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Effect of Salt Intensity on *Ad Libitum* Intake of Tomato Soup Similar in Palatability and on Salt Preference after Consumption

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Abstract

Sensory properties of food play an important role in satiation. Studies on the effect of taste intensity on satiation show conflicting results. This may be due to the notion that in these studies taste intensity and palatability were confounded. The objective of this study was to investigate the effect of salt intensity of tomato soup on *ad libitum* intake (satiation), while controlling for palatability on an individual basis. Forty-eight subjects consumed both a low-salt (LS) and high-salt (HS) soup *ad libitum* from a self-refilling bowl. The results showed no difference between LS and HS soup in *ad libitum* intake, eating rate, changes in appetite ratings, and changes in hedonic ratings after intake. After intake of HS soup, LS soup was perceived as more bland than before intake of HS soup. After intake of LS soup, HS soup was perceived as more salt intense than before intake of LS soup. In conclusion, this study found no effect of salt intensity on satiation of tomato soups that were similar in palatability. During consumption, subjects adapted quickly to the exposed salt intensity as contrasting salt intensities were rated further from the ideal salt intensity and therefore perceived as less pleasant after consumption.

Key words: *ad libitum* intake, contrast effect, salt intensity, satiation

Introduction

Obesity is an increasing problem in Western society. Increased meal size is considered to be a major cause of weight gain (Fisher et al. 2003; Louis-Sylvestre et al. 2003). Insight in the meal termination (satiation) process may provide tools to prevent overconsumption during a meal. Satiation is regulated by sensory factors, physiological factors, and psychological factors (De Graaf et al. 2004; Smith and Ferguson 2008). It is likely that sensory factors are of primary importance in satiation due to their early onset during consumption (Blundell and King 1996; Hetherington 1996; Porrini et al. 1997).

Several sensory properties have been shown to influence satiation. For instance, a clear negative relationship was found between the viscosity of a food and the amount of *ad libitum* intake (Zijlstra et al. 2008). The effect was attributed to the duration of sensory exposure in the oral cavity as a prolonged sensory exposure per bite resulted in less *ad libitum* intake (De Wijk et al. 2008; Weijzen et al. 2009; Zijlstra et al. 2009). Apart from sensory exposure time, the intensity of sensory exposure may also influence satiation because an elevated intensity also increases the amount of sensory exposure, in this case not in time but in strength.

A number of studies investigated the effect of taste intensity, mostly in sweet products, on *ad libitum* intake, but the results are conflicting. Some studies indicated that yoghurts with high sweet intensity decrease *ad libitum* intake more than yoghurts with low sweet intensity (Lucas and Bellisle 1987; Vickers et al. 2001), whereas results from other studies found no clear differences (Daillant and Issanchou 1991; Perez et al. 1994) or even an opposite effect (Vickers et al. 1998). Moreover, a pasta sauce high in intensity, obtained by salt intensity (Yeomans 1998) and oregano intensity

(Yeomans 1996), resulted in lower intake than the pasta sauces low in intensity. It is difficult to extrapolate from these studies whether intensity had an effect on *ad libitum* intake because pleasantness differs among intensities, and this may overrule the effect of intensity on intake. Palatability is considered to be a strong predictor of the amount consumed (Bellisle et al. 1984; Bobroff and Kissileff 1986; Yeomans 1996, 1998; De Graaf et al. 1999). Initial pleasantness should, therefore, be kept constant to study the effect of taste intensity on satiation.

Exposure to a high or low intense taste may change the perception of intensity and preferred level of intensity. Helson's theory of adaptation level (Helson 1948), originating from psychophysical experiments, suggests that judgments are made with respect to a frame of reference. People refer to the most recent experience in evaluating the sensory properties of a food. Studies that investigated contextual effects on perception of taste intensity showed a shift in perceived intensity when a product was tasted after exposure to a low or high intense product. The shift in intensity is the common result of a contrast effect, products are perceived more intense when exposed to low intense tastes and less intense when exposed to high intense tastes (Lawless 1983; Rankin and Marks 1991; Olabi and Lawless 2008).

A change in perceived intensity may also affect palatability because intensity is related to palatability (Lucas and Bellisle 1987; Daillant and Issanchou 1991; Perez et al. 1994; Yeomans 1996, 1998; Vickers et al. 1998, 2001; Zandstra et al. 1999). By itself, palatability is also able to trigger a contrast effect, for instance, a ''neutral'' beverage was increased in palatability when subjects were previously exposed to an unpalatable beverage (Sakai et al. 2001). The opposite of contrast is assimilation, meaning that the stimulus becomes similar to the preceding stimulus or expectation (Cardello and Sawyer 1992). Cardello and Sawyer (1992) studied the effect of expectations on perception of foods and found mainly assimilation effects, for example, a higher sweetness expectation resulted in higher perceived sweetness.

The studies above (Lawless 1983; Rankin and Marks 1991; Cardello and Sawyer 1992; Sakai et al. 2001; Olabi and Lawless 2008) highlight the importance of contextual effects on perception of intensity and palatability. This indicates that consumption of one food can affect the perception of other foods, which is interesting because people consume different foods during one meal. In the experiments that showed contrast effects (Lawless 1983; Rankin and Marks 1991; Sakai et al. 2001; Olabi and Lawless 2008), however, only small amounts were tasted. Whether these effects still remain when a food is consumed till satiation is unclear. When consuming a food until satiation, pleasantness decreases specifically for the consumed food, whereas pleasantness of other foods does not decrease or decreases less, this phenomenon is called ''sensory specific satiety'' (SSS) (e.g., Rolls 1986). When a food is eaten to satiation, its pleasantness decreases and people will switch to other foods that taste more pleasant; therefore, SSS also encourages humans to consume a variety of different foods (Rolls 2007). When eating a food that is low in taste intensity, people may get tired of the bland taste and prefer foods higher in taste intensity afterward or vice versa. Some studies showed a shift in preferred intensity toward lower concentrations, as observed in sweet intensity level (Lucas and Bellisle 1987; Perez et al. 1994; Zandstra et al. 1999) and in salt intensity level (Bellisle et al. 1988) after consumption of a food ''optimal'' in taste intensity.

The primary objective of the present study was to investigate the effect of taste intensity on satiation in foods similar in initial palatability. The effect of taste intensity on satiation when palatability is kept constant has not been studied before. For each subject individually, a low-salt (LS) and high-salt (HS) tomato soup were selected with similar initial pleasantness ratings. Subjects consumed *ad libitum* from the LS and HS tomato soup during lunchtime. The secondary objective was to asses changes in perception and preferences of salt intensity after *ad libitum* intake of LS versus HS soups.

Subjects and methods

Experimental design

The study consisted of 3 different stages. In the first stage, analytical taste profiles of soups with varying salt concentrations were established. The aim of this stage was to verify whether salt intensity ratings increased linearly with geometric increasing salt concentrations (a factor 1.55 between adjacent salt concentrations) (Shepherd et al. 1984b; De Graaf and Frijters 1989) and to give insight in the perception of sweet and sour intensity when salt intensity increases.

In the second stage, subjects rated pleasantness and relative-to-ideal salt intensity ratings of soups with varying salt concentrations. This was performed to determine salt concentrations for LS, ideal-salt (IS), and HS soups per subject. An inverted U shape describes the relationship between pleasantness and salt intensity with the most pleasant soup containing the ideal salt concentration in the middle (Shepherd et al. 1984b). One salt concentration below (LS) and one salt concentration above the ideal salt concentration (HS) were selected for each subject by linear interpolation based on equal initial pleasantness.

In the third stage, subjects visited the laboratory 4 times during lunch time and consumed LS soup and HS soup each 2 times. Subjects consumed tomato soup from a self-refilling bowl as described by Wansink et al. (2005); this was done to minimize self-monitoring of the amount consumed. Subjects were aware of the fact that the bowl was refilling.

Before and after *ad libitum* intake, small samples of LS, IS, and HS soups were rated on several hedonic and analytical aspects (Table 1). Hedonic (pleasantness and relative-to-ideal salt intensity) and analytical aspects (salt intensity) were rated in separate lunches; therefore, both LS and HS soup were consumed twice. A distinction between

Table 1 Measurements during the 4 lunch session

Ad libitum intake of:	Ratings of:
LS1 soup	Pleasantness, desire-to-eat, relative-to-ideal salt intensity
LS2 soup	Salt intensity, expected satiation
HS1 soup	Pleasantness, desire-to-eat, relative-to-ideal salt intensity
HS2 soup	Salt intensity, expected satiation

hedonic and analytical aspects was made to measure salt intensity independent of hedonics. The aim was to get insight in changes in both salt intensity preference (pleasantness and relative-to-ideal salt intensity, measured in LS1 and HS1) and in salt intensity perception (salt intensity, measured in LS2 and HS2) after intake.

Subjects

Subjects were recruited from a database of people interested in taking part in trials from the Division of Human Nutrition at Wageningen University, Wageningen, The Netherlands. Forty-eight subjects (24 females and 24 males) were selected; all were students from Wageningen University. Subjects were healthy, had a normal weight (body mass index: BMI 18.5–25 kg/m^2), were aged between 18 and 27 years (mean ± standard deviation [SD] = 20.8 ± 1.99) and liked creamy tomato soup (pleasantness score > 5 on a 9-point hedonic scale). Exclusion criteria were restrained eating (Dutch eating behavior questionnaire [DEBQ] score men: >2.25, women: >2.79), having followed an energy-restricted diet during the last 2 months, gained or lost >5 kg weight during the last year, having a lack of appetite, smoking, having gastrointestinal illness, having diabetes, having thyroid disease or any other endocrine disorder, having hypertension, suffering from kidney diseases, and being pregnant or giving breast feeding. In addition, staff and students from the Division of Human Nutrition were excluded from participation. Subjects were unaware of the aim of the research. The study was approved by the Medical Ethical Committee of Wageningen University and all subjects signed an informed consent form.

Test product: tomato soup

Tomato soup with varying salt concentrations was used as test product in this study. One kilogram of soup was made from 600 g mashed tomato pieces (Heinz), 80 g cream (kookroom, private label Albert Heijn), 310 g water, and 10 g sucrose. The mixture was heated to 80 °C. The macronutrient composition was calculated at: 0.8 g protein, 3.3 g carbohydrates, 1.6 g fat, and 129 kJ (31 kcal) energy per 100 g soup. Eight sodium concentrations were used with equal geometric distances (factor 1.55): 63 (soup 1), 98 (soup 2), 151 (soup 3), 234 (soup 4), 363 (soup 5), 561 (soup 6), 870 (soup 7), and 1349 (soup 8) mg Na/100 g soup. The sodium concentration in soup 1, to which no salt was added, was calculated from the used ingredients. Soups were equal in viscosity; soup 1 and 7, the soups with lowest and highest salt concentration selected for *ad libitum* intake, had a viscosity of 0.246 and 0.223 Pa/s, respectively, at a shear rate of 45 (1/s) at 55 °C.

Analytical taste profile

Subjects rated all 8 salt concentrations in soups on analytical attributes: salt intensity, sour intensity, and sweet intensity. Subjects received 15 g of each soup in random order. The temperature of the soups was ±55 °C. The salt intensity question was "How strong is the salty taste of this soup?"; the scale was labeled "very weak" at the left end (0 mm) and "very strong" at the right end (100 mm) on a 100-mm visual analogue scale (VAS). Similar questions were asked for sweet and sour.

Selection of LS, IS, and HS soups and hedonic taste profile

To select LS, IS, and HS soups on an individual basis, subjects rated 15 g of sampled soups with varying salt concentrations on relative-to-ideal salt intensity and pleasantness. The question that refers to relative-to-ideal salt intensity was "How salty is the taste of this soup?"; the scale was labeled "not nearly salty enough" (–50 mm) at the left end, "just right" in the middle (0 mm), and "much too salty" at the right end (50 mm) of the scale. The pleasantness question was "How pleasant is the taste of this soup?"; the scale was labeled "very unpleasant" at the left end (0 mm) and "very pleasant" at the right end (100 mm). The soups were presented in an interactive procedure according to the method specified by Booth et al. (1983). This procedure was developed as a quick method to find the individual ideal (i.e., most pleasant or optimal) salt concentration.

Soup 5, with a sodium concentration similar to that in commercially available tomato soups, was presented first. Depending on the rating of the first sample on relative-to-ideal, the second sample was chosen in a way to be rated on the other side of ideal from the first sample. For example, if the first sample was rated above ideal, then the second sample would be below ideal or vice versa. The procedure was continued until there were 5 ratings: 2 below ideal, 1 close to ideal (–10 < 0 < 10 mm), and 2 above ideal. After a 15-min break, subjects received the same 5 soups in a different order, however, again alternating on each side of ideal (Booth et al. 1983).

For each subject, the means of duplicates were calculated and plotted against geometric sodium concentration. The IS soup was selected as the soup that was rated closest to the "just right" point (i.e., 0 mm on relative-to-ideal salt intensity ratings). The LS and HS concentrations were chosen at each side of ideal based on equal pleasantness (<10 mm difference on pleasantness ratings) as determined by linear interpolation. Each pair of LS and HS soups was selected in a way that the distance in geometric sodium concentration (i.e., the ratio) was the same between LS and HS soup. HS soup was for each individual 3.72 times higher than LS soup, which equals 2 soup number in between (Table 2).

Ad libitum intake

Over a period of 4 weeks, subjects visited the lab during lunch time once a week to eat *ad libitum* from the selected LS soup and HS soup from a self-refilling bowl. LS1, LS2, HS1, and HS2 soups were presented in random order to the subjects. Subjects were instructed to consume the same breakfast and to abstain from eating and only allowed to drink water or weak tea 3 h before the lunch started. Moreover, they were asked to refrain from drinking 1 h before the test started. After each test lunch, subjects had to answer questions about what they consumed for breakfast and whether they consumed or drank between breakfast and test lunch. To make sure subjects would take the test seriously, they were not allowed to eat 1 h after the test.

The procedure of a test day was as follows: first, subjects started rating their feelings of hunger, fullness, prospective consumption (i.e., how much they thought they could eat) (Rogers and Blundell 1979), and thirst on a 100-mm VAS. Thereafter, subjects tasted a small sample (15 g) of the individually selected LS, IS, and HS soup and rated various aspects (Table 1). Following this, subjects were seated in front of a soup bowl covered by aluminum foil. A laptop was placed behind the bowl with instructions for the subjects. They were instructed to take off the aluminum foil and push a button when they started eating and when they finished eating, so that eating time was recorded. Subjects were instructed to terminate eating when they felt they had enough. The mean initial temperature of the *ad libitum* selected soup was 55 °C (SD = 5.3 °C). When they finished eating, they rated again their feelings of hunger, fullness, prospective consumption, and thirst. Finally, they rerated the soup samples on several aspects according to Table 1.

Table 2 The distribution of the selected salt concentration for LS and HS soups

N	LS soup		HS soup	
	mg Na/100 g	Soup no.	mg Na/100 g	Soup no.
3	63	1	234	4
4	98	2	363	5
2	121	2.5	503	5.5
17	151	3	561	6
2	168	3.25	626	6.25
12	188	3.5	698	6.5
1	210	3.75	779	6.75
7	234	4	870	7

The ratings according to Table 1 were asked as follows. The question that refers to desire-to-eat was ''How much would you like to eat this soup at this moment?'', from ''not at all'' at the left end to ''very much'' at the right end. The question that refers to expected satiation was ''How filling is this soup?'' from ''not at all'' at the left end to ''very much'' at the right end. The remaining questions from Table 1 are described in ''Analytical taste profile'' and ''Selected LS, IS, and HS soups and hedonic taste profile.''

Self-refilling bowl

Subjects received the soup during the lunch in a self-refilling bowl as described by Wansink et al. (2005). The self-refilling bowl can be visualized as follows. A bowl and a pan were placed on a table (82 cm distance); under the table, the bowl and pan were connected through a food-grade silicon tube. The bottom of the pan and bowl contained holes to be connected with the tube; however, subjects were not able to see the hole in the bowl due to the color of the soup. The soup was refilled through a gravity-feed mechanism. During consumption, the level of the soup in the bowl decreased slowly but was never empty.

Data analyses

Statistical analyses were performed using SAS version 9.1.4 (SAS Institute Inc.). Data are presented as means ± standard deviation, P values < 0.05 were considered significant.

During the taste tests, the effect of salt concentration on salt intensity, sour intensity, sweet intensity, pleasantness, and relative-to-ideal salt intensity were analyzed by a linear model that included the effect of subject.

One subject did not eat LS soup and was therefore excluded from data analysis. Pearson correlations between intake of the same soup, HS or LS (duplicates), and between intakes of the different soups were calculated. Effects of salt intensity (LS vs. HS soup) on soup intake (mean of duplicates) were assessed with a linear model that included gender and subject nested within gender. Preliminary analyses revealed that gender only affected intake; therefore, gender was omitted from the other analyses (see below). Appetite ratings (hunger, fullness, prospective consumption and thirst), pleasantness, desire-to-eat, relative-to-ideal salt intensity, salt intensity, and expected satiation were compared from preintake to postintake with a linear model that included the effect of subject.

Initial ratings of pleasantness, desire-to-eat, relative-to-ideal salt intensity, salt intensity, and expected satiation were compared between LS, IS, and HS sampled soups by a model that included the effect of subject. Delta ratings (postintake – preintake) of pleasantness, desire-to-eat, relative-to-ideal salt intensity, and salt intensity were compared between LS, IS, and HS sampled soups by a linear split-plot model that included effects of salt intensity of the *ad libitum* soup (HS vs. LS); effects of salt intensity in *ad libitum* soup were tested against the effect of subject within *ad libitum* soup condition. Bonferroni adjustments were used for *post hoc* comparisons. The GLM procedure in SAS was used for all linear models.

Results

Analytical taste-profile

Salt intensity ratings increased with geometric salt concentrations, $F_{7,321} = 174$, $P < 0.001$ (Figure 1). Sour intensity ratings did not change with increasing salt concentrations, $F_{7,321} = 1.41$, $P = 0.20$. Sweet intensity decreased from 363 mg Na/100 g to higher salt concentrations, $F_{7,321} = 12.7$, $P < 0.001$.

Selected LS, IS, and HS soups and hedonic taste profile

Relative-to-ideal salt intensity ratings showed an increase with increasing geometric salt concentrations, $F_{7,178} = 169$, $P < 0.001$ (Figure 2). The ideal salt concentration is where the relative-to-ideal salt intensity curve crosses the x axis (the just-about-right point), and the average was 363 ± 56.8 mg Na/100 g. The pleasantness curve showed an inverted U-shape against logarithmic salt concentration $F_{7,178} = 30.6$, $P < 0.001$. The top of the inverted U-shape is defined as the ideal salt concentration. The pleasantness curve was asymmetrical; soups with salt concentrations above ideal decreased more in pleasantness than soups with salt concentrations below ideal. The relative-to-ideal salt intensity ratings did not reach the "not nearly salty enough" (–50 mm) end, whereas the "much too salty" end (50 mm) was almost reached, 43 mm.

For each individual, relative-to-ideal salt intensity and pleasantness curves were plotted individually. LS and HS concentrations were selected per individual by linear interpolation (Table 2). The mean salt concentration selected for LS was 165 ± 52 mg Na/100 g and the one selected for HS was 613 ± 194 mg Na/100 g. The distance in geometric salt concentration was equal between each selected LS and HS soup. The mean salt concentration selected for IS was 340 ± 113 mg Na/100 g (range: 98–561 mg Na/100 g).

Figure 3 illustrates individual differences in relative-to-ideal salt intensity ratings. It shows the difference in ideal salt concentration and the tolerance toward different salt concentrations (i.e., distance from ideal) between subjects. The tolerance for different salt concentrations is expressed by the slope in relative-from-ideal salt intensity; this varied from 22.8 mm/log mg Na per 100 g (most tolerant) to 132 mm/log mg Na per 100 g (least tolerant). The mean slope was 61.7 ± 22.0 mm/log mg Na per 100 g (mean R^2 = 0.90 ± 0.1). There were no gender differences in relative-to-ideal salt intensity ratings and selection of LS and HS concentrations (data not shown).

Ad libitum intake

We found no differences between the *ad libitum* intakes of LS versus HS soup, 375 ± 165 grams versus 388 ± 147 g, $F_{1,94} = 0.72$, $P = 0.39$ (Figure 4). Also, eating rate did not differ between consumption of LS versus HS soup, LS: 73.1 ± 3.6 g/min versus HS: 76.4 ± 4.2 g/min, $F_{1,94} = 1.89$, $P = 0.18$. *Ad libitum* intake was highly correlated for duplicate measurements (LS soups: $r = 0.79$, HS soups $r = 0.85$, $P < 0.001$)

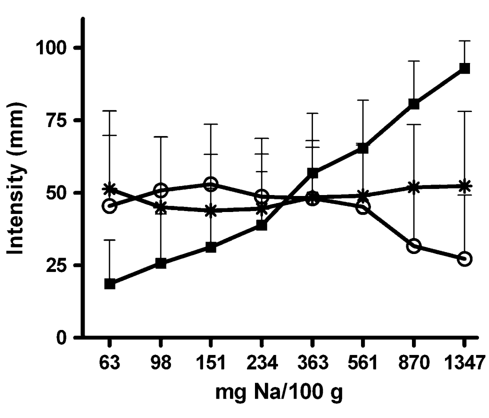

Figure 1 Mean ratings and SD of salt intensity (■), sour intensity (*), and sweet intensity (○) as a function of salt concentration in tomato soup on 100 mm VAS.

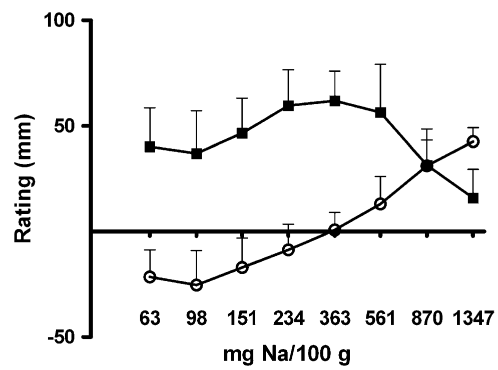

Figure 2 Mean ratings and SD of pleasantness (■) (0: very unpleasant, 100: very pleasant) and relative-to-ideal salt intensity (○) (−50: not nearly salty enough, 0: just-about-right, 50: much too salty) as a function of salt concentration in tomato soup on 100 mm VAS.

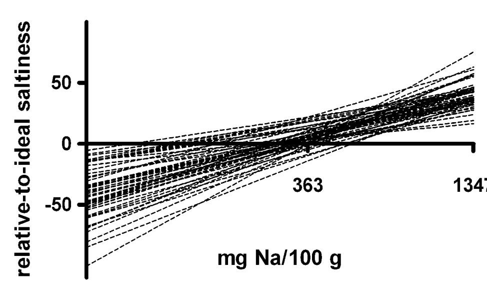

Figure 3 Individual tolerance to different salt concentrations in soup. Linear trend lines derived from the relative-to-ideal salt intensity ratings of the 48 subjects.

and for different soups within subjects (LS vs. HS soup, 4 different combinations: LS1 vs. HS1 r = 0.68, LS2 vs. HS1: 0.72, LS1 vs. HS2: 0.73, and LS2 vs. HS2: 0.76, P < 0.001).

Initial ratings of hunger, fullness, prospective consumption, and thirst did not differ between LS versus HS soup, which indicates that subjects were in the same hungry state before *ad libitum* intake of the soup (Table 3). After *ad libitum* intake of both LS and HS soup, ratings of hunger decreased (LS: $F_{1,93}$ = 431, P < 0.001, HS: $F_{1,94}$ = 530, P < 0.001), ratings of prospective consumption decreased (LS: $F_{1,93}$ = 340, P < 0.001, HS: $F_{1,94}$ = 428, P < 0.001), and ratings of fullness increased (LS: $F_{1,93}$ = 375, P < 0.001, HS: $F_{1,94}$ = 668, P < 0.001). Ratings of thirst decreased after intake of LS soup ($F_{1,93}$ = 4.38, P = 0.04) but did not change after intake of HS soup ($F_{1,94}$ = 1.15, P = 0.29). Changes in ratings of hunger, fullness, prospective consumption, and thirst did not differ after intake of LS soup compared with HS soup (Table 3).

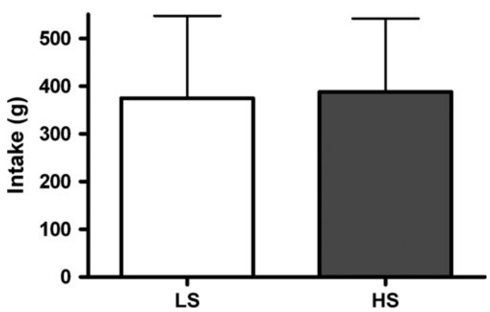

Figure 4 Mean values and SD of *ad libitum* intake (g) of LS soup and HS soup.

Table 3 Mean ± SD of initial and delta (postintake − preintake) ratings of hunger, fullness, prospective consumption, and thirst for LS and HS soups

N = 48	LS soup	HS soup	$F_{1,94}$	P
Hunger				
Initial	70.1 ± 11.8	71.1 ± 11.8	0.05	NS
Δ	−51.2 ± 17.3[a]	−53.6 ± 15.9[a]	0.59	NS
Fullness				
Initial	23.6 ± 11.8	21.2 ± 10.4	0.97	NS
Δ	50.9 ± 19.4[a]	54.7 ± 14.5[a]	2.37	NS
Prospective consumption				
Initial	67.8 ± 10.4	68.8 ± 11.1	0.17	NS
Δ	−43.8 ± 16.6[a]	−47.6 ± 15.9[a]	2.98	NS
Thirst				
Initial	61.2 ± 13.9	65.6 ± 13.9	2.75	NS
Δ	−6.72 ± 34.6[a]	−3.81 ± 22.2	0.88	NS

NS, nonsignificant.
[a]Significance difference between pre- and postintake ratings.

The mean sodium intake from LS soup was 593 ± 278 mg, the mean sodium intake from HS soup was 2356 ± 1173 mg. The mean sodium intake from the samples (LS, IS, and HS before and after *ad libitum* intake) was 333 ± 49 mg.

Changes in ratings for the consumed soup (LS after LS and HS after HS)

The initial pleasantness and desire-to-eat did not differ between LS and HS soup (Table 4). HS soup was rated as more salt intense according to both the relative-to-ideal salt intensity and the salt intensity ratings. Initial ratings of expected satiation (i.e., how filling they thought the soup was) was higher for the HS soup compared with the LS soup.

After *ad libitum* intake of both LS and HS soup, ratings of pleasantness decreased (LS: –9.34 ± 22.9, P = 0.006, HS: –13.8 ± 22.9, P < 0.001) (Figure 5A) and the degree of decrease did not differ between soups ($F_{1,46}$ = 1.19, P = 0.28). Also, the desire-to-eat after both soups decreased (LS: –30.2 ± 22.9, P < 0.001, HS: –29.6 ± 22.9, P < 0.001) (Figure 5B) and the degree of decrease did not differ between soups ($F_{1,46}$ = 0, P = 0.95). After *ad libitum* intake of LS soup, relative-to-ideal salt intensity and salt intensity ratings did not change (Figure 5C,D). After *ad libitum* intake of HS, the relative-to-ideal salt intensity tended to be rated further to the "much too salty" end (4.2 ± 15.2, P = 0.08), whereas salt intensity ratings did not change.

Changes in ratings for soups with contrasting salt intensity (HS after LS and LS after HS)

Each sampled soup decreased in pleasantness after *ad libitum* intake of LS or HS soup (P < 0.01) (Figure 5A). After intake of LS soup, the decrease in pleasantness differed among samples ($F_{2,138}$ = 4.14, P = 0.02), HS soup decreased more in pleasantness compared with both IS and LS soup (P < 0.05). After intake of HS soup, the decrease in pleasantness did not differ significantly among the sampled soups ($F_{2,141}$ = 1.18, P = 0.31); however, LS soup numerically decreased the most in pleasantness. In addition, the decrease in desire-to-eat after LS and HS soup did not differ between the sampled soups (Figure 5B); however, drops in desire-to-eat showed similar patterns as the drops in pleasantness.

When comparing ratings from pre- to postintake, after intake of LS soup, the sampled LS and IS soup did not differ in relative-to-ideal salt intensity, whereas the HS soup was rated more to the "much too salty" end (P < 0.001) (Figure 5C). Salt intensity ratings also showed that LS soup was not rated differently after intake of LS soup, whereas IS soup seemed be to rated somewhat more salt intense (P = 0.14) and HS soup was rated as more salt intense (P = 0.04) (Figure 5D). After intake of HS soup, HS and IS samples showed no change in relative-to-ideal salt intensity ratings, whereas LS soup was rated more to the "not

Table 4 Mean ± SD of initial ratings of pleasantness, desire-to-eat, relative-to-ideal salt intensity, salt intensity, and expected satiation for LS, IS, and HS soups

N = 48	LS soup	IS soup	HS soup	$F_{1,94}$	P
Pleasantness	56.8 ± 2.19[a]	66.1 ± 2.26[b]	50.8 ± 2.79[a]	12.7	<0.001
Desire-to-eat	56.5 ± 2.49[a]	65.4 ± 2.34[b]	52.6 ± 2.90[a]	10.6	<0.001
Relative-to-ideal salt intensity	−12.9 ± 1.58[a]	0.22 ± 1.26[b]	14.5 ± 1.62[c]	96.0	<0.001
Salt intensity	31.7 ± 2.08[a]	47.9 ± 1.88[b]	71.0 ± 1.96[c]	101.0	<0.001
Expected satiation	45.0[a] ± 1.85	53.9[b] ± 1.57	57.8[b] ± 2.07	12.6	<0.001

Mean ratings with different superscript letters (a, b, c) in the same row were significantly different.

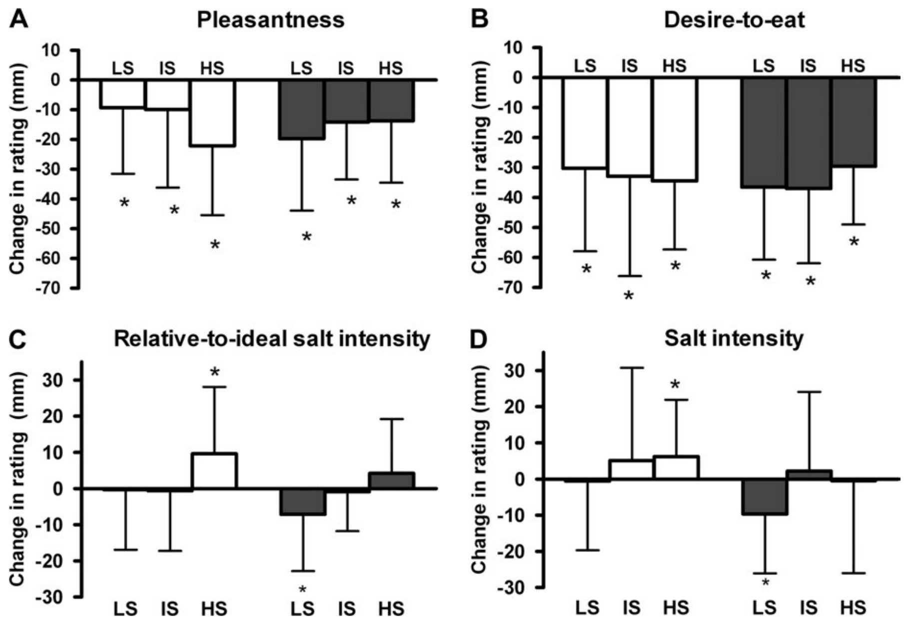

Figure 5 Mean ratings and SD for changes in ratings of **(A)** pleasantness, **(B)** desire-to-eat, **(C)** relative-to-ideal salt intensity, and **(D)** salt intensity ratings after *ad libitum* intake of the LS soup (white bars, left) and HS soup (gray bars, right). "*" Significant change from pre- to postintake.

nearly salty enough'' end (P = 0.004) (Figure 5C). In accordance, salt intensity ratings after intake of HS soup showed no change for HS and IS ratings, whereas LS soup was rated less salt intense (P < 0.001) (Figure 5D). In general, total relative-to-ideal salt intensity ratings were lower after intake of HS soup compared with LS soup (HS: –1.25 ± 1.23, LS: 2.89 ± 1.51; $F_{1,93}$ = 4.37, P = 0.04) as similar results were found for salt intensity ratings (HS: –2.64 ± 1.84, LS: 3.60 ± 1.72; $F_{1,94}$ = 6.72, P = 0.01).

Discussion

The present study clearly shows that salt intensity does not affect satiation, which was measured as *ad libitum* intake. In accordance, neither did salt intensity affect the decrease in reward of the just consumed soup (i.e., subjective ratings of pleasantness and desire-to-eat) nor eating rate, hunger, and fullness ratings after soup intake. The soups were only different in salt concentration and similar in initial pleasantness, energy density, temperature, and viscosity. This is the first study that demonstrated that salt intensity does not affect satiation when controlling for palatability on an individual basis. After intake of HS soup, salt intensity ratings showed no difference for the consumed HS soup; however, LS soup was perceived as more bland. After intake of LS soup, salt intensity ratings showed no difference for the consumed LS soup; however, HS soup was perceived as more salt intense.

Individuals vary largely in salt preference as shown by this and other studies (Booth et al. 1983; Shepherd et al. 1984a, 1984b; Shepherd et al. 1991). Consequently, a certain salt concentration may be too salty for one person and just right or even not salty enough for another. Selecting 2 fixed concentrations for all subjects would give a great variability in perceived salt intensity and pleasantness and therefore *ad libitum* intake. To overcome these individual differences, we selected salt concentrations for LS and HS soups for each subject, as less salty and more salty, respectively, than their ideal salt concentration. Moreover, the salt concentrations were selected based on equal pleasantness for each subject. As a result, effect of salt intensity was studied apart from hedonics. As stated in the Introduction, satiation is not only determined by sensory factors but also by certain physiological and psychological factors (De Graaf et al. 2004; Smith and Ferguson 2008), which may disturb the effect of salt intensity on *ad libitum* intake. Visual cues, such as self-monitoring of the amount consumed and the natural tendency to finish the bowl, have been shown to greatly influence the amount consumed (Pudel and Oetting 1977; Wansink et al. 2005). These effects were diminished by using a self-refilling bowl. This study attempted to keep the physiological contribution constant by having the subjects arrived in the same metabolic state as subjects were instructed not to eat 3 hours before and consume the same breakfast.

The perceived salt intensity did not change for the soup that was eaten *ad libitum*. In contrast, hedonic ratings decreased. This is consistent with previous findings showing that eating to satiation did not affect the perceived taste intensity but resulted in a less pleasant taste (Rolls et al. 1983; Kringelbach et al. 2003). Above findings are supported by several neurophysiological studies (Yaxley et al. 1985; Rolls et al. 1986, 1989, 1999; Kringelbach et al. 2003; Rolls 2008). In the brain, taste quality and intensity are processed in the primary taste cortex (i.e., the primate anterior insula and adjoining frontal operculum), whereas the secondary taste cortex (i.e., caudolateral orbitofrontal cortex) reflects the hedonic value and motivation to eat (Kringelbach et al. 2003; Rolls 2008). When eating to satiation, the response in the secondary taste cortex was shown to decrease in humans (Rolls et al. 1986, 1989, 1999; Kringelbach et al. 2003; Rolls 2008), whereas no decrease of response was seen in the primary taste cortex and in the nucleus of the solitary tract in nonhuman primates (Yaxley et al. 1985; Rolls 2008). This is in line with a study that used a habituation paradigm, hedonic responses to repeated presentation of the same food habituated (i.e., decreased in response), whereas there was no clear habituation observed for the experienced intensity (Epstein et al. 1992). Taken together, this underpins that taste intensity may not directly influence the motivational state of eating during intake and, therefore, may not cause an effect on *ad libitum* intake.

Another possible explanation why salt intensity does not influence *ad libitum* intake may be the lack of a physiological mechanism to adjust the amount of salt within a meal because it is not associated with energy. Sweet is considered to be associated with energy, as in sugar. Sweetness may affect meal size regulation as a function of short-term energy regulation. Studies with animals illustrated that amount of intake was adjusted to carbohydrate concentration (Booth 1972; Sclafani 1997, 2001), this phenomenon is called ''conditioned satiation.'' This means that the orosensory stimuli derived from sweetness of carbohydrates could predict the postingestive energetic consequences and adjust the amount of intake (Booth 1972; Swithers and Davidson 2008). It would be of interest to replicate the present study with sweetness.

Moreover, the experimental setting might have influenced effects of salt intensity on satiation. We assumed that sensory factors would be a major determinant of meal termination; however, this may not have been the case in the present study. Subjects were in a hungry state and soup was the only food available. It is possible that subjects consumed until their stomachs were filled and possible effects of salt intensity may have been overruled. Weight and volume are well-known controllers of short-term intake (Poppitt and Prentice 1996; Bell et al. 2003; Rolls et al. 1998; De Castro 2005; Osterholt et al. 2007). De Castro (2005) showed that the average weight of the nutrients and fluids estimated to be present in the stomach at the end of the meals was 400–500 g. Intake in the present study was about the same (380 g plus in total 6 samples of 15 g for several ratings before and after consumption). Because people tend to eat a constant weight during a meal, sensory factors that contribute to satiation may be more important in circumstances when people are able to switch to other foods. In addition, a less hungry state may reduce physiological contribution and enhance the sensory contribution of satiation. Whether salt intensity affects *ad libitum* intake when subjects, first, have more food choice and, second, are in a more satiated state will be investigated in the next study.

To get insight in changes of salt intensity preference and perception after *ad libitum* intake of either LS or HS soup, small samples of LS, IS, and HS soup were tasted and evaluated. During *ad libitum* intake, the frame of reference in salt intensity became lower (in the case of LS) or higher (in the case of HS) than before consumption, which increases the difference in salt intensity when tasting the ''opposite'' salt intensity. Contrast effects were observed in both directions, LS was perceived as more bland after consumption of HS soup and HS soup was perceived as more salty after consumption of LS soup. The change in analytical salt intensity ratings suggests that subjects perceived the salt intensity differently after consumption, independent of hedonics. These contrasting effects observed in salt intensity ratings affected the hedonic value in a negative way. The ''contrasting'' salt intensities were rated further from the ideal salt intensity and therefore less palatable, which is confirmed by the pleasantness ratings as shown in the results. No contrast effect was observed for IS soup as it was not rated differently in salt intensity after consumption. The difference between the consumed soup and the IS soup might be too small to produce a contrast effect. This suggests that a certain difference in salt intensity is needed to obtain a contrast effect.

The results of this study suggest that a substantial difference in salt intensity in a food decreases the palatability because people adapt to the exposed intensity. This adaptation toward lower salt intensity is in favor of the recommended salt intake, which is 5 g/day (WHO, 2006) and is much lower than the average consumption of 9–10 g/day (Dutch Health Council, 2000) in the Netherlands. The results showed that after consumption of LS soup, HS soup was rated as more salty and decreased more in pleasantness than the consumed LS soup. Therefore, it is unlikely that consumption of an LS soup will trigger higher salt intake from other foods afterward. This is in accordance with the finding that subjects on a reduced salt diet did not compensate by increased table salt usage (Beauchamp et al. 1987). However, there is a need to investigate to what extent the adaptation for LS intensity can be translated into other foods.

As far as we know, we showed for the first time that contrast effects still remain after a food is consumed till satiation. Previously, contrast effects for intensity were shown after consuming a small amount of a liquid (Lawless 1983; Rankin and Marks 1991; Sakai et al. 2001; Olabi and Lawless 2008). When a food is consumed to satiation, its pleasantness decreases and this decline is larger than the decline in pleasantness of uneaten foods (Rolls et al. 1981, 1982, 1984; Guinard and Brun 1998; Hetherington et al. 2006). Therefore, people tend to choose foods that have different sensory properties compared with the consumed foods (Rolls et al. 1984; Hetherington et al. 2006). In this study, the used test foods (i.e., soup) that only differed in salt intensity. We were interested whether people would prefer a stronger taste after being exposed to a bland soup and vice versa. In contradiction, this study showed a larger decrease in pleasantness for the ''uneaten'' soup (the soup with ''contrasting'' salt concentration) compared with the eaten soup, caused by contrast effects. This indicates that the decrease in pleasantness is apparently not driven by taste intensity *per se* (bland or salty) and that exposure to a different salt concentration is perceived as less palatable.

IS soup (~363 mg Na/100 g) was most pleasant and is similar to the salt concentration in commercially available tomato soups (290–450 mg Na/100 g). The results illustrate, however, that there is a wide range in sodium concentration that is still acceptable (LS: ~151 mg Na/100 g to ~HS: 561 mg Na/100 g), which means pleasantness ratings of >50 mm on a 100-mm VAS. The results of this study suggest that when sodium is reduced by ~50% (mean IS compared with mean LS), the soup is still acceptable for consumption. Moreover, studies that expose subjects foods low in salt intensity for longer term, illustrated a preference shift to lower salt intensities. Reduction of dietary salt for 3 months (Blais et al. 1986) or 5 months (Bertino et al. 1982) showed a preference shift toward lower concentrations and a decreased preference for salty foods. In accordance, an increase of dietary salt for 4 weeks showed a preference shift to higher salt concentrations (Bertino et al. 1986). In this study, we did not observe a preference shift in terms of a shift of the most preferred salt concentration (i.e., no shift of ideal and most pleasant salt concentration in soup), but we did observe a decreased preference of the contrasting salt concentrations in soup.

In conclusion, our study showed that salt intensity did not affect satiation in soups when they are similar in pleasantness. Subjects were shown to adapt to an LS or HS intensity during consumption. The contrasting salt intensities (LS after HS and HS after LS) were therefore perceived as less pleasant after consumption.

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