energy intake increased over time. Previous studies showed that liquid calories are not well perceived (5, 12, 18). Liquids are rapidly swallowed, which leads to a very short presence in the mouth and low orosensory stimulations (36, 37), which could limit the effect of the cephalic phase on satiation (38, 39). Moreover, because sweet beverage exposure took place before lunch, we assumed that children were in a hungry state when they consumed beverages; their stomachs were empty, which led to a rapid gastric emptying (40), a poor caloric detection, and a poor satiation signal. In another respect, the increase in energy intake over time could have been linked to increased needs in relation with the growth of children, to a seasonal effect as previously observed with younger children (41), or to other environmental factors not controlled for.

Contrary to our hypothesis, the effect of the number of days of beverage exposure during the initial conditioning period on liking and caloric adjustment was not significant. Therefore, only 2 exposures may have been sufficient to produce a conditioned response. This result is consistent with previous studies conducted in children, which showed that caloric adjustment was improved after 2 or 3 exposures to an unfamiliar food (19, 20, 22). In adults, it has previously been shown that flavor-nutrient hedonic learning may occur after only 1 or 2 exposures (23, 24). However, this null finding may have also been related to a lack of power of the current design to reveal it.

This study must be considered in light of its strengths and limitations. To be as close to children’s usual consumption contexts, intake measurements were conducted in the school canteen. In addition, we measured the impact of sweet beverages consumed shortly before a meal, which reflected a common consumption situation. However, children were not isolated during beverage exposures or during liking and caloric-adjustment assessments, despite the recognized peer influence on eating behaviors (42, 43). Because the study was conducted according to a within-subject design, peers’ influences may be considered consistent throughout the study. Food intake was only measured at the meal after the preload; which could partly explain why the caloric adjustment was partial because it has been shown that energy adjustment at a particular meal is less accurate than daily energy intake adjustments (44, 45). However, hunger was measured just before the meal and considered in the analysis to limit the impact of the interindividual variability in previous food intakes and physical activity levels. No significant difference was observed in hunger ratings after the consumption of both beverages even though children ate less after the HE beverage. Hunger ratings did not reflect children’s food intakes, which may have been due to a lack of sensitivity of the hunger rating scale; moreover, it has been previously shown that premeal hunger ratings are not a reliable predictor of energy intake at the next meal (46, 47).

The current study suggested that flavor-nutrient hedonic learning and flavor-nutrient satiety learning occurred in children but differed in terms of stability and resistance to relearning. The initial pairing of a novel flavor with high ED was not necessary for the initial learning but induced a more stable learning than did repeated exposure. Flavor-nutrient hedonic learning may be particularly stable because it is important to learn quickly and durably the flavor of safe and nutritious foods (15, 48); and on the contrary, flavor-nutrient satiety learning may not be as stable because humans constantly need to adjust energy intake to foods varying in ED. This aspect deserves additional investigation because such a phenomenon may have consequences on energy intake control for children exposed alternatively to regular and diet beverages of similar flavors.

In conclusion, the current results may partly explain why the consumption of sugar-sweetened beverages might be a plausible cause of energy imbalance. With the high prevalence of overweight and obesity, these results may have practical implications such as limiting children’s consumption of sugar-sweetened beverage before a meal.

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wrote the manuscript; SN: had primary responsibility for the final content of the manuscript; and all authors: read and approved the final manuscript. None of the authors had a conflict of interest.

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