

ORIGINAL COMMUNICATION

Influence of repeated consumption of beverages containing sucrose or intense sweeteners on food intake

V Van Wymelbeke¹, M-E Béridot-Thérond¹, V de La Guéronnière² and M Fantino^{1*}

¹*Equipe Nutrition et Métabolisme Humain et CREABIO, Université de Bourgogne, Dijon, France; and* ²*SEV, Bourg la Reine, France*

Objective: To investigate the influence of ingestion of beverages with sucrose or with intense sweeteners on food intake (FI) and on hunger ratings in before and after a month of daily consumption of beverages.

Design: Experimental study.

Setting: Department of Physiology, University Hospital, Dijon, France.

Subjects: In all, 12 men and 12 women, aged 20–25 y.

Intervention: Four beverages contained either sucrose (E+: 100 g/l, 1672 kJ) or intense sweeteners (E–: null energy content) and were flavoured with either orange (O) or raspberry (R). FI was measured in the lab during two 2-consecutive-day periods, carried out on 2 successive weeks (session 1). The subjects drank 2 l of either E+ or E– beverages on the first day of both weekly periods, according to a balanced randomised design. E+ was paired with O for 50% of subjects and with R for the other 50%. Subjects were then habituated over a 4-week period to both beverages, consuming 1 l of E+ beverage on odd days and 1 l of E– drink on even days. After this period, the measurements of session 1 were repeated (session 2, weeks 7–8). Finally, FI was measured for two more 2-day periods (weeks 9–10) after the association between flavour and energy content was reversed (session 3).

Results: The E– drinks were less palatable than the E+ drinks. Besides, we observed that FI was not reduced in response to a liquid extra caloric load and there was no change in hunger ratings after the beverages in any of the sessions.

Conclusion: Ingestion of caloric beverages induced a positive energy balance and the continuous exposure phase to these beverages over 1 month did not improve FI adaptation in response to the extra energy provided by the beverages.

Sponsorship: This study was sponsored by SEV, Bourg la Reine, France; the French Ministère de la Recherche et de la Technologie (Programme AGROBIO-Aliments Demain) and the Regional Council of Burgundy (Dijon, France).
European Journal of Clinical Nutrition (2004) 58, 154–161. doi:10.1038/sj.ejcn.1601762

Keywords: feeding behaviour; human; caloric beverages; intense sweeteners; aspartame; sucrose; food intake control; flavour

Introduction

It is now recognised that obesity is the most common nutritional disease in the world, with an increase in the

prevalence of overweight by more than 50% in the last 10 y in American adults (Strauss & Pollack, 2001), 8–10% increase in prevalence of obesity in the adult population in France (Basdevant, 2000), and a significant increase in height and weight in Australian children between 1899 and 1999 (Olds & Harten, 2001). The factors responsible for the weight gains have to be yet identified. Physical activity and diet, particularly the consumption of drinks, have received a special attention (Blundell & Cooling, 2000). In addition, the consumption of caloric beverages has increased for some time (Dennison, 1996) with, for example, a 65% increase in volume of soft drinks consumed by American adolescent boys from 1989–1991 to 1994–1995 (Morton & Guthrie, 1998). The results of a previous study in our laboratory

*Correspondence: M Fantino, Département de Physiologie Humaine, Faculté de Médecine, Université de Bourgogne, 7Boulevard Jeanne d'Arc, BP 87900, F-21079 Dijon, Cedex, France.
E-mail: mfantino@u-bourgogne.fr

Guarantor: M Fantino.

Contributors: VVW contributed to writing. MBT was responsible for conduct of the experiments, recording of food intakes, results analysis and writing. MF was responsible for design of protocol, recording of food intakes, results analysis, discussion and writing. VLG was responsible for initiation of the study and discussion.

Received 31 July 2002; revised 18 February 2003; accepted 1 March 2003

indicated that hunger ratings and energy intakes did not differ after the consumption of aspartame-sweetened or sucrose-sweetened beverages (Béridot-Thérond *et al*, 1998). Consequently, a significantly higher total energy intake was noted when beverages with sucrose were consumed. Actually, compensation seems to be poor if the load is a liquid product. Surveys have shown that beverages containing energy (eg soda, milk, juice) taken during a meal or as a preload, exert little effect on food intake (FI) during this meal or in the subsequent meals (Rolls *et al*, 1990; De Castro, 1993,1994). Tournier and Louis-Sylvestre showed that the total subsequent caloric intake was higher when the calories were drunk than when the calories were consumed in solid form (Tournier & Louis-Sylvestre, 1991). In a recent review, Ludwig *et al* suggested that sugar-sweetened drink consumption could be an important contributory factor of excessive body weight and could constitute a health risk in USA (Ludwig *et al*, 2001). This lack of short-term adjustment for energy-bearing liquids raises the question of their consequences on the long-term regulation of body weight. Many studies have shown that the consumption of carbohydrate promotes carbohydrate oxidation (Flatt, 1988; Jequier, 1993). So it is possible that after the repeated ingestion of sweetened caloric drinks, the energy provided by these beverages is taken into account in the energy balance. For example, Spiegel (1973) and Porikos (Porikos *et al*, 1982) found that the adjustment of energy balance by control of FI occurred over a period of days, while Booth and McAleavey (Booth *et al*, 1976) showed that subjects may progressively acquire the ability to adjust their FI by associating the sensory characteristics of ingested foods with their true nutritional properties. Initially discovered in the rat by Le Magnen (1957), the phenomenon has been confirmed and extensively studied in adult human subjects (Booth *et al*, 1982; Booth & Toase, 1983; Bellisle & Perez, 1994). It has now been described in both young children (Birch & Deysher, 1985; Birch & Fisher, 1997) and adolescents (Louis-Sylvestre *et al*, 1989).

The objective of the present study was to determine the effects of repeated consumption of a beverage sweetened with sucrose or a beverage sweetened with intense sweeteners on subsequent hunger ratings and FI. The subjects could discriminate the different beverages by their distinctive sensory characteristics. We noted hunger ratings in healthy male and female subjects, and measured intakes at the subsequent lunch and at the following meals for 2 days in response to the ingestion of beverages, before and after a 4-week period of alternated daily intake of both beverages.

Methods

Research design and methods

Subjects. A total of 24 healthy volunteers (12 men and 12 women) aged 20–25 y (21 ± 7.3) with a body mass index (in kg/m^2), of 19–24 were recruited from the Burgundy student

population (Dijon, France). The female subjects took contraceptive pills. None of the subjects smoked and none had any history of medical disorders. Each subject completed a 7-day food record: daily dietary intake was assessed in the month preceding the first experimental day from quantitative 1-week food records. The subjects were instructed by a dietician to note in detail their daily food and drink intake and the portion size, either weighed or expressed in usual household measures. The record was then reviewed and validated by the dietician who translated the quantities expressed as household measures into grams using a computerised dietary system. The software converted the collected data into daily energy and nutrient intakes using a food composition database containing the energy (kJ) and 41 food constituents of more than 1500 food items (compilation of Souci, Southgate and CIQUAL databases). Each subject had a regular food pattern consuming 3 meals/day. They did not use regularly intense sweeteners, did not indulge in either snacking or nibbling and had no aversion for the foods composing the experimental meals. The subjects were instructed to maintain a constant pattern of activity during the study, to not change their eating habits and to avoid alcohol intake before each experimental day. The protocol was approved by the Advisory Committee for the Protection for Humans in Biomedical Research of Burgundy, and written, informed consent was obtained from all subjects. All subjects were instructed on the experimental procedures and techniques, although they were naive as to the true purpose of the experiment.

Experimental beverages. The experimental beverages used in this study were composed of mineral water flavoured with an orange (O) or a raspberry (R) aroma, and sweetened with sucrose (E+ :100 g/l, 1672 kJ/l) or containing a mixture of intense sweeteners (E-: aspartame: 20 mg/l; acesulfame K: 110 mg/l; saccharin: 30 mg/l, null energy content). The orange-flavoured beverage was yellow and the raspberry was pink. For the Latin-square design, half of the subjects received the orange aroma associated with sucrose (caloric beverage, E+) and the raspberry aroma associated with the intense sweeteners (no calorie, E-); the other half received the opposite association: raspberry aroma associated with sucrose (E+) and orange aroma associated with the intense sweeteners (E-).

All experimental beverages were served at ambient temperature ($20 \pm 1^\circ\text{C}$). The days when spontaneous FI was measured, the subjects had to drink 2l of one beverage, scheduled as follows: 0.5l at breakfast, 0.5l during the morning, 0.5l at lunch and the last 0.5l during the afternoon and the dinner. Mineral water was available *ad libitum* after intake of the mandatory drink.

Study design. In the first session (weeks 1 and 2; Figure 1), FIs were measured during two consecutive 2-day periods each separated by an interval of 7 days. The subjects were required to drink 2l of one experimental beverage during the

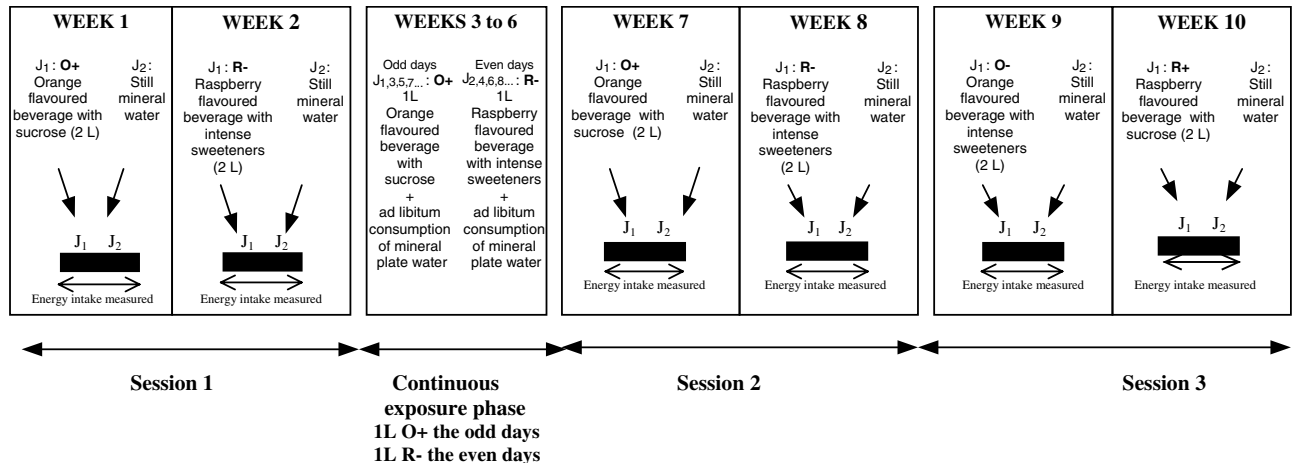


Figure 1 Example of sequences of the sessions for six subjects (25% of the group). Weeks 1–8: O + : orange-flavoured beverage with sucrose, R – : raspberry-flavoured beverage with intense sweeteners. Weeks 9–10: O – : orange-flavoured beverage with intense sweeteners, R + : raspberry-flavoured beverage with sucrose. J1: day 1 of the 2-day period where the beverage was consumed; J2: day 2 of the 2-day period where only still mineral water was ingested. The association flavour/energy content and the sequences of the beverage given weeks 1–8 were randomised for the whole group according a Latin-square design (see text).

first day of each period. To be sure that the subjects drank the beverages according to the imposed schedule, on the one hand, the empty bottle were taken to the laboratory, and on the other hand, they were informed that, in the beverages, a substance was added and would be measured in their urine and they had to collect urine for the said purpose (in fact, no substance was added). The second day of the 2-day period, subjects had to consume only mineral water as beverage. The order of the consumption of the experimental beverages was randomised according to a Latin-square design: during the first day of the first week, half of the subjects received the sucrose-containing beverage, flavoured with orange for 25% of the subjects and with raspberry for the other 25%, and half of the subjects received the intense sweetener-containing beverage, flavoured with orange for 25% of the subjects and with raspberry for the other 25%. During the first day of the second week, the alternate aroma/energy content drink was presented. The subjects were then habituated (weeks 3–6) to consume the beverages tested during the first session during a 4-week period. They had to drink 1 l of one beverage on the odd days and 1 l of the other beverage on the even days (Figure 1).

A second session of 2 weeks of FI measurements was conducted (weeks 7 and 8) similar to the first session, with the same consumption of both the beverages. For each subject, from week 1 to week 8, the association aroma/caloric content of the beverages was kept constant.

Finally, in the last session (weeks 9 and 10), FI was measured in the same way, but the association between flavour and energy content of the drink was reversed (Figure 1).

The day before each session, the subjects were requested not to eat or drink anything (except natural water) after 21.00. On both experimental days, breakfast was fixed in

energy and macronutrient content and was taken at 08.00 at home. The subjects were instructed not to eat anything between breakfast and lunch, and between lunch and dinner. During each 2-day period of FI measurements, the subjects had lunch and dinner in the laboratory in order to measure accurately all food and drink intakes. Each subject came to the laboratory between 12.00 and 13.00 for lunch and between 19.00 and 20.00 for dinner. For these two meals, subjects had *ad libitum* access to a buffet of 45 palatable foods served in excess (Appendix A) including meats, vegetables, cheeses and desserts. After the lunch, the subjects could go back to usual activities, or rest in the laboratory until dinner. After the dinner, the subjects were required to remain in the laboratory until 22.00, and were requested not to eat or drink anything until breakfast on the following day (except mineral water). On the second day, FI was measured exactly as on the first day, but the subjects did not receive any experimental beverage and only had *ad libitum* access to mineral water.

Experimental measurements. The following measurements related to FI were made: (1) the energy intakes and macronutrient contents of the foods ingested during lunch and dinner; (2) hunger ratings at the beginning and at the end of lunches and dinners, and (3) the hedonic values of meals taken at lunch and at dinner. Hunger and hedonic values were rated on 100 mm visual analogue scales (VAS). The VAS of hunger anchored 'extremely hungry' at one extremity and 'not at all hungry' at the other extremity. The hedonic value of the experimental beverages was also rated on a 100 mm VAS at the start of lunch and dinner on the first day of each measurement periods. This VAS anchored 'extremely good' at one extremity and 'extremely bad' at the other extremity.

In addition, to discern a possible effect of supplemental calories from beverages, the subjects were weighed at the beginning of the study (week 1) and at the end (week 10).

Statistical analysis

Data were expressed as means (s.d.). Hedonic ratings of beverages tested, foods ingested at each meals, energy intakes and macronutrient contents were compared by repeated-measures analysis of variance (ANOVA) with the type of beverage tested or session (1–3) as experimental factor. The ANOVA was followed by a *post hoc* multiple-comparison Tukey–Kramer test when appropriate ($P < 0.05$). The mean values of the parameters in a session for the different beverages were compared using Student's paired *t*-test. All statistical analyses were conducted using the NCSS 2000 statistical package (BMDP Statistical System for Windows, Number Cruncher Statistical Systems, Kaysville, UT, USA).

Results

Body weight of subjects

The body weights of our subjects did not change over the study period (64.3 ± 9.3 kg at week 1 vs 64.2 ± 9.3 kg at week

10), whereas the theoretical weight gain because of the extra calories provided by the repeated consumption of beverages containing sucrose would have been almost 0.7 kg.

Energy intake

Total energy intakes during both 2-day periods of the three sessions are presented in Table 1. In this study, in all sessions, the total energy intake after the ingestion of beverages with sucrose were significantly higher than after the ingestion of beverages with intense sweeteners ($P < 0.001$, Table 1). Furthermore, the subjects tended to eat increasing amounts between sessions 1 and 3.

Session 1. The ingestion of beverage with sucrose provided an additional 3344 kJ on the first day, which represented an extra caloric mean load of 41% of the energy provided by *ad libitum* food consumption on that day. After the ingestion of both beverages, the subjects consumed significantly less solid food on the first day than on the second day of the measurement periods, but the difference was only significant after the beverage with sucrose ($P < 0.01$, Table 1). The total energy provided by the *ad libitum* solid FI independent of fluid intake on 2 days did not differ significantly between the two 2-day measurement periods, irrespective of the

Table 1 Food intake during both 2-day measurement periods of the three sessions*

Association flavour/ energy content	Session 1		Session 2		Session 3		P [†]
	Sucrose	Intense sweeteners	Sucrose	Intense sweeteners	Sucrose	Intense sweeteners	
For 50% of subjects	O+	R–	O+	R–	R+	O–	
For 50% of subjects	R+	O–	R+	O–	O+	R–	
<i>Energy consumed</i>							
Provided by solid foods on day 1 (kJ)	8069 ± 3219	8608 ± 2719	8490 ± 2846	8889 ± 2655	8997 ± 3248	9128 ± 2327	NS
Provided by drink on day 1 (kJ)	3344	0	3344	0	3344	0	
Provided by the beverage (%)	41	0	39	0	37	0	
Provided by foods on day 2 (kJ)	9315 ± 3042 [‡]	9137 ± 3081	9498 ± 2748 [‡]	9364 ± 2675	9818 ± 2498 [‡]	9829 ± 2640	NS
<i>Total food intake over 48 h</i>							
Total energy intake (kJ)	20728 ± 6031 ^a	17745 ± 5653 ^b	21332 ± 5408 ^a	18253 ± 5198 ^b	22159 ± 5506 ^a	18957 ± 4654 ^b	<0.001
Protein in foods (g)	183 ± 68	194 ± 69	182 ± 54	187 ± 54	188 ± 49	190 ± 59	NS
(%)	18 ± 2.4	18 ± 2.9	17 ± 2.9	17 ± 2.9	17 ± 2.9	17 ± 0.7	NS
Fat in foods (g)	151 ± 59	154 ± 64	163 ± 64	167 ± 59	176 ± 54	179 ± 64	NS
(%)	32 ± 5.9	32 ± 5.9	33 ± 6.9	34 ± 5.9	34 ± 6.4	35 ± 5.4	NS
Carbohydrate in foods (g)	515 ± 184	521 ± 163	528 ± 165	529 ± 162	551 ± 150	533 ± 162	NS
(%)	50 ± 6.9	50 ± 6.4	50 ± 6.9	49 ± 6.4	49 ± 6.4	48 ± 5.9	NS
Carbohydrate in drink (g)	200	0	200	0	200	0	

*Data collected are means ± s.d.; $n=24$. According to the crossover design, 50% of the subjects had the orange flavour and the other 50% the raspberry flavour. On session 3, the association flavour/energy content was inverted for each subject. O: orange flavour for 50% of the subjects; R: raspberry flavour for the other 50%; +: beverage with sucrose (energy); -: beverage with intense sweetener (no energy).

†The means were compared with use of repeated-measures analysis of variance. Means within columns with different superscript letters are significantly different (ANOVA and Tukey–Kramer test, $P < 0.05$).

‡The food intake on day 2 is significantly larger than the food intake on day 1 (paired *t*-test, $P < 0.01$).

(%): Macronutrient intakes expressed as a percentage of the energy provided by food intake.

sweetener in the experimental beverages. However, when the calories of beverages were added at the energy ingested, the total energy consumption on 2-day measurement period was significantly higher after the beverage with sucrose (20728 ± 6030 kJ) than that ingested on the 2-day period after ingestion of the intense sweetened beverage (17745 ± 5653 kJ) ($P < 0.001$). There was no significant change in the amount of macronutrients consumed during both FI measurement periods (Table 1).

Session 2. After the 4-week period of alternating ingestion of each beverage, the results for FI parameters were the same as in the first session, that is, a significant reduction in FI on the first day after the ingestion of beverage with sucrose compared to the second day ($P < 0.01$) and no significant difference of FI between the 2-day measurements after the ingestion of beverage with intense sweeteners (Table 1). However, the total energy intake over the 2-day measurement periods was still significantly higher after the beverage with sucrose than after the beverage with intense sweeteners because of the additional calories from the sucrose-contain-

ing beverage ($P < 0.001$, Table 1). No difference was observed for the intake of macronutrients (Table 1).

Session 3. The inverted association of flavour/sweetened caloric content of the beverages did not modify the subjects' food consumption, with results comparable to those in sessions 1 and 2 for the food ingested during the 2-day period ($P < 0.01$), for the total energy ($P < 0.001$), and for the macronutrient intakes (Table 1). Thus, repeated intake of the beverages did not induce any conditioned adjustment of FI to flavour cues.

We observed that the FI on the first day of each session was slightly, but not significantly, lower after the ingestion of beverage with sucrose than after that with intense sweetener (Table 1). This small difference vanished on the second day of each session.

Hedonic and hunger ratings

Table 2 shows that the hedonic ratings for the foods consumed at different meals ranged from 68 to 81 mm

Table 2 Hedonic and hunger ratings given by the 24 subjects during both 2-day food intake measurement periods of the three sessions

	Session 1		Session 2		Session 3		ANOVA
	Sucrose	Intense sweeteners	Sucrose	Intense sweeteners	Sucrose	Intense sweeteners	
Association flavour/energy content							
For 50% of subjects	O+	R-	O+	R-	R+	O-	
For 50% of subjects	R+	O-	R+	O-	O+	R-	
Hedonic ratings of meals							
Lunch day 1	73 ± 15	68 ± 15	75 ± 15	73 ± 15	77 ± 15	77 ± 15	NS
Dinner day 1	73 ± 15	71 ± 15	74 ± 15	76 ± 15	77 ± 20	78 ± 15	NS
Lunch day 2	75 ± 15	73 ± 20	80 ± 15	75 ± 15	79 ± 20	79 ± 15	NS
Dinner day 2	73 ± 15	75 ± 15	78 ± 20	78 ± 15	81 ± 15	78 ± 20	NS
Hunger ratings at the beginning of the meals							
Lunch day 1	52 ± 24*	60 ± 24	59 ± 24	66 ± 20	71 ± 20*	66 ± 20	<0.05
Dinner day 1	66 ± 20	70 ± 15	67 ± 20	71 ± 20	68 ± 24	69 ± 24	NS
Lunch day 2	72 ± 15	70 ± 20	71 ± 15	74 ± 10	71 ± 20	69 ± 20	NS
Dinner day 2	74 ± 20	74 ± 15	73 ± 20	72 ± 15	70 ± 20	73 ± 20	NS
Hunger ratings at the end of the meals							
Lunch day 1	6 ± 7	4 ± 3	7 ± 7	5 ± 3	4 ± 3	5 ± 7	NS
Dinner day 1	8 ± 10	8 ± 10	8 ± 10	6 ± 7	7 ± 10	4 ± 7	NS
Lunch day 2	7 ± 10	6 ± 7	5 ± 3	5 ± 7	4 ± 7	7 ± 7	NS
Dinner day 2	5 ± 7	4 ± 3	5 ± 7	9 ± 10	6 ± 7	6 ± 7	NS
Hedonic ratings of beverages							
(at the beginning of the meals of day 1 of each session)							
Lunch day 1	58 ± 20 ^{a,†}	39 ± 29 ^b	61 ± 20 ^{a,†}	47 ± 20 ^{a,b}	56 ± 24 ^a	51 ± 24 ^{a,b}	<0.01
Dinner day 1	59 ± 20 ^{a,†}	43 ± 24 ^b	63 ± 20 ^{a,†}	52 ± 20 ^{a,b}	61 ± 24 ^a	55 ± 24 ^a	<0.01

Data collected are means ± s.d.; $n=24$. According to the crossover design, 50% of the subjects had the orange flavour and the other 50% the raspberry flavour. On session 3, the association flavour/energy content was inverted for each subject. O: Orange flavour for 50% of the subjects; R: Raspberry flavour for the other 50%; +: beverage with sucrose (energy); -: beverage with intense sweetener (no energy).

The means were compared with use of repeated-measures analysis of variance. Means with different superscript letters are significantly different (ANOVA and Tukey-Kramer test, $P < 0.05$).

*The two values indicated are significantly different (Tukey-Kramer test, $P < 0.05$).

†The rating is significantly higher than the other one in the same session (paired t -test for the energy content, $P < 0.001$).

(mean: 76.3 on a 100 mm scale), with no significant difference according to the period of measurement. This indicated that the subjects liked the foods equally well for the same meal over the three sessions. In addition, there was no significant difference in hunger ratings at the beginning of the meals, except for a lower rating at the lunch of session 1 associated with the beverage sucrose as compared to the lunch of session 3 ($P < 0.05$, Table 2). The hunger ratings at the end of the meals did not differ between the experimental conditions.

Hedonic ratings of beverages

At lunch and at dinner, the ratings of beverages containing intense sweeteners were lower than the ratings given to the beverages containing sucrose specially when the subjects ingested them for the first time (session effect at lunch: $P < 0.01$ and session effect at dinner: $P < 0.001$ following by the Tukey–Kramer test, $P < 0.05$). In sessions 1 and 2, the subjects slightly, but significantly, preferred the beverages containing sucrose to those containing intense sweeteners. This preference for the beverages with sucrose had declined by session 3 (paired *t*-test for energy content: $P < 0.001$). There was no difference, at any session, in the hedonic ratings of orange vs raspberry flavours.

Discussion

In each 2-day session, the energy intake of food ingested was slightly but not significantly lower after the beverages with sucrose than after the beverages with intense sweeteners. This difference was quite small on the first day (respectively 16, 12 and 4% of the extra energy provided by the beverages with sucrose) and disappeared on the second day of the 2-day measurement period. In addition, the subjects ingested less food on the first day than on the second day in all measurement periods: after ingestion of the beverages with sucrose, these differences were significant and reached 37% in session 1, 30% in session 2 and 24% in session 3; after the beverage with intense sweeteners, they were 15% in session 1, 14% in session 2 and 21% in session 3. This may be because of the gastric distension by the beverages ingested during the first day. Both observations are in line with the finding of Cecil (Cecil *et al*, 1998) that a caloric liquid produces a large suppression of appetite after oral administration indicating an interaction of orosensory, gastric and intestinal factors. Study Cecil *et al* also demonstrated that gastric distension tended to overwhelm any direct influence of intestinal stimulation on appetite, although the effect was influenced by information about the food (Cecil *et al*, 1998). Lappalainen *et al*. (1993) reported that consumption of an extra 400 ml of water during breakfast decreased the sensation of hunger during a meal. Another recent study has shown that a sucrose preload increases fullness and decreases prospective consumption over the following 3 h compared with water when given orally (Lavin *et al*, 2002).

However, in our study, when the energy of beverages (3344 kJ) was added to that from the *ad libitum* FI, the total energy ingested over 48 h was significantly higher after the drink with sucrose than after the drink with intense sweeteners. This result is in line with other reports (Stokley *et al*, 1984; Rodin, 1990; Rolls *et al*, 1990; Foltin *et al*, 1993) and corroborates our previous findings that, in adults, the energy content of ingested fluids did not modify FI and that energy provided by a sucrose-sweetened beverage was not taken into account by the energy-balance mechanism (Béridot-Thérond *et al*, 1998). In another study, it was shown that energy from beverages added to total energy (De Castro, 1993). Harnack observed that school children drinking an average of 255 ml or more of soft drinks daily consumed almost 785 kJ more total energy per day than did those not consuming this type of beverage (Harnack *et al*, 1999). Tordoff and Alleva compared the consumption of sugar-sweetened drinks and artificially sweetened drinks for 3 weeks and found that total energy intake and body weight increased with the former and decreased with the latter (Tordoff & Alleva, 1990). Di Meglio and Mattes reported differences in the effect of matched liquid (soda) and solid (jelly beans) carbohydrate loads of 1880 kJ/day on diet and body weight over two 4-week periods (Di Meglio & Mattes, 2000). Dietary energy compensation was quite precise (118%) after consumption of the solid food, but inaccurate (–17%) after the matched liquid one. In consequence, body weight and body mass index increased significantly only during the liquid ingestion period of the study (Di Meglio & Mattes, 2000). A recent study of Raben observed that when overweight subjects consumed large amounts of sucrose mostly in the liquid form, energy intake, body weight and fat mass increased more than when they consumed the same amounts of liquid with artificial sweeteners (Raben *et al*, 2002). These studies indicate that drinks with energy as carbohydrate promote positive energy balance, and that this consumption might lead to obesity or overweight because of poor compensation. These findings also agree with meta-analysis of 42 studies that found a mean compensatory dietary response error of approximately 36% to solid food challenges, but a 109% error to fluid vehicles (Mattes, 1996).

In our study, no learning of caloric content arose since the total energy intake was always higher after the beverages with sucrose on sessions 2 and 3 after the 4-week daily beverage consumption period. However, the body weights of our subjects did not change during the 10 weeks of the study, whereas the consumption of 1672 kJ/day during the 4-week period should have led to a mean body weight gain of about 0.7 kg. It is possible that the extra consumption of carbohydrate was burned rather than stored by a corresponding rise in energy expenditure. Measurements of nutrient balance and respiratory exchanges should throw more light on this question. Leblanc and co-workers showed that postprandial thermogenesis is increased after the ingestion of palatable foods by human subjects (Leblanc *et al*, 1991;

Leblanc & Souci, 1996). In a previous study, we showed that the rate of energy expenditure was not different after four lunch meals differing in energy content, although the rates of fat and carbohydrate oxidation were significantly different (Van Wymelbeke et al, 2001). The consumption of a beverage with sucrose should have induced negative alliesthesia (Cabanac, 1971; Cabanac & Fantino, 1977; Fantino, 1984), an effect that may reduce ingestion of carbohydrate at the next meal. Our subjects did not significantly modify their food ingestion or the amounts of the macronutrients after the beverages.

In conclusion, the present study indicated that when subjects consume beverages with sucrose, their total energy intake is significantly higher than after ingestion of beverages made equally sweet with noncaloric substances. The compensation of FI for energy provided by drinks containing sweetened calories is imprecise and no adjustment of energy intake was observed even after some weeks of consumption. The subjects do not appear to learn to take account of the calories in liquid form. These observations indicate that nutritional guidelines should include caveats about the ingestion of sugars in liquid form.

Acknowledgements

The authors thank F Fuchs and P Noirod for their technical assistance.

References

- Basdevant A (2000): Obesity: epidemiology and public health. *Ann. Endocrinol.* **61** (Suppl 6), 6–11.
- Bellisle F & Perez C (1994): Low-energy substitutes for sugars and fats in the human diet: impact on nutritional regulation. *Neurosci. Biobehav. Rev.* **18**, 197–205.
- Beridot-Therond ME, Arts I & Fantino M (1998): Short-term effects of the flavour of drinks on ingestive behaviours in man. *Appetite* **3**, 67–81.
- Birch LL & Deysher M (1985): Conditioned and unconditioned caloric compensation: evidence for self-regulation of food intake in young children. *Learn. Motiv.* **16**, 341–355.
- Birch LL & Fisher JO (1997): Food intake regulation in children. Fat and sugar substitutes and intake. *Ann. N. Y. Acad. Sci.* **819**, 194–220.
- Blundell JE & Cooling J (2000): Routes to obesity: phenotypes, food choices and activity. *Br. J. Nutr.* **83** (Suppl 1), 33–38.
- Booth DA, Lee M & McAleavey C (1976): Acquired sensory control of satiation in man. *Br. J. Psychol.* **67**, 137–147.
- Booth DA, Mather P & Fuller J (1982): Starch content of ordinary foods associatively conditions human appetite and satiation, indexed by intake and eating pleasantness of starch-paired flavours. *Appetite* **3**, 163–184.
- Booth DA & Toase AN (1983): Conditions of hunger/satiety signals as well as flavour cues in dieters. *Appetite* **4**, 235–236.
- Cabanac M (1971): Physiological role of pleasure. *Science* **173**, 103–1107.
- Cabanac M & Fantino M (1977): Origin of olfacto-gustatory alliesthesia: intestinal sensitivity to carbohydrate concentration? *Physiol. Behav.* **18**, 1039–1045.
- Cecil JE, Francis J & Read NW (1998) : Relative contributions of intestinal, gastric, oro-sensory influences and information to changes in appetite induced by the same liquid meal. *Appetite* **31** (3), 377–390.
- De Castro JM (1993): The effects of the spontaneous ingestion of particular foods or beverages on the meal pattern and overall nutrient intake of humans. *Physiol. Behav.* **53**, 1133–1144.
- De Castro JM (1994): Accommodation of particular foods or beverages into spontaneously ingested evening meals. *Appetite* **23**, 57–66.
- Dennison BA (1996): Fruit juice consumption by infants and children: a review. *J. Am. Coll. Nutr.* **15**, 4S–11S.
- Di Meglio DP & Mattes RD (2000): Liquid versus solid carbohydrate: effects on food intake and body weight. *Int. J. Obes. Relat. Metab. Disord.* **24**, 794–800.
- Fantino M (1984): Role of sensory input in the control of food intake. *J. Auton. Nerv. Syst.* **10**, 347–358.
- Flatt JP (1988): Importance of nutrient balance in body weight regulation. *Diabetes/Metab. Rev.* **6**, 571–581.
- Foltin RW, Kelly TH & Fischman MW (1993): Ethanol as an energy source in humans: comparison with dextrose-containing beverages. *Appetite* **20**, 95–110.
- Harnack L, Strang J & Story M (1999): Soft drink consumption among US children and adolescents: nutritional consequences. *J. Am. Diet. Assoc.* **99**, 436–441.
- Jequier E (1993): Body weight regulation in humans: the importance of nutrient balance. *NIPS. Am. Physiol. Soc.* **8**, 273–276.
- Lappalainen R, Mennen L, Van Weert L & Mykkänen H (1993): Drinking water with a meal: a simple method of coping with feelings of hunger, satiety and desire to eat. *Eur. J. Clin. Nutr.* **47**, 815–819.
- Lavin JH, French SJ & Read NW (2002): Comparison of oral and gastric administration of sucrose and maltose on gastric emptying rate and appetite. *Int. J. Obes. Relat. Metab. Disord.* **26**, 80–86.
- Leblanc J, Diamond P, Griggio M, Nadeau A & Richard D (1991): Control of cephalic thermogenic phase of feeding. In: *Obesity in Europe*, eds G Ailhaud et al., pp 241–247. John Libbey & Company Ltd.
- Leblanc J & Soucy J (1996): Interactions between post prandial thermogenesis, sensory stimulation of feeding, and hunger. *Am. J. Physiol.* **271**, R936–R940.
- Le Magnen J (1957): Role de la densité calorique dans le mécanisme d'établissement des appétits. *J. Physiol. (Paris)* **49**, 274–278.
- Louis-Sylvestre J, Tournier A, Verger P, Chabert M, Delorme B & Hossenlopp J (1989): Learned caloric adjustment of human intake. *Appetite* **12**, 95–103.
- Ludwig DS, Peterson KE & Gortmaker SL (2001): Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective observational analysis. *The Lancet* **357**, 505–508.
- Mattes R (1996): Dietary compensation by humans for supplemental energy provided as ethanol or carbohydrate in fluids. *Physiol. Behav.* **59**, 179–187.
- Morton JF & Guthrie JF (1998): Changes in children's total fat intakes and their food group sources of fat, 1989–91 vs 1994–95: implications for diet quality. *Fam. Econ. Nutr. Rev.* **11**, 44–57.
- Olds TS & Harten NR (2001): One hundred years of growth: the evolution of height, mass, and body composition in Australian children, 1899–1999. *Hum. Biol.* **73**, 727–738.
- Porikos KP, Hesser MF & Van Itallie TB (1982): Caloric regulation in normal-weight men maintained on a palatable diet of conventional foods. *Physiol. Behav.* **29**, 293–300.
- Raben A, Vasilaras TH, Moller AC & Astrup A (2002): Sucrose compared with artificial sweeteners: different effects on *ad libitum* food intake and body weight after 10 week of supplementation in overweight subjects. *Am. J. Clin. Nutr.* **76**, 721–729.
- Rodin J (1990): Comparative effects of fructose, aspartame, glucose, and water preloads on calorie and macronutrient intake. *Am. J. Clin. Nutr.* **51**, 428–435.
- Rolls BJ, Kim S & Fedoroff IC (1990a): Effects of drinks sweetened with sucrose or aspartame on hunger, thirst and food intake in men. *Physiol. Behav.* **48**, 19–26.

Spiegel TA (1973): Caloric regulation of food intake in man. *J. Comput. Physiol. Psychol.* **84**, 24–37.
 Stokley L, Jones FA & Broadhurst AJ (1984): The effects of moderate protein or energy supplements on subsequent nutrient intake in man. *Appetite* **5**, 209–219.
 Strauss RS & Pollack HA (2001): Epidemic increase in childhood overweight, 1986–98. *JAMA* **286**, 2845–2848.
 Tordoff MG & Alleva A (1990): Effect of drinking soda sweetened with aspartame or high-fructose corn syrup on food intake and body weight. *Am. J. Clin. Nutr.* **50**, 963–969.

Tournier A & Louis-Sylvestre J (1991): Effect of the physical state of a food on subsequent intake in human subjects. *Appetite* **16**, 17–24.
 Van Wymelbeke V, Louis-Sylvestre J & Fantino M (2001): Substrate oxidation and control of food intake in men after a fat substitute meal compared with meals supplemented with an isoenergetic load of carbohydrate long-chain triacylglycerols, or medium-chain triacylglycerols. *Am. J. Clin. Nutr.* **74**, 620–630.

Appendix A

Food choices provided during the *ad libitum* lunches and dinners are given in Table 3.

Table 3

Food items	Energy* (kJ)	Protein (g)	Fat (g)	Carbohydrate (g)
Apples	231	0.3	0.4	12.6
Bananas	417	1.2	0.2	23.3
Bread	1066.7	7	0.8	55
Brillat Savarin cheese ^a	1224	14.8	25.4	1.16
Butter ^b	3143	0.7	83	0.5
Butter cookies ^c	1865	9.5	12	74
Camembert cheese ^d	1197	20.5	25.1	0.12
Carrots ^e	137	0.8	0.3	6.7
Chicken ^f	734	29.3	6.5	0
Chocolate cookies ^c	2100	6.5	23	67
Chocolate pudding ^c	577	3.7	4.8	19.8
Comté cheese ^c	1666	29.2	31.3	0
Cream cheese ^g	487	7.7	8	3.4
Dark chocolate ^c	2243	4	30	63
Diced vegetables ^e	229	1.9	0.3	11.2
Eggs (hard boiled) ^c	644	12.5	11.1	1
Fruit sugar ^h	936	0	0	56
Fruit yoghurt ^c	419	3.2	2.5	16
Gherkin ^c	34.2	0.5	0.07	1.4
Green beans ⁱ	98	1.4	0.2	4
Green peas ^e	284	4	0.4	12
Gruyère cheese ^c	1692	29.8	32.3	0
Ham ^c	426	20.1	2.2	0.4
Hash beef steak ^j	900	20	15	0
Kiri cheese ^k	1422	9	32.9	2
Lentils ^l	431	7.6	0.5	17
Mayonnaise ^c	3031	1.4	80	2.8
Milk chocolate ^c	2201	7	29	57
Mustard ^m	406	6	5	7
Tuna-Fish ^c	510	26.5	1.7	0
French dressing ^c	1047	0.5	26.6	3.2
Oranges	184	1	0.2	9.5
Pears	234	0.5	0.3	12.8
Potatoes	355	2	0.1	19
Powdered sugar ⁿ	1667	0	0	99.7
Radish	79	1	0.1	3.5
Ravioli ^o	611	9.2	4.9	16.3
Rice ^p	1460	7	0.8	78.5
Salad	103	1.5	0.3	4
Stew ^c	326	1	6.2	4.5

Table 3 (continued)

Food items	Energy* (kJ)	Protein (g)	Fat (g)	Carbohydrate (g)
Tabouleh ^q	757	3.5	8.4	23
Turkey breast ^r	460	24.2	1.5	0
Uncooked carrots	182	1.2	0.3	9

*Per 100 g.

^aCheese-dairy of the Brie, Saint-Simeon, France.

^bFlorimont, Clermont-Ferrand, France.

^cCarrefour, Evry, France.

^dMoulin d'argent, Paris, France.

^eA.Le Breton, Rosporden, France.

^fMaitre Co, qSaint Fulgent, France.

^gMennel, Paris, France.

^hSaint-Siffrein, Carpentras, France.

ⁱA.Le Breton.Vaulx-Vraucourt, France.

^jCarrefour, Cuiseaux, France.

^kCheese-dairy Bel, Paris, France.

^lValoire, Montargis, France.

^mLMA, Dijon, France.

ⁿSugar-refinery, Chalon/Saône, France.

^oTaviani, Tarascon, France.

^pVivien-Paille, Valenciennes, France.

^qGarbit et Panzani, Lyon, France.

^rRonsard, Bignan, France.