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Research report

Taste perception and implicit attitude toward sweet related to body mass index and soft drink supplementation☆

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ABSTRACT

These studies examined the differences in sweet taste perception and implicit attitude toward sweet between normal-weight and overweight/obese adults; and tested the effects of soft drink consumption on sweet taste, explicit preference and implicit attitude toward sweet in normal-weight subjects. In study 1, normal-weight ($n = 22$) and overweight/obese ($n = 11$) adults were assessed for sweet taste intensity and pleasantness. Implicit attitude toward sweet was assessed by implicit association test (IAT). In study 2, normal-weight, lightly active adults ($n = 12$) underwent one month soft drink supplementation (≈760 ml/day). This increased their daily carbohydrate intake by 2.1 ± 0.2 g/kg body weight. Sweet taste perception, explicit preference and implicit attitudes to sweet were assessed. In both studies salty taste was also assessed as a contrasting perception. Overweight/obese subjects perceived sweet and salty tastes as less intense (−23% and −19%, respectively) and reported higher IAT scores for sweet than normal-weight controls (2.1-fold). The supplementation changed sweet intensity/pleasantness ratings and it increased explicit preference (2.3-fold) for sweet in a subgroup of initial sucrose-dislikers. In conclusion, overweight/obese individuals are more implicitly attracted to sweet. One month of soft drink supplementation changed sweet taste perception of normal-weight subjects.

Introduction

In westernized countries the consumption of soft drinks has increased consistently over the last three decades (Barquera et al., 2008; Duffey & Popkin, 2007; Nielsen & Popkin, 2004; Vereecken, Inchley, Subramanian, Hublet, & Maes, 2005). Indeed, the total estimated delivery of caloric high-fructose corn syrup and glucose syrup for domestic food and beverages has increased 11.6 times from 1966 to 2003 in the US (ERS, 2004). Additionally, soft drinks provide the largest amount (47%) of added sugars in the diet of US Americans (Guthrie & Morton, 2000). The strong palatability of sweet taste (Lenoir, Serre, Cantin, & Ahmed, 2007) along with the high energy density and the low cost of soft drinks (Drewnowski & Bellisle, 2007) might explain their escalating popularity.

Considering the low physical activity levels in westernized countries (Booth, Gordon, Carlson, & Hamilton, 2000; Hayes et al., 2005), high and chronic soft drink consumption has a detrimental impact on public health. In fact, there is epidemiologic and experimental evidence that high consumption of soft drinks is associated with weight gain and obesity (Malik, Schulze, & Hu, 2006). Consuming one or more soft drinks per day is associated with increased odds of developing metabolic syndrome (Dhingra et al., 2007). Furthermore, a high consumption of soft drinks has been associated with an increased risk of developing type 2 diabetes (Montonen, Jarvinen, Knekt, Heliovaara, & Reunanen, 2007; Palmer et al., 2008; Schulze et al., 2004).

Taste is the most important factor influencing food choice (Glanz, Basil, Maibach, Goldberg, & Snyder, 1998). Sweetness is a basic drive for food selection (Birch, 1999; Booth, Conner, & Marie, 1987), and there is a positive correlation between the percentage of calorie intake from sweet, and sweet preference (Mattes & Mela, 1986). Several investigations have tried to elucidate the relationship between sweet taste perception and obesity (Donaldson, Bennett, Baic, & Melichar, 2009), yet there is still some divergence on the nature of this relationship (Bartoshuk, Duffy, Hayes, Moskowitz, & Snyder, 2006). In fact, some investigations showed that obese and normal-weight individuals have the same sensitivity for sweet (Grinker, 1978; Grinker & Hirsch, 1972), and others showed that obese persons have a lower sensitivity for sweet than normal weight controls (Bartoshuk et al., 2006).

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Taste is a plastic system (Heath, Melichar, Nutt, & Donaldson, 2006). Indeed, hedonic ratings for high-fat food were reduced by 12 weeks of reduced-fat diet, when the sensory exposure to fat was restricted (Mattes, 1993). Accordingly, it is possible that a regular consumption of soft drinks might move the taste threshold for sweet to a higher level and potentially alter perception of both intensity and pleasantness. These effects could eventually enhance regular soft drink consumers' preference for sweet tasting food/drinks. There is some existing evidence that a short term period (8 days) of sweet orangeade exposure can increase children's preference for this orangeade (Liem & de Graaf, 2004). However, this effect was not seen in young adults (Liem & de Graaf, 2004). This discrepancy was probably due to the fact that in that study the children liked the sweet orangeade more than the adults, who tended to reduce their orangeade consumption throughout the study (Liem & de Graaf, 2004). In the present article it is hypothesized that if a leading soft drink on the market, preferred by adults, is used and a longer time of exposure is applied, the preference for sweet could be increased in adults as well.

Implicit or non-conscious preferences or attitudes might also play a key role in the high consumption of soft drinks, particularly among obese individuals. Implicit attitudes are unconsciously held positive or negative evaluations of an object and they reflect automatic associations in memory between concepts (Greenwald et al., 2002). The implicit association test (IAT) is frequently used to assess implicit attitudes. The IAT is a computerized method for indirectly assessing attitudes toward an object by measuring the strengths of associations among concepts through the speed with which individuals respond to the presentation of stimuli associated with the concepts. The assumption behind the IAT is straightforward: if two concepts are highly associated in memory (e.g., sweet food and favorable attributes), then they are easier to associate via IAT's sorting tasks, than if the two concepts are weakly associated (e.g., sweet food and unfavorable attributes) (Greenwald & Nosek, 2001). Thus, response latencies are faster for strongly associated concepts. It seems that obese people have different implicit food preferences from their non-obese counterparts (Capaldi, 1996; Drewnowski, Kurth, Holden-Wiltse, & Saari, 1992). To the authors' knowledge it is not yet known whether implicit attitude toward sweet differs between obese people and normal-weight people.

Moreover, changes in eating behavior might have some links to increased adipokines caused by augmented adiposity induced by the soft drink supplementation. Leptin is an adipokine that is involved in long term regulation of appetite and its levels vary, directly according to the amount of body fat mass (Considine et al., 1996; Friedman & Halaas, 1998). Leptin diminishes the perception of food reward and enhances the response to satiety signals generated during food consumption (Farooqi et al., 2007). A study in mice has shown that leptin selectively inhibits sweet taste responses through activation of outward K^+ currents, and that in diabetic *db/db* mice, taste cells are not affected by leptin levels (Kawai, Sugimoto, Nakashima, Miura, & Ninomiya, 2000). Moreover, recent investigations in humans showed that sweet taste perception varies with leptin levels (Nakamura et al., 2008). It is possible that changes in taste sensitivity and concomitant changes in food preference are influenced by body weight-induced leptin level alterations. For this reason, in the present article also the possible involvement of leptin on sugar consumption was investigated.

The authors conducted two studies. The purpose of study 1 was to test the hypothesis that there are differences in sweet taste perception and/or implicit attitude toward sweet between normal-weight and overweight/obese young adults. The aim of study 2 was to test the hypotheses that one month of consumption of a commercially available soft drink would alter taste perception (intensity and pleasantness) of sweet, and explicit preferences and implicit attitudes toward sweet in healthy, lightly physically active subjects. Secondarily, study 2 tested if there is a correlation between leptin levels and sugar consumption. In both studies salty taste was also assessed as a contrasting perception.

Materials and methods

Study 1

Subjects and study design

Thirty-four young healthy adults, fourteen males and twenty females (mean age 22.8 ± SD 2.5 yrs; BMI mean 24.7 ± SD 4.7) were recruited via university e-mail announcements within the Bangor University population. The subjects completed a medical questionnaire to verify that none of them had any chronic diseases. Sweet and salty taste and IAT toward sweet were tested twice. The thirty-four subjects were split into two groups according to their BMI. The normal-weight (NW) group had a BMI ≥18 and <25, the overweight/obese (Ov/Ob) group had a BMI ≥25. Consequently, twenty-two subjects (seven males and fifteen females) were allocated in the NW group, eleven subjects (seven males and four females) in the Ov/Ob group, and one subject was excluded because of a BMI less than 18 (Table 1).

Taste test

Eleven concentrations of sucrose (0, −0.5, −0.75, −1, −1.25, −1.5, −1.75, −2, −2.25, −2.5, −2.75 log[sucrose] mol/L) and seven concentrations of sodium chloride (−1, −1.25, −1.5, −1.75, −2, −2.25, −2.5 log[NaCl] mol/L) were prepared with demineralised water. These concentrations were used to determine perception across threshold and into the suprathreshold concentration range, rather than at a single suprathreshold concentration. Generalized Labeled Magnitude Scales (gLMS) (Green et al., 1996) of intensity (150 mm) and pleasantness (±86 mm) were adopted to measure the perceptions of intensity and pleasant/unpleasantness of the sucrose or sodium chloride solutions by the subjects. The use of the gLMS was carefully explained to all subjects prior to testing by means of standard information, but the subjects received no prior training. The low (barely detectable) and the high (the strongest imaginable sensation of any kind) anchor points of the intensity scale and the low and high anchor points of the pleasantness scale (anchors: most unpleasant imaginable, most pleasant imaginable, midpoint 0 = neutral) were established prior to the beginning of the test. All solutions (5 ml each) were presented at room temperature. The various concentrations were presented in a random order and they were labeled with undetectable code names. Moreover, the operator who provided the solutions did not know their concentrations. Intensity and pleasantness were assessed using a standard 'sip-and-spit' procedure. The subjects were asked to sip the solution and wash their mouths with it for about 5 s, discharge the solution and rate how strong and how pleasant the taste was using the gLMS (Mattes, 2009).

The subjects were informed whether the solutions were meant to be sweet or salty, but not about their concentration. Between

Table 1
Subject's characteristics (study 1).

	NW (22)	Ov/Ob (11)	*t*-Value (df = 31)	*P* level
Age (yrs)	23.1 ± 2.9	22.2 ± 1.6	1.022	0.315
Height (m)	1.70 ± 0.08	1.72 ± 0.08	−0.609	0.547
Weight (kg)	64.3 ± 8.6	89.0 ± 8.7	−7.741	<0.001***
BMI (kg/m²)	22.2 ± 2.0	30.2 ± 3.6	−6.964	<0.001***
IAT scores	0.40 ± 0.57	0.85 ± 0.30	−2.954	0.006**

BMI, body mass index; IAT, implicit association test; Ov/Ob, overweight/obese group; NW, normal-weight group.
** $P < 0.01$.
*** $P < 0.001$.

each taste they rinsed their mouths with dematerialized water for about 20 s. The order of the taste tests (sucrose intensity and pleasantness, sodium chloride strength and pleasantness) was randomized.

All subjects were asked to refrain from alcohol for 24 h prior to the test days and from caffeine consumption on test days. They were asked to be well hydrated before undergoing this test. Before the test the subjects were asked to complete the Spielberger State and Trait questionnaire (1983) as anxiety is known to affect taste perception (Heath et al., 2006). The State and Trait inventory, developed by Spielberger (1983), discriminates the temporary emotion (i.e., the current level of anxiety) from the predisposition of a person to be anxious. It is a consolidated and reliable measure of anxiety (Shek, 1988).

Implicit association test

Inquisit 3.0 (2008) which measures response latencies to keyboard presses with millisecond accuracy was used to generate the test and collect the data. The IAT was presented in seven blocks, five of which were practice trials to acquaint subjects with the stimulus materials and categorization rules. The target category exemplars comprised images of sweet (e.g., chocolate and cola drinks) and non-sweet (e.g., savoury foods and water) foods and drinks. Practice blocks comprised 20 trials each. The critical test blocks were the fourth (20 trials) and fifth (40 trials), labeled compatible blocks, where the sweet exemplars were paired with positive attribute words (e.g., 'pleasure') on one response key and the non-sweet exemplars with the negative attribute words (e.g., 'tragic') on another response key, and the sixth and seventh blocks (20 and 40 trials, respectively), labeled incompatible blocks, in which these pairings were reversed. There were eight images and attribute words in each category. Exemplar and attribute stimuli were presented randomly without replacement within blocks, independently for each subject. Order of presentation of compatible and incompatible blocks was counterbalanced across subjects. Response latencies were recorded for the test block trials and an IAT score was computed from the mean difference between performance on the compatible and incompatible blocks using the *D*-score algorithm for IAT data (Greenwald, Nosek, & Banaji, 2003).

Study 2

Subjects and study design

A pre-test post-test, within subject design was used to test the authors' research hypotheses. An initial screening for lifestyle and soft drink consumption was executed, before the first visit, via qualitative questionnaires within the Bangor University population.

Healthy people with low physical activity, no more than 1–3 days of light exercise a week, and consuming less than one pint of soft drink and or fruit juices per week were considered eligible to take part. The physical activity scores used in this study were defined as follows: 1 = physically inactive (little or no exercise), 2 = lightly active (light exercise or sports 1–3 days a week), 3 = moderately active (moderate exercise or sports 3–5 days a week) and 4 = very active (hard exercise or sports 6–7 days a week). Soft drink consumption scores: 1 = more than 4 pints a week, 2 = 1–2 pints a week, 3 = less than 1 pint (or can) a week and 4 = none. Out of 213 people screened, 32 were considered eligible.

Out of the 32 eligible people 12 subjects, 7 females and 5 males, consented to take part in this study (age: 26 ± 6 yrs, height: 1.73 ± 0.09 m, weight: 65.5 ± 9.6 kg, BMI: 21.7 ± 1.5, physical activity scores: 2.00 ± 0.60, soft drink scores: 3.42 ± 0.51). Subjects were informed that upon completion of testing they would receive a £100 monetary compensation. Before and after the intervention period, subjects attended Bangor University's laboratories for two testing sessions. Although all the subjects included in this study were physically lightly active, they were asked to refrain from heavy exercise for 24 h prior to all tests. Moreover, the subjects were asked to keep their normal physical activity constant throughout the duration of the intervention. Unless otherwise mentioned, all the tests described in study 2 were conducted before or 36 h after the last soft drink supplementation.

Diet diaries

Subjects were introduced to diet diaries via standard instructions (Gibson, 1993) and were informed about the importance of the accuracy and precision of their reports as crucial requirements of this study. Then, subjects were asked to keep a seven day diet diary for a week before the intervention started. The adherence of their records to the standards required was checked at the pre-test sessions and further instructions about the standards required were given. During the supplementation month subjects were asked to keep a fourteen day diet diary. The fourteen days were randomly chosen over the intervention period of four weeks. Energy balance was estimated from measurements of changes in body composition by using Elia, Stratton, and Stubbs' method (2003). Diet diaries were recorded in order to assess energy intake and macronutrient changes due to the intervention.

Analytical procedures

An overnight fasting venous blood sample (4 ml) was collected into heparinized vacutainers from the antecubital vein of each subject. The plasma sample aliquots were then stored at -40 °C for later analysis. Leptin was also analyzed from fasting plasma samples by ELISA (BioVendor, Laboratoní medicína, Modrice, Czech Republic). Out of range values were excluded from statistical analysis.

Taste test, IAT and preference test

Taste and IAT were carried out on the subjects of study 2 as described in study 1. Since no differences in salty taste perception were expected to occur with the intervention, intensity and pleasantness scores of salty taste were measured as a control. Additionally, a sucrose preference test was conducted (adapted from Liem & Mennella, 2002). Five different sucrose solution concentrations (0, -0.5, -0.75, -1 and -1.25 log[sucrose] mol/L) were presented in ten random pairs. After tasting the two sucrose solutions the subjects had to indicate the one they preferred. The number of times in which the subjects preferred the highest concentration was calculated as a percentage of the total number of presentations. The median preference score at baseline was used to split the group into "sucrose-likers" (preferred the most concentrated solution > median 55%) and "sucrose dislikers" (preferred the most concentrated solution < median-scores). The preferences for sweetness by the "sucrose-likers" and the "sucrose dislikers" were compared using a Fisher's exact test.

A pilot study conducted on eight subjects showed that the soft drink used in this study (Lucozade Energy, orange and apple flavors) had intensity and pleasantness scores in the range of the sucrose solutions used in the taste tests (Orange: 2.95 ± 0.98 cm, 0.77 ± 0.51 cm; Apple: 3.76 ± 1.52 cm, 0.61 ± 2.71 cm).

Study intervention

The subjects underwent a four week soft drink (Lucozade Energy, GlaxoSmithKline plc, UK) supplementation on top of their habitual diet. Soft drink supplementation was carried out on the basis of a carbohydrate intake ≈2.0 g/kg body weight per day (Reiser et al., 1979). Post-test analysis determined a carbohydrate intake of 2.1 ± 0.2 g/kg body weight per day. This corresponded, on average, to 760 ml energy drink per subject per day. Experimenters provided the subjects with the energy drinks (on average 2 times a week). Subjects were told to keep all the other aspects of their habitual diet constant throughout the duration of the intervention. Subjects' urine was collected throughout the intervention period without prior notice on random days. The subjects were told that their urine samples were tested for energy drink specific markers in order to check the compliance of the subjects to the supplementation. This deception was implemented to improve adherence to the protocol. Subjects were debriefed at the end of the study. In addition, empty drink bottles were collected.

The experimental protocols of these two studies were approved by the School of Sport, Health and Exercise Sciences Research Ethics Committee (Bangor University) in accordance with the Declaration of Helsinki. Subjects were asked to sign the informed consent prior to taking part in the study. Taste tests, explicit and implicit tests were performed by the same investigator in all cases – investigator and subjects were blind to the hypotheses of the studies.

Analysis

The statistical analysis was performed using SPSS 14 standard version. Unless otherwise specified, all data are reported as means ± standard deviations. For study 1 the differences between the NW group and the Ov/Ob group were analyzed via independent samples *t*-test. In case of the taste tests, two way three way repeated measures ANOVA were used with concentration as the within subject factor and group the between subject factor. The outcomes of study 2 were analyzed with Student's paired-samples *t*-tests. Taste curves were analyzed by three-way repeated measures ANOVAs (time and concentration as within subject factors and gender as between subject factor). Preference test and IAT scores (for split groups) in study 2 were analyzed via two-way repeated measures ANOVAs (time as within subject factor and subgroups as between subject factor). A within-subject correlation coefficient was computed for the correlations between IAT and preference scores, leptin levels and sugar intakes and leptin levels and preference scores using the method described by Bland and Altman (1995). This method adjusts for repeated observations within subjects (baseline and post intervention) by using multiple regression with 'subject' treated as a categorical factor using dummy variables. Appropriate post hoc test with Bonferroni correction were used. The significance level was set at 0.05 (two-tailed). The probability value for trends was set at 0.10.

Results

Study 1

Taste tests in overweight-obese and normal-weight subjects

The overweight-obese subjects tasted the sweet sucrose solutions as being 23% less intense than the normal-weight subjects. In the sucrose taste test there was a significant increase in

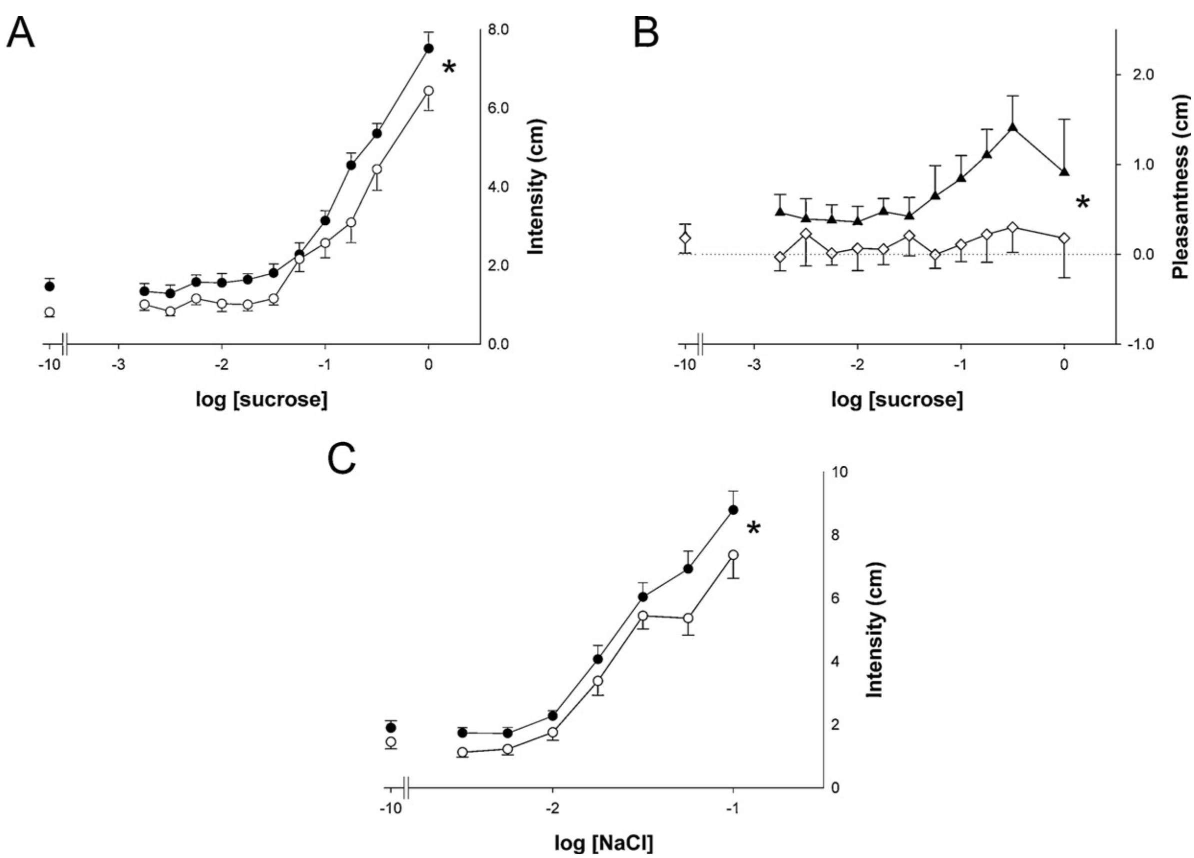

Fig. 1. (A) Sucrose intensity scores for normal-weight (closed circles, *n* = 22) and overweight/obese (open circles, *n* = 11) young adults. $^*P < 0.05$ main effect of group. (B) Sucrose pleasantness score differences between males (closed triangles, *n* = 14) and females (open diamonds, *n* = 19). $^*P < 0.05$ main effect of gender. (C) Salt intensity score differences between normal-weight (closed circles) and overweight/obese (open circles) young adults. $^*P < 0.050$ main effect of group. Data points are expressed as mean and SEM. Intensity scale equivalents (A and C): barely detectable = 0 cm; weak = 1.1 cm; moderate = 2.7 cm; strong = 5.5 cm; very strong = 8 cm; strongest imaginable sensation of any kind = 15 cm. Pleasantness scale equivalents (B): neutral = 0 cm; slightly pleasant = 0.5 cm; moderately pleasant = 1.9 cm; pleasant = 3 cm; very pleasant = 4.5 cm; most pleasant imaginable = 8.6 cm; slightly unpleasant = −0.5 cm; moderately unpleasant = −1.9 cm; unpleasant = −3 cm; very unpleasant = −4.5 cm; most unpleasant imaginable = −8.6 cm.

Table 2
Average energy and macronutrient intake (means ± standard deviations, $n = 12$) at baseline and during the 4 weeks of intervention (study 2).

	Baseline	During the intervention	t-Value (df = 11)	P level	η^2 partial
Energy intake (kcal/day)	2383 ± 624	2413 ± 542	−0.169	0.869	0.003
Protein (g/day)	81.5 ± 21.2	70.6 ± 22.1	2.891	0.015*	0.432
CHO (g/day)	265 ± 69	339 ± 68	−3.276	0.007**	0.494
Sugar (g/day)	95.0 ± 40.4	179.5 ± 34.1	−9.698	<0.001***	0.895
MUFA (g/day)	40.5 ± 15.0	32.7 ± 16.9	1.980	0.073#	0.263
PUFA (g/day)	12.4 ± 7.5	8.1 ± 5.0	2.742	0.019*	0.406
SFA (g/day)	41.6 ± 18.1	30.8 ± 16.4	2.251	0.046*	0.315
Dietary fiber (g/day)	19.5 ± 5.6	17.8 ± 6.0	1.578	0.143	0.184

CHO, carbohydrate; MUFA, monounsaturated fat; PUFA, polyunsaturated fat; SFA, saturated fat.
# $P < 0.1$.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

intensity scores with increasing concentrations, as expected (main effect of concentration, $F(11,341) = 105.85$, $P < 0.001$, η^2 partial = 0.773). The Ov/Ob group showed significantly lower sucrose intensity scores across the range of concentrations compared to the NW group (main effect of group, $F(1,31) = 7.12$, $P < 0.05$, η^2 partial = 0.187) (Fig. 1A). There was no significant interaction between group and concentration in the sucrose intensity scores (group × concentration interaction, $F(11,341) = 0.95$, $P = 0.490$, η^2 partial = 0.030).

Pleasantness scores were not strongly affected by sucrose concentration; a trend toward a significant main effect of concentration was found in the sucrose pleasantness test ($F(11,341) = 1.65$, $P = 0.085$, η^2 partial = 0.050). A trend toward a higher pleasantness was found in the Ov/Ob group (main effect of group, $F(1,31) = 3.98$, $P = 0.055$, η^2 partial = 0.114), however, males rated all the sucrose solutions 5-fold more pleasant than females (main effect of gender $F(1,29) = 5.65$, $P < 0.050$, η^2 partial = 0.163), and the proportion of males vs. females in the Ov/Ob group (∼2:1) was ∼2 times greater than in the NW group (∼1:2) (Fig. 1B).

Salt taste test revealed a significant increase in intensity scores with increasing concentrations (main effect of concentration $F(7,217) = 90.43$, $P < 0.001$, η^2 partial = 0.745) and the Ov/Ob group rated all sodium chloride solutions as less intense (−19%) than the NW group (main effect of group, $F(1,31) = 4.74$, $P < 0.050$, η^2 partial = 0.133) (Fig. 1C). Salt pleasantness tests showed only a significant main effect of concentration ($F(7,217) = 47.54$, $P < 0.001$, η^2 partial = 0.605). Higher concentrations were rated significantly less pleasant than the lower concentrations. No other effects were found for salt taste intensity and pleasantness.

Implicit attitude changes in overweight-obese subjects

The overweight-obese subjects had a 2.1-fold stronger automatic attraction to sweet than the normal-weight counterparts. The computer based IAT indicated that the Ov/Ob group had significantly higher scores than the NW group (Table 1), indicating a stronger implicit attitude to sweet in overweight/obese subjects. A significant Pearson correlation between IAT scores and BMI was observed ($n = 33$, $r = 0.36$, $P < 0.050$).

Study 2

Eating behavior and energy intake

Energy and macronutrient intakes gathered from subject's diet diaries are reported in Table 2. During the soft drink intervention subjects changed their diet composition by increasing the CHO by 12% and decreasing fat and protein by 10% and 2%, respectively. The amount of alcohol consumed before and during the intervention showed a similar reduction, it was on average 22 kcal/day less during the intervention.

The supplementation was intended to increase the daily energy intake by about 600 kcal/day. This study's diet diary data showed a non-significant increase in energy intake of only about 30 kcal a day. Estimation of energy balance established by body composition changes (see Table 3) indicates that an increase of circa 1 kg of fat mass with no changes in lean mass in one month corresponds to about 345 kcal energy surplus a day.

Perception of sucrose and salt intensity and pleasantness

The soft drink intervention altered both intensity and pleasantness taste perceptions of sweet. Temporal and long-standing anxiety as measured by state and trait Spielberger inventory were within the normal range prior to the intervention, and did not significantly change with the soft drink supplementation (Table 3). It is unlikely therefore that anxiety level contributed to any change in taste perception. Analysis of variance of the sucrose intensity tests showed a significant time × sucrose concentration interaction ($F(11,110) = 3.11$, $P < 0.001$, η^2 partial = 0.237), meaning that the intervention altered the perception of taste intensity for sucrose. Sucrose intensity scores significantly increased with increasing concentration (main effect of concentration, $F(3,31) = 83.8$, $P < 0.001$, η^2 partial = 0.893). No significant main effect of time was found ($F(1,10) = 0.07$, $P = 0.799$, η^2

Table 3
Body composition, leptin and anxiety levels before and after the soft drink supplementation (means ± standard deviations, $n = 12$) (study 2).

	Baseline	4 weeks intervention	t-Value (df = 11)	P level	η^2 partial
Body weight (kg)	65.5 ± 9.6	66.6 ± 10.5	−1.936	0.079#	0.254
Fat mass (kg)	15.7 ± 5.1	16.8 ± 4.9	−2.99	<0.050*	0.448
Lean mass (kg)	47.2 ± 12.4	47.2 ± 12.8	0.03	0.975	<0.001
Plasma leptin (ng/ml)[a]	6.33 ± 6.23	7.66 ± 6.98	−2.23	<0.050*	0.383
Normalized plasma leptin[a] (ng/ml/kg)	0.10 ± 0.98	0.12 ± 0.11	−1.971	0.084#	0.277
Anxiety-State	30.4 ± 9.8	30.9 ± 6.6	−0.219	0.831	0.004
Anxiety-Trait	32.2 ± 7.2	35.3 ± 11.6	−1.441	0.177	0.159

[a] $n = 9$, df = 8.
# $P < 0.10$.
* $P < 0.05$.

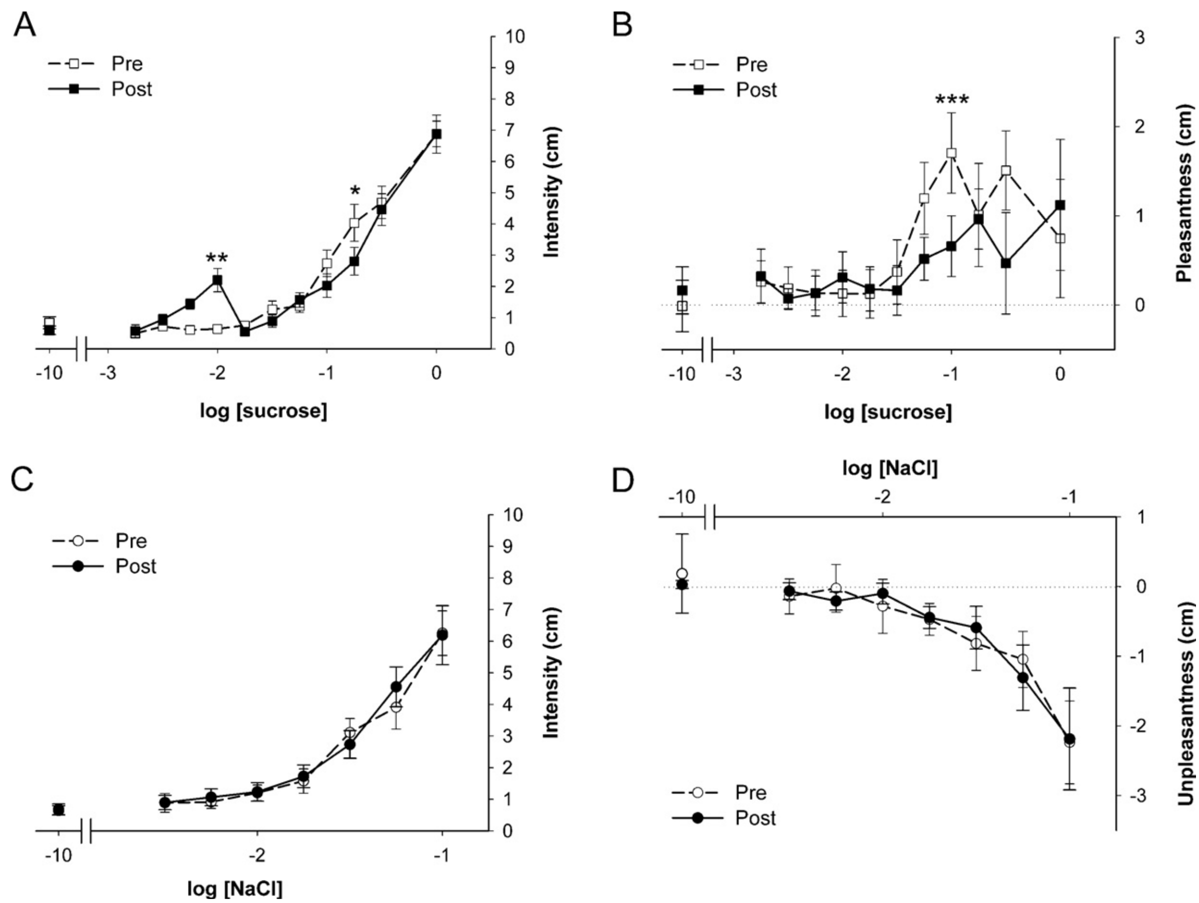

Fig. 2. Changes in taste perception induced by 4 weeks of soft drink consumption. Baseline and post intervention sucrose scores are represented as squares (A and B) and sodium chloride scores as circles (C and D). Pre intervention scores are represented with open symbols and post intervention scores with closed symbols. Data points are expressed as mean and SEM. $^{*}P < 0.050$, $^{**}P < 0.010$, $^{***}P < 0.001$, $n = 12$. For intensity and pleasantness equivalents see legend of Fig. 1.

partial = 0.007). Post hoc Bonferroni tests for simple main effects of time (sucrose intensity before vs. sucrose intensity after intervention) revealed a significant difference only for 10 mM (−2 log[M]) and 178 mM (0.75 log[M]) sucrose concentrations ($t(11) = 3.77$, $P < 0.010$, and $t(11) = 2.97$, $P < 0.050$) (Fig. 2A).

A significant time × sucrose concentration interaction ($F(11,110) = 1.91$, $P < 0.050$, η^2 partial = 0.148) was found for pleasantness, whereas there was no significant main effect of sucrose pleasantness concentration ($F(2,23) = 2.42$, $P = 0.105$, η^2 partial = 0.195). No significant main effect of time was found for sucrose pleasantness ($F(1,10) = 0.35$, $P = 0.567$, η^2 partial = 0.034). Follow-up Bonferroni corrected *t*-tests showed a significant decrease in pleasantness with soft drink intervention only for 100 mM (−1 log[M]) ($t(11) = 5.58$, $P < 0.001$) (Fig. 2B). Gender did not contribute to differences in sucrose taste perception; no gender interactions or main effects were detected for sucrose intensity or sucrose pleasantness.

No effect of the soft drink supplementation was detected in the salt taste tests. There was no significant time × concentration interaction for salt intensity and pleasantness scores ($F(218,19) = 0.34$, $P = 0.731$, η^2 partial = 0.037; $F(3,38) = 0.37$, $P = 0.823$, η^2 partial = 0.035, respectively). Main effects of salt concentration were found for salt intensity and pleasantness ($F(2,22) = 43.1$, $P < 0.001$, η^2 partial = 0.827; $F(1,18) = 7.05$, $P < 0.010$, η^2 partial = 0.414, respectively). There were no main effects of time for salt intensity and pleasantness scores ($F(1,9) = 0.35$, $P = 0.571$, η^2 partial = 0.037; $F(1,9) = 0.01$, $P = 0.910$, η^2 partial = 0.001, respectively) (Fig. 2C and D). No gender interactions or main effects of gender were found for salt intensity and pleasantness measures.

Changes in preference for sweetness

The soft drink intervention increased sweet liking in subjects who did not prefer sweet at baseline. Considering the group as a whole ($n = 12$), the preference for sweeter or less sweet solutions did not change; no significant difference was found between baseline and post-intervention preference scores (50.8 ± 37.5 vs. 57.5 ± 30.5, $t(11) = -0.85$, $P = 0.421$, η^2 partial = 0.062). However, when the subjects were split into two groups based on a median split of the baseline preference scores (sucrose-likers, $n = 6$ and sucrose-dislikers, $n = 6$), a significant effect of the supplementation was found (time × group interaction, $F(1,10) = 7.04$, $P < 0.050$, η^2 partial = 0.413). There was also a significant main effect of group ($F(1,10) = 18.3$, $P < 0.010$, η^2 partial = 0.646) and no main effect of time ($F(1,10) = 1.13$, $P = 0.313$, η^2 partial = 0.101). Follow-up tests revealed a significantly increased sucrose preference in the initial sucrose-dislikers group ($t(5) = -2.83$, $P < 0.050$, η^2 partial = 0.628), but no difference in the initial sucrose-likers group ($t(5) = 1.04$, $P = 0.348$, η^2 partial = 0.176) (see Fig. 3A), after the intervention. There was a trend toward a significant correlation between the baseline sugar intakes of the twelve subjects and their baseline preference scores ($n = 12$, $r = 0.54$, $P = 0.071$).

Implicit attitude toward sweet food

Automatic attraction to sweet was not changed by the soft drink intervention. IAT scores did not show any alteration with the soft drink intervention (0.95 ± 0.50 vs. 0.97 ± 0.41, $t(11) = -0.11$, $P = 0.917$). No statistical difference was observed even when IAT scores were analyzed for the sucrose-likers and sucrose-dislikers subgroups (IAT time × group interaction: $F(1,10) = 0.30$, $P = 0.598$, η^2 partial = 0.029; IAT main effect of time: $F(1,10) = 0.01$, $P = 0.920$, η^2

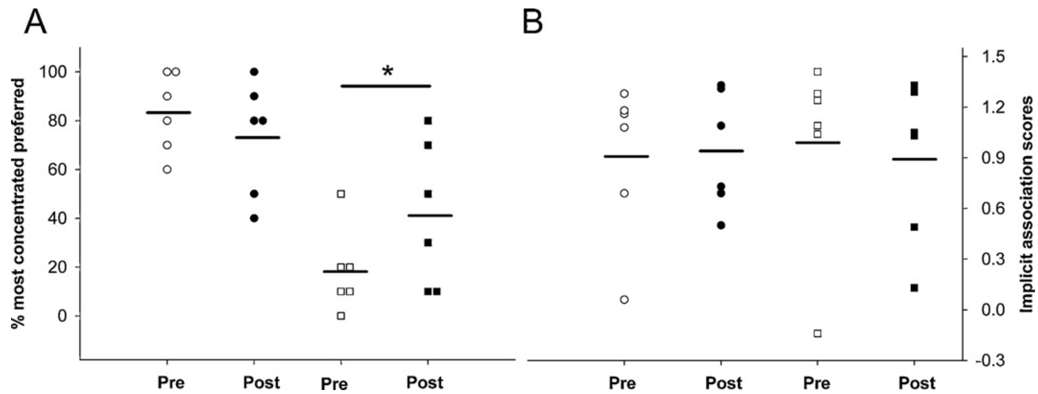

Fig. 3. Influence of soft drink supplementation on explicit preference (A) and implicit attitude (B) toward sweet. Pre-post sucrose-likers' scores are shown with circles ($n = 6$) and pre/post sucrose-dislikers' scores with squares ($n = 6$). Pre intervention scores are represented with open symbols and post intervention scores with closed symbols. Data points are expressed as mean and SEM.*$P < 0.050$.

partial = 0.001 and IAT main effect of group: $F(1,10) = 0.09$, $P = 0.775$, η^2 partial = 0.009). There was no within-subject correlation between IAT scores and preference scores ($n = 12$, $r = 0.18$, $t = 0.62$, $P = 0.547$) (Fig. 3B).

Changes in appetite and plasma leptin

Out of twelve subjects, six reported a smaller overall appetite during intervention compared with before; five reported the same overall appetite and only one a larger appetite. There was a significant increase in post-intervention fasting plasma leptin, which became a trend once leptin was normalized by body weight (Table 3). Although, an effect of gender was found for either unnormalized and normalized leptin levels ($F(1,7) = 8.232$, $P = 0.024$, η^2 partial = 0.540; $F(1,7) = 10.219$, $P = 0.015$, η^2 partial = 0.593, respectively), no time × gender interaction was observed ($F(1,7) = 0.051$, $P = 0.828$, η^2 partial = 0.007; $F(1,7) = 0.126$, $P = 0.733$, η^2 partial = 0.018, respectively). There was a trend toward a significant within-subject correlation between leptin levels and sugar intakes ($n = 9$, $r = 0.60$, $t = 2.123$, $P = 0.067$). This was weakened once leptin was normalized ($n = 9$, $r = 0.54$, $t = 1.810$, $P = 0.108$). However, the trend between leptin levels and preference taste scores ($n = 9$, $r = 0.57$, $t = 1.935$, $P = 0.089$) disappeared once leptin was normalized ($n = 9$, $r = 0.34$, $t = 1.020$, $P = 0.335$).

Discussion

The purpose of the current investigation was to elucidate the relationship between sweet taste perception and obesity, and to study the implicit attitude of overweight/obese individuals toward sweet food/drinks. Moreover, the authors aimed to test whether an environmental factor, such as soft drink consumption, could alter sweet taste perception (intensity and pleasantness) and explicit preferences and implicit attitudes for sweet in healthy, lightly active, normal-weight subjects. A second aim was to determine whether leptin levels and sugar consumption are correlated. In this study it was found that there are differences in sweet and salty taste perceptions and implicit attitude toward sweet food/drinks between young overweight/obese individuals and normal-weight controls of the same age, and that sweet taste perception can be altered by one month of soft drink supplementation in young, normal-weight, healthy subjects.

Study 1

Taste intensity

In this study, sweet (sucrose) and salty (sodium chloride) taste intensity and pleasantness were measured using a gLMS in a group of young overweight/obese individuals and normal-weight controls. Sucrose as well as sodium chloride taste intensity scores were lower in the Ov/Ob group compared with the NW group. This indicates that young overweight/obese individuals perceive sweet and salty as being less intense compared to normal-weight persons. The difference in sweet intensity scores is in line with the findings of Bartoshuk et al. (2006). The fact that the Ov/Ob group perceived the salty solutions as less salty than the NW group possibly reflects higher dietary levels of salt in the Ov/Ob group diet. In fact, previous studies have shown that salt intensity ratings are dependent upon the level of salt consumed habitually, in that higher salt consumption leads to lower intensity scores (Bertino, Beauchamp, & Engelman, 1982). A similar explanation might also be true for the lower sucrose intensity scores in the Ov/Ob group. Indeed, individuals who have a lower sensitivity for sweetness have a higher intake of added sugar (Duffy, Peterson, Dinehart, & Bartoshuk, 2003).

Taste pleasantness

The authors observed a trend toward higher pleasantness scores for sweet taste in the Ov/Ob group. This seems to agree with Bartoshuk et al. (2006) who found that sweet liking increases with body weight. However, in the present study, this could be due to the higher proportion of males in the Ov/Ob group, which was twice as high as in the NW group. In fact, in this study, males showed a higher pleasantness for sweet than females. This gender difference is in complete agreement with a previous investigation on pleasantness of sweet taste and alliesthesia (Laeng, Berridge, & Butter, 1993). Moreover, a previous study reported no difference in pleasantness of sucrose between overweight and normal-weight individuals (Frijters & Rasmussen-Conrad, 1982).

Sodium chloride (salty) pleasantness scores, in the present study, did not differ between the Ov/Ob group and the NW group. However, a recent study with a greater sample size revealed that normal weight men and overweight women have a higher liking for salty taste than overweight men and normal weight and obese women (Donaldson et al., 2009). The fact that in the current study no difference associated with BMI was observed might be related to the typology of the test. A previous study analyzing the effect of a low-sodium diet on salt pleasantness showed no effects on hedonic ratings when subjects had to rate the pleasantness of salty solutions, but they did report an effect when subjects rated the pleasantness of salty soups or crackers (Bertino et al., 1982).

Implicit attitude

The authors also tried to obtain some insights into the automatic responses related to sweet food and drinks. In this study it was demonstrated for the first time that young overweight/obese individuals have a stronger implicit attitude toward sweet food than their normal-weight counterparts. This is in agreement with previous studies on implicit attitude toward food in general. Previous studies have indicated that obese children manifest a more positive implicit attitude toward food, regardless if it is healthy or unhealthy, than non-obese children (Craeynest et al., 2005). Moreover, there is a strong implicit association between unhealthy food and good taste and enjoyment (Raghunathan, Naylor, & Hoyer, 2006). Interestingly, Roefs and Jansen (2002) found that both obese and non-obese people have a negative implicit and explicit attitude toward high-fat foods. Additionally, healthy people had stronger implicit attitude toward food when hungry (Seibt, Hafner, & Deutsch, 2007). Taken together, the present results and previous findings might suggest that obese people have a larger appetite (central leptin resistance) and therefore a more positive attitude toward food in general (healthy and unhealthy). They might also be more susceptible to the positive reward that good tasting food (e.g., sweet food) gives them than non-obese individuals.

Study 2

In study 2 healthy, normal-weight subjects underwent one month of soft drink supplementation. Adverse health outcomes associated with the supplementation were found (submitted manuscript). Fasting plasma glucose and insulin were increased, fat mass was augmented, and the increase in resting respiratory exchange ratio indicates a worsened metabolism (i.e., lower basal fat oxidation).

Taste intensity and pleasantness

The authors measured sweet and salty taste perception before and after the soft drink supplementation. It was hypothesized that dietary levels of sugar would influence only sweet taste, thus the researchers measured salty taste as a control. In fact, no effect of the intervention was present in intensity and pleasantness of salty taste.

Importantly, the present study showed that the glucose syrup based supplementation did alter sweet taste; sensitivity to sweet was increased for weak concentrations and decreased for stronger concentrations (Fig. 2A). Interestingly, the reduction in sucrose intensity scores was in a similar range to the intensity scores measured for the soft drink used in this study. The sucrose-pleasantness test showed a reduced liking for the same sweet concentrations after the soft drink intervention. This might be explained by a shift of the post-test pleasantness curve to the right (Fig. 2B), meaning that liking for sweet was shifted toward higher sucrose concentrations. Unfortunately, this could not be verified in the current study since the concentration range did not extend above 1 M sucrose. The rather rapid alteration in sweet taste found in this intervention study is remarkable. Consistently, taste plasticity was demonstrated in response to other stimuli, such as a short period of exercise (Cartwright et al., 2010), or at a peripheral level by increases in available serotonin and noradrenalin (Heath et al., 2006).

Preference for sweet

The important implication of the taste change is that environment-induced alteration (i.e., continuous soft drink exposure) could determine an explicit preference change (i.e., greater liking for sweet) and consequently a dietary behavior change (i.e., higher sugar intake). The authors tried to address this issue by testing sweet preference. It was noticed that a subgroup of subjects who did not like sweet at baseline (sucrose-dislikers) increased their preference for sweet after the intervention (Fig. 3A). However, the division into two groups, high and low initial preference, cannot exclude that such a result might be a regression to the mean among the sucrose-dislikers. On the other hand, if this result is replicated it will have important implications, supporting the hypothesis that regular soft drink use can change explicit sweet preference within a short period of time, at least among those who do not initially like sweet tastes.

Interestingly, the authors confirmed a strong trend toward a significant correlation between the baseline sucrose preference scores and the baseline dietary sugar consumption, as shown previously by Mattes and Mela (1986). All the other nutrients, carbohydrates included, did not correlate at all with the preference scores. An important implication of this is that if soft drink consumption enhances explicit preference for sweet, sugar use could increase as an effect of chronic soft drink consumption. This vicious circle brings us back to the fact that taste is the main determinant in food choice, and that its alteration has a direct effect on eating behavior.

Leptin

Fasting plasma leptin was increased after the soft drink intervention. The increase in fasting circulating leptin could be explained by the increase in fat mass (Speakman, Stubbs, & Mercer, 2002). Although, the food reports kept by the subjects before and throughout the intervention in this study showed no significant energy intake increase, the increase in fat mass is likely to be due to the energy excess caused by the soft drink supplementation. This discrepancy between body composition changes and diet diary data may be due to inaccuracy in keeping the diet diary and/or probably to reduced energy excretion, which was not measured in this study.

Leptin and insulin are known to function within the central nervous system as satiety signals diminishing food intake when energy levels are met and adipose tissue is restored (Davis, Choi, & Benoit, 2009). Recently, a study on mice showed a specific sweet taste inhibition linked to leptin (Kawai et al., 2000). In the current study two strong trends has been found toward a significant positive correlation between leptin levels and dietary sugar intakes, and leptin levels and sweet preference scores. Although the present outcomes do not provide direct evidence that leptin levels influence sweet preference by changing sweet taste, if this phenomenon took place, leptin would reduce sweet taste sensitivity and sweet-taste-induced reward. In food restricted rats, leptin replacement reduced sweet food-induced reward, and dopamine was required for the sweet food-induced reward (Figlewicz, Higgins, Ng-Evans, & Havel, 2001). Maybe individuals with chronically higher leptin levels perceive less sweet taste reward. Consequently, they have to increase sugar intake to experience the same reward as persons with chronically lower leptin levels and high sweet taste reward. Indeed, obese individuals have fewer dopamine D_2 receptors than normal-weight controls (Wang et al., 2001) and may seek more palatable food to compensate for the decreased dopamine-induced reward (Davis, Strachan, & Berkson, 2004).

Implicit attitude

The soft drink supplementation applied in the current study did not affect IAT scores, suggesting that implicit preference for sweet food and drinks in normal-weight healthy subjects may not be easily changeable. This does not exclude that a longer period of chronic soft drink consumption might alter central appetite regulation in normal-weight healthy subjects and implicit attitudes toward sweet food or food in general.

Implications and conclusions

Brownell et al. (2009) suggested that behavioral and biologic mechanisms might explain the link between soft drink consumption and adverse health outcomes. Moreover, they hypothesized that high intake of soft drinks may have chronic adverse effects on taste preferences and food acceptance (Brownell et al., 2009). The present article's findings give credit to their hypotheses. It is clear that exogenous high-glucose availability, when it is not accompanied by an adequate energy expenditure (e.g., physical exercise), has deleterious effects on people's health. The general positive reward, or in other words, the good taste of sweet food and drinks, combined with their low cost, undoubtedly explains their increasing popularity. Furthermore, it seems that obese people have a stronger implicit attraction to sweet, which might be a result of taste differences, originating from both genetic and environmental factors. The stronger automatic drive of obese individuals to the consumption of sweet food/drinks might also be associated with central leptin resistance. This article demonstrates that chronic soft drink consumption changes taste and food preference. Therefore, it could be one of the environmental factors leading to obesity. However, the effects of soft drinks on sweet taste need to be confirmed by longer intervention studies. Those studies should also include an artificial sweetener group, which could clearly discriminate the effect of sweet from the effects induced by calorie surplus.

In conclusion, young, overweight-obese adults showed lower sweet and salty taste intensity scores compared to normal-weight controls. Young men had a higher liking for sweet than women of the same age. Moreover, one month of commercially available soft drink consumption (about 760 ml a day) induced adverse health outcomes (i.e., increased fat mass, fasting glucose and insulin and reduced basal fat oxidation, submitted manuscript) and altered taste perception of sweet, but did not affect implicit attitude toward sweet in lightly active, normal-weight subjects. Finally, a subgroup of sucrose-dislikers showed an augmented preference for sweet after the soft drink supplementation.

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