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Temporal Contrast of Salt Delivery in Mouth Increases Salt Perception

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Abstract

The impact of salt delivery in mouth on salt perception was investigated. It was hypothesized that fast concentration changes in the delivery to the receptor can reduce sensory adaptation, leading to an increased taste perception. Saltiness ratings were scored by a panel over time during various stimulation conditions involving relative changes in NaCl concentration of 20% and 38%. Changes in salt delivery profile had similar effect on saltiness perception when delivered either by a sipwise method or by a gustometer. The impact of concentration variations and frequency of concentration changes was further investigated with the gustometer method. Five second boosts and 2 s pulses were delivered during 3 sequential 10-s intervals, whereas the delivered total salt content was the same for all conditions. Two second pulses were found to increase saltiness perception, but only when the pulses were delivered during the first seconds of stimulation. Results suggest that the frequency, timing, and concentration differences of salt stimuli can affect saltiness. Specifically, a short and intense stimulus can increase salt perception, possibly through a reduction of adaptation.

Key words: gustometer, pulsatile, saltiness, sipwise, time-intensity

Introduction

There is strong scientific evidence of the link between high sodium intake from food products and hypertension (World Health Organisation [WHO] 2007). Furthermore, it has been demonstrated that significantly reduced sodium intake is an effective method to lower hypertension and associated risks on cardiovascular disease (Sacks et al. 2001). The WHO currently recommends a daily intake of 5 g of salt (NaCl) per day, instead of typical daily intakes of 9–12 g of salt (WHO 2007). A number of different approaches for salt reduction have been developed and reviewed, but these are primarily limited to reductions of up to 20–30% salt in products (Kilcast and Angus 2007; Cobcroft et al. 2008). Hence, there is a need for further methods that enable salt reduction in products while maintaining the same consumer acceptance. The study reported here was conducted in order to investigate the impact of salt delivery on perception.

It is generally accepted that receptors (for vision, temperature, taste, odor, etc.) are contrast detectors (Alberts et al. 1994). One can view the experiments of Linforth et al. (2007) in this light. They compared in vivo aroma release and aroma perception in gels containing concentrated suspended droplets of aroma and the same amount of aroma compounds homogeneously distributed in the gel. Adding aroma compounds in droplets was found to increase both the maximum intensity of volatiles in the nasal cavity and the perceived aroma intensity. The conditions that delivered the largest in-nose contrast in concentration were perceived as more intense. In rats, it has been shown that the phasic portion of neural responses, that is, that part of the response that is transitional/adaptive, is influenced by the flow rate of salt solutions. The slower the flow, the smaller the maximums and the longer it takes to reach the peak of the phasic response (Smith and Bealer 1975; Marowitz and Halpern 1977; Matsuo and Yamamoto 1992). This suggests that (at least in rats) the rate of taste molecules transported to the taste receptors can influence the receptor response.

Prolonged or repeated stimulation of receptors often leads to a gradual loss of the magnitude of the perceived intensity, which is called adaptation (Meiselman 1972). This loss of intensity is also often referred to as habituation (Thompson and Spencer 1966), which is defined at the level of perception. Here we use the term adaptation, which is defined at the level of sensation. Sensory adaptation is a change over time in the responsiveness of the sensory system to a constant stimulus. Adaptation occurs at the level of nerve activity after stimulation of the receptor. Adaptation is observed for all senses (McBurney

1985). Adaptation has been demonstrated in electrophysiological (e.g., Smith et al. 1978) and psychophysical experiments (e.g., Meiselman 1968; O'Mahony 1972, 1984; Gent and McBurney 1978). The time frame of the adaptation of sodium receptors is expected to be of the order of 100 ms (reaction time to salt stimuli) to seconds (Kelling and Halpern 1983). In the case of salty taste, sodium receptors have been shown to adapt to the sodium content of their surrounding medium, which can be Na^+ from the saliva in the mouth or from previous stimulations (O'Mahony 1972). Through the application of rapid stimuli to the receptor, adaptation may be reduced, which consequently may increase the resulting taste perception. We hypothesized that relevant parameters that may influence perception are the firing rate at the receptor and the time required to distinguish between input signals. Because of the fast receptor adaptation time (Kelling and Halpern 1983), fast concentration change rates are required for a change in sensory adaptation. Such rates cannot be investigated using sipwise sampling with cups, for which the minimum sampling rate was found to be around 15 s. Recently, several authors reported a "continuous" flow delivery system to deliver solutions of different concentrations and compositions into the mouth (Hort and Hollowood 2004, Bult et al. 2007).

The aim of this paper was to investigate whether saltiness perception can be modified by changing the concentration and frequency of the salt stimulus delivered onto the tongue. Trained panellists were exposed to stimuli varying in concentration of salt over time, delivered via different methods (cups and continuous flow). Continuous flow delivery was achieved using a gustometer, a software controlled system with 8 pumps to deliver liquid stimuli into the mouth of panellists. Panellists scored saltiness intensity over time using time-intensity (TI) methodology. In a first experiment, the impact of salt variation on saltiness perception was investigated using a classical sipwise approach and a gustometer approach. The overall salt delivery profiles (concentration and frequency [15 s]) were the same. In the second experiment, the role of salt concentration (high–in-salt vs. constant stimulations) and frequency of presentation (2 and 5 s) was further investigated.

Materials and methods

Subjects

In experiment 1, 11 panellists (all females [39–62 years]) and 12 panellists (7 women and 5 men [20–47 years]) took part in the sipwise condition and gustometer condition, respectively. For experiment 2, the panel was composed of 5 women and 5 men (22–55 years). Assessors were selected using ranking tests and trained to score saltiness as a function of time (see below).

Stimuli

In experiment 1 (sipwise and gustometer), 3 stimuli of 80 ml each were provided to panellists. In the sipwise condition, the stimuli consisted of series of 8 samples of 10 ml each offered at a frequency of 15 s (stimulus duration 120 s). In the gustometer condition, each stimulus was offered under continuous flow; when different concentrations were delivered they were changed every 15 s. All stimuli had the same overall average concentration (6.3 g/l NaCl in demineralized water). The same amount of total salt was delivered in each stimulus. The stimuli were created as follow (Figure 1a): the salt concentration was either kept constant over the full delivery time ("Constant" stimulus; constant concentration 6.3 g/l) or varied: 5.6 and 7 g/l alternatively (20% concentration variation). For sequences varying in concentration, the sequence started either with the lower concentration ("Low–high" stimulus) or with the higher concentration ("High–low" stimulus; Figure 1a).

In experiment 2, the impact of salt concentration and frequency was further investigated. The average salt concentration was kept the same as in experiment 1 (6.3 g/l NaCl), but the frequency of concentration variation and the concentration levels were varied. Five stimuli of 40-s delivery were offered to panellists: a Constant stimulus and 4 stimuli varying in salt concentration (Figure 1b). A 20% concentration variation was used (5.6 and 7 g/l), and this was varied every 5 s. A 38% concentration difference (5.6 and 9.1 g/l) was also used, delivering a 2-s Pulse every 10 s. Hereafter "Boost" and "Pulse" refer to stimuli varying in concentrations every 5 and 2 s, respectively. Moreover, Low–high and High–low refer to the stimuli beginning with the low or high concentration, respectively. The sampling duration was 30 s, followed by a constant delivery of 6.3 g/l NaCl for 10 s for all conditions (Figure 1b).

All samples were provided at room temperature. Between stimuli, panellists were provided with mineral water and unsalted crackers as palate cleanser. The stimuli were offered to the panel members following a balanced Latin square design. In experiment 2, a dummy stimulus was given at the beginning of each session. All stimuli were evaluated in duplicate. Conductivity measurements were used to verify the actual delivery of salt solutions via the gustometer.

Sipwise delivery conditions

In experiment 1, sipwise conditions were chosen to be representative of the consumption conditions of a bouillon. Ten microliters of samples were provided in small cups. Every 15 s panellists were asked to put the full contents of a cup into the mouth and to swallow 2–3 s later. FIZZ 2.0 (Biosystems, Couternon, France) was used to indicate the actual timing of sipping the samples.

Gustometer delivery conditions

The gustometer was constructed from 8 pumps, a central control unit, a computer with dedicated software, and a manifold (Bult et al. 2007). Eight identical membrane liquid pumps (KNF Stepdos FEM03.18RC, KNF Verder, Vleuten, The

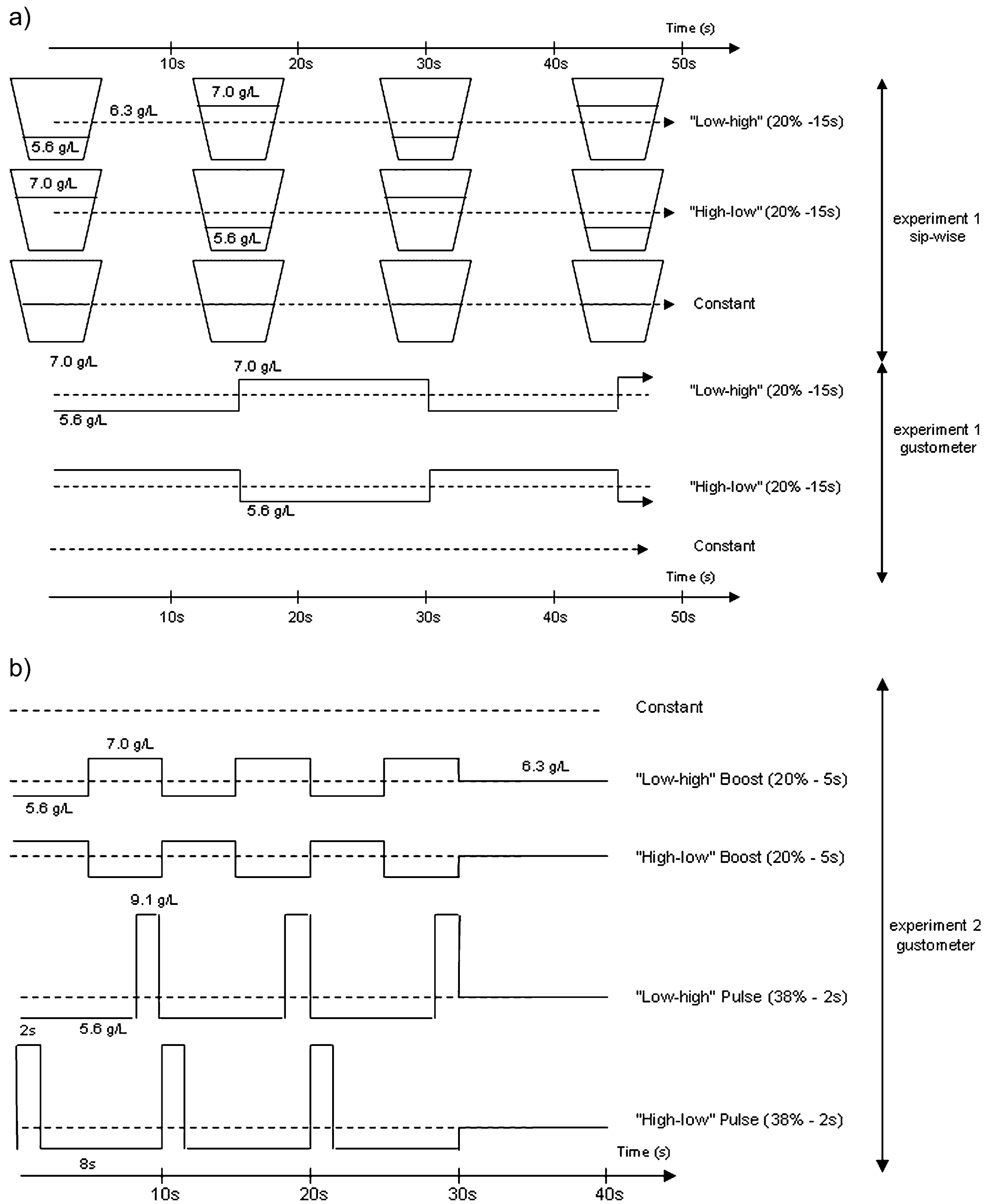

Figure 1 Overview of experiments 1 and 2. Schematic overview of the stimuli used in (**a**) experiment 1 (sipwise and gustometer) and (**b**) experiment 2 (gustometer). Salt concentrations and frequency as delivered in cups or via gustometer are indicated. Dashed line (- - -) indicates average salt concentration of 6.3 g/l for all conditions. For experiment 1, stimulus duration was 120 s; data were collected for 240 s. Experiment 2: stimulus duration, 40 s; data collection, 90 s.

Netherlands; 0.030–30.0 ml/min) were connected via Teflon tubing (1.6-mm inner diameter) to an 8-channel input–1-channel output manifold (Inacom, Veenendaal, The Netherlands). Each input channel was fitted with an in-line check valve and mixing took place in the manifold. From the manifold, an approximately 10 cm long Teflon tube leads to the mouth of an assessor. Pump flow rates can be adjusted at any time from the central control unit (terminal eliminator plus, Black Box, Lawrence, PA), using the dedicated software (Bult et al. 2007). In experiments 1 and 2, the flow rate of all stimuli was fixed at 40 ml/min (same overall frequency as in the sipwise setup). The flow rates of individual pumps were varied in order to deliver different concentrations into the mouth of the panellist by combining 1% (w/w) salt solutions and water. During the sessions of experiment 2, panellists wore headphones to restrict possible impact of pump noise on panellist evaluation. The effect of wearing headphones to restrict sound was further investigated in an extra session. Results (not presented here) showed that the minor sound that panellists could hear did not significantly impact their scoring.

TI measurements

TI measurements were used to investigate saltiness perception over time. For each experiment, panel members were trained during at least 2 sessions. For the sipwise experiments, special attention was given to taking in the samples at exactly the right time, the actual perception of the taste intensity, and continuously scoring on the scale of the perceived intensity. For the gustometer experiments, the training of panel members focused on the familiarization with the gustometer method, with continuous sample delivery and on TI scoring, using representative delivery profiles.

TI data of the sipwise experiment were collected using FIZZ 2.0 (Biosystems, Couternon, France). For the gustometer experiments, in-house Time-intensity (TI) software (Visual Basic.NET) was used. In all experiments, the scale was set from 0 to 100. In the gustometer experiments, panel members received a reference (10 g/l salt solution) before each sequence was delivered. This reference was given a fixed score of 100 and 80 in gustometer experiments 1 and 2, respectively. Data were collected during sample delivery (120 and 40 s) and afterwards (aftertaste) (120 s and 50 s) for experiments 1 and 2, respectively.

Data analysis

The TI measurements produced data with multiple peaks, for which traditional analysis of TI data was not suitable. For all TI curves, obtained from experiments 1 and 2, area under the curves (AUC) were analyzed, which are highly correlated with the perception of taste at a given point (e.g., Lee and Pangborn 1986; Cliff and Noble 1990). For each individual "panellist–replicate" curve obtained for each method (sipwise or gustometer) and each stimulus (Constant, Boost, Pulses, Low–high, and High–low; Figure 1), the following parameters were extracted: Taste AUC (AUC corresponding to the tasting time) and Aftertaste AUC (AUC corresponding to the aftertaste of the sequence of samples; the aftertaste started after delivery of the last salt sample into the mouth). Extracted parameters were analyzed using an analysis of variance (ANOVA). Data for experiment 1 were analyzed using a 3-way ANOVA (panellist within method, method, and stimulus; with panellists within method as random factor). Data from experiment 2 were submitted to a 3-way ANOVA (panellist, stimulus, and replicate). When the stimulus effect was significant ($P < 0.05$), an LSMEANS post hoc comparison test was performed. Statistical analyses were performed with SAS software (version 9.1, SAS Institute Inc., Cary, NC).

Results

Experiment 1: impact of salt variation on saltiness perception using 2 different delivery methods

Average TI curves from the sipwise condition are presented in Figure 2a. The intake of 8 samples every 15 s induced TI profiles with multiple peaks. Whereas the stimulus with constant salt concentration produced 8 peaks with small amplitude, stimuli with alternating salt concentrations show 4 peaks of higher amplitude. These peaks can be related to the actual delivered salt concentrations. TI profiles from the continuous flow condition (gustometer) are shown in Figure 2b. For the constant concentration curve, a peak is observed at the start, followed by a more or less constant lower intensity. For High–low and Low–high sequences, TI profiles consisted of 4 peaks in a regular pattern. Both in the sipwise and in the gustometer experiments, the alternating sequence starting with a low concentration (Low–high sequence) shows a lower maximum for the first peak. Furthermore, for both delivery methods, the sequence ending with a high concentration (Low–high sequence) displays increased saltiness intensity compared with the sequence ending with the low concentration. This effect extends into the aftertaste interval. Upon closer inspection of the shape of the TI profiles resulting from concentration variations, differences can be observed between the 2 delivery methods. The relative position of the curves and where they cross each

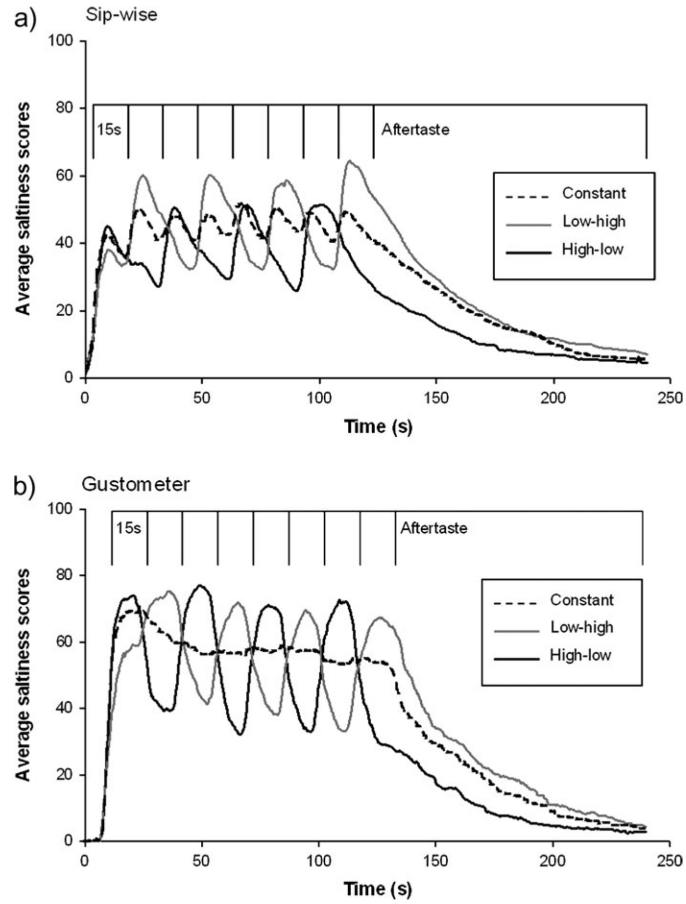

Figure 2 Average TI curves of experiment 1. Average salt concentration is 6.3 g/l; salt concentration difference is 20% (7 and 5.6 g/l). Vertical lines indicate concentration changes every 15 s (in-mouth) and the aftertaste interval. **(a)** Sipwise condition and **(b)** gustometer condition.

other is different. For the sipwise experiment, the positions of the minimums and maximums mirror each other for the "opposite" stimuli, but their shapes are skewed. The minimums and maximums of the 2 opposite sequences of the gustometer profiles have similar values, and the profiles cross each other on the constant concentration curve. The relative size of the amplitude of minimum and maximum peaks for the alternating salt concentrations was of comparable magnitude, 55% and 68% for sipwise and gustometer delivery, respectively.

As shown in Figure 3, cup-wise delivery elicited a weaker taste (judged by Taste AUC) than delivery by gustometer ($F_{1,21}$ = 13.07, $P < 0.01$). For each delivery method, data from individual panellists differed significantly ($F_{21,111}$ = 4.10, $P < 0.001$). However, the way by which NaCl was presented in time (Constant, or with a 20% concentration variation) did not affect taste significantly for both methods used. With regards to the perception of the aftertaste (judged by the aftertaste AUC; Figure 3), the method used to deliver the stimuli did not significantly affect the perception. For the cupwise and gustometer delivery methods, data from individual panellists differed significantly ($F_{21,111}$ = 6.70, $P <$ 0.001). The salt delivery profile affected the aftertaste ($F_{2,111}$ = 16.15, $P < 0.001$). As shown in Figure 3, the High–low 20% variation stimulus induced a weaker aftertaste than the Low–high and Constant stimuli, whatever the delivery method used.

Experiment 2: impact of different salt delivery profiles on saltiness perception

In experiment 2, the gustometer was used to deliver salt concentrations with a faster frequency than in experiment 1. Boost and Pulse stimuli (see Materials and methods and Figure 1) with high–in-salt concentration delivery of 5 and 2 s, respectively, were provided to panellists. Stimuli were shortened to 30 s and a 10-s delivery of 6.3 g/l salt was added to all stimuli (from 30 to 40 s) because a large impact of the last concentration on aftertaste was observed in experiment 1. This 10-s supplementary delivery was added to all stimuli to ensure that all sequences ended with the same salt concentration. All stimuli had the same average salt concentration. Average TI curves are presented in Figure 4. For the Constant stimulus, saltiness scores stay almost constant over the 40 s of delivery (Figure 4a and b). Concerning the Boost and Pulse stimuli, TI curves present multiple peaks that can be related to salt concentration delivery. From these curves, it can be assumed that panellists were able to discriminate between salt concentrations.

It can be noticed that all stimuli showed an increase in saltiness with time. This seems less apparent for the Constant condition. This effect is more apparent under the pulsed conditions (Figure 4b), which suggests that the Pulse stimuli have been perceived as saltier than the other stimuli, the effect being more obvious for the High–low Pulse. The latter stimulus also shows a high increase in saltiness score around 45 s that is not observed for the other stimuli. Concerning the

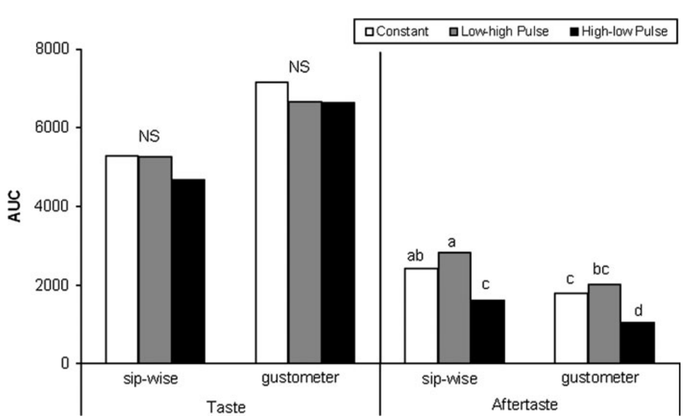

Figure 3 Areas under the curve for experiment 1. Taste and Aftertaste AUC for sipwise and gustometer conditions. Mean values associated with the same letter are not significantly different (α = 0.05). NS, not significantly different.

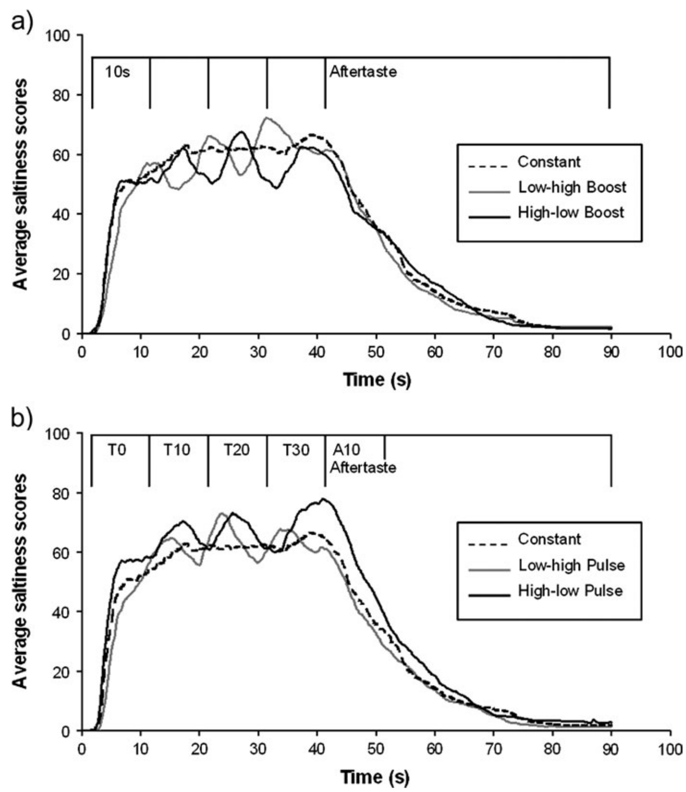

Figure 4 Average TI curves of experiment 2 (gustometer condition). Average salt concentration is 6.3 g/l. Constant condition is displayed in **(a and b)**. **(a)** Salt concentration difference is 20% (7 and 5.6 g/l); high–in-salt Boosts of 5 s every 10 s were delivered 3 times, followed by a 10-s delivery of 6.3 g/l. Vertical lines indicate concentration changes every 10 s (in-mouth) and the aftertaste interval. **(b)** Salt concentration difference is 38% (9.1 and 5.6 g/l); high–in-salt Pulses of 2 s every 10 s were delivered 3 times, followed by a 10-s delivery of 6.3 g/l. 10-s epochs are indicated: T0 corresponds to the taste interval between 0 and 10 s; T10 corresponds to the taste interval between 10 and 20 s, etc. A10 corresponds to the first 10 s of the aftertaste interval (the interval between 40 and 50 s).

3 remaining stimuli (Boost and Constant; Figure 4a), the curves present a similar average saltiness TI score, the Constant stimulus lying mainly in between the up and down parts of the Boost curves.

For taste and aftertaste, data from individual panellists (judged by Taste and Aftertaste AUCs) differed significantly ($F_{9,36} = 18.55$, $P < 0.001$ and $F_{9,36} = 39.52$, $P < 0.001$, respectively). There was no significant replicate effect. As shown in Figure 5, the way by which NaCl was presented in time affected taste ($F_{4,36} = 3.22$, $P < 0.05$) and aftertaste ($F_{4,36} = 2.69$, $P < 0.05$). The High–low Pulse stimulus elicited stronger taste and aftertaste than other stimuli. As observed from the curves (Figure 4), saltiness intensity of the Low–high and High–low Boost stimuli and the Constant stimulus were not found to be significantly different.

The effect of salt delivery on saltiness perception over time was further investigated by examining the evolution of AUC every 10 s (corresponding to the repetitive element of each stimulus). Each individual TI curve was divided into epochs of 10-s intervals, and the AUC was calculated for each 10-s epoch (T0, T10, T20, T30, and A10, corresponding to the first 10 s of the aftertaste). For each stimulus, average epoch AUCs increased from T0 to T10 and decreased after salt delivery from T30 to A10 (Figure 6; results are shown for Constant and Pulse conditions only). No evidence of an adaptation effect (a decrease in perceived saltiness intensity upon prolonged stimulation) was observed between 10- and 30-s stimulation, as based on simple examination of the evolution of epochs over time (Figure 6).

Moreover, from Figure 6 it can be observed that for each 10-s interval the AUC is higher for the High–low Pulse (Figure 6). Such effect was not observed for the delivery profile of the Low–high Pulse. The main differences between the 2 Pulse sequences consisted in the timing of the high–in-salt Pulses: these Pulses are presented first for the High–low Pulse and only after 8 s for the other stimulus.

The results reported here show that saltiness perception may be modified by changing the salt delivery profile. A pulsatile profile (2-s Pulses) starting with a high–in-salt Pulse resulted in higher saltiness scores. The data suggest that panellists are specifically influenced by the concentration of salt during the 2 first seconds of delivery.

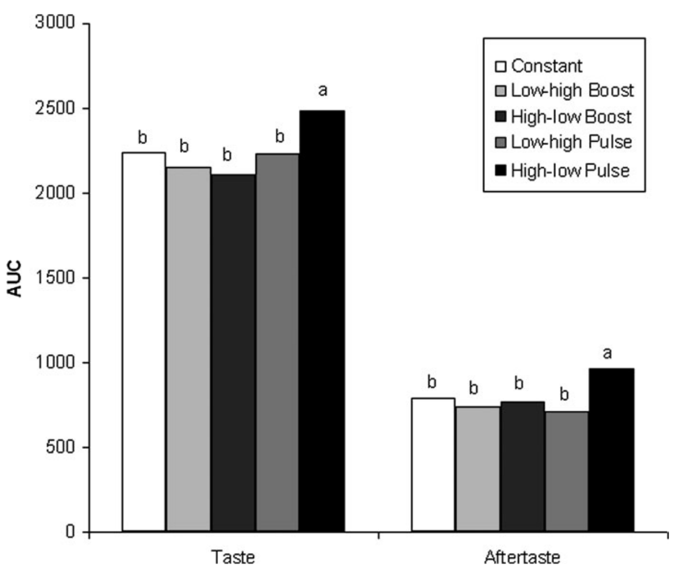

Figure 5 Areas under the curve (AUC) for experiment 2 (gustometer condition). Taste and aftertaste AUC for all 5 conditions. Mean values associated with the same letter are not significantly different (α = 0.05).

Discussion

In experiment 1, salt solutions of constant and alternating salt concentrations were delivered into the mouth of panellists during 120 s via 2 methods. The overall delivery conditions had been matched. In the sipwise condition with constant concentration, the saltiness score was reduced somewhat during each 15-s interval. This may be due to dilution with saliva, swallowing, and adaptation. The beginning of the next sip of the same concentration was consequently perceived as slightly higher due to contrast. Hence, constant concentrations assessed under sipwise conditions produced 8 small peaks, which are in accordance with studies by Guinard et al. (1986), Bornstein et al. (1993), and Schiffman et al. (1994, 2003), who obtained similar curve shapes for such experiments. In the constant concentration condition, delivered under continuous flow with the gustometer, a constant flow of liquid was delivered in mouth and after an initial peak a constant perception level was reached.

Variation of the concentration in both delivery methods (experiment 1) produced similar but not identical TI profiles comprising of 4 peaks, which can be attributed to the contrast experienced with the preceding 15-s sample of different concentration. This effect has been defined as successive cumulative contrast: solutions preceded by a high

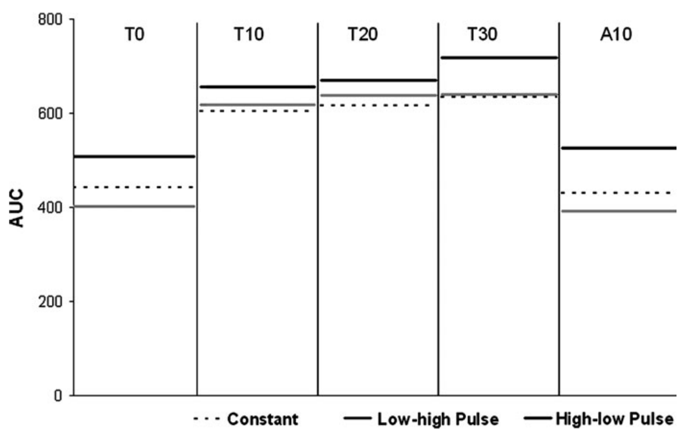

Figure 6 Epoch analysis of experiment 2 (gustometer condition). AUCs for 10-s intervals for the Constant, Low–high Pulse, and High–low Pulse condition. T0 corresponds to the taste interval between 0 and 10 s; T10 corresponds to the taste interval between 10 and 20 s, etc. A10 corresponds to the first 10 s of the aftertaste interval (the interval between 40 and 50 s).

concentration level are judged to be significantly less intense than solutions proceeded by a low concentration level (Schifferstein and Oudejans 1996).

Delivery conditions for the 2 methods have been matched, that is, same concentrations and overall the same sampling frequency of 10 ml per 15 s have been applied. However, there is intrinsically a different temporal delivery profile associated with each method. With the cups, 10 ml is placed in the mouth at once, and this is repeated every 15 s ("batchwise"). With the gustometer, 10 ml is delivered over a period of 15 s, and this is repeated without a pause with the same or different concentrations (continuous). These differences impact the evolution and timing of the TI profiles. The TI profiles obtained with the gustometer display stable shapes. This may be attributed to highly controlled sample delivery into the mouth (concentration, flow, and timing) for the gustometer setup, whereas for the sipwise condition, only the intake time of each cup and its volume and concentration can be controlled. In-mouth processing (mouth movements and timing of swallowing) was not controlled in the 2 conditions. The panel composition has not been the same in the 2 conditions due to availability of panel members, but all panel members were trained. Despite significant differences in AUC observed between the 2 studies—conducted with different delivery methods and different panellists—reported in experiment 1, similar effects of salt concentration on saltiness perception were observed, whatever the delivery method used.

No increase in perception was observed upon concentration variations for both delivery methods. Both contrast and adaptation effects are assumed to play a role upon sequential delivery of concentration variations, and these effects appear to have counteracted each other. Rather, a faster stimulation frequency might be needed to reduce adaptation and hence increase perception. The impact of faster frequency delivery rates on perception was assessed using the gustometer in experiment 2.

In experiment 2, analysis of the evolution of AUC over time (10-s intervals) suggested that there was no adaptation effect. This is in line with results of Meiselman and Halpern (1973), who reported absence of adaptation under conditions designed to simulate drinking, with pulsatile delivery of salt and water stimuli onto the tongue (Halpern and Meiselman 1980). Hence, the results presented here suggest that fast concentration changes can lead to increased perception, which is attributed to a reduction of the adaptation experienced at the receptor. Such effects at the receptor have been reported for studies involving rats (Smith and Bealer 1975; Marowitz and Halpern 1977; Matsuo and Yamamoto 1992).

An increase in saltiness perception (as represented by AUC) was observed for the Pulse condition with the high–in-salt concentration delivered at the beginning of the sequential 10-s intervals. The difference in saltiness between this stimulus and other stimuli (especially the Low–high Pulse) can possibly be attributed to different parameters of the delivery design. It can be hypothesized that the first 2-s interval of the stimulus is a relevant parameter influencing the overall saltiness rating (from the beginning and until the aftertaste). The effect could be due to a perceptual effect (a strong saltiness at the beginning of a stimulus inducing a stronger overall saltiness perception) and/or to a scoring effect (the higher scores rated at the beginning of the scoring inducing an overall higher intensity score over time, via continuous rating on the scale). The fixed concentration at the end of the stimulus delivery is another parameter possibly influencing the saltiness rating of the High–low Pulse. It was observed that for this condition, there was a relatively large increase in saltiness perception during the 30- to 40-s interval. There may be a contribution in increased saltiness perception from the fixed salt concentration of 6.3 g/l at this interval, which has been an increase as compared with the concentration delivered prior to it. Such effects on aftertaste have been observed in experiment 1. However, it should be noted that such an effect was not observed for the High–low Boost condition.

As a conclusion of this study, a significantly increased perception for 2-s high–in-salt Pulses was shown, when starting the sequence with a Pulse. It has been primarily suggested that this could be attributed to a reduction of adaptation as induced by fast concentration changes delivered in mouth. Analysis of the results also suggests other parameters that could impact on saltiness rating. This preliminary study, in which samples were delivered with a gustometer and the effects on saltiness perception were investigated using TI, would need further validation. Further work is recommended in order to understand if saltiness perception is more influenced by the frequency (2 s or less) or the salt concentration differences of short salt stimuli and to understand the importance of timing in the sequence of the Pulse. Furthermore, it is recommended to measure the overall salt perception (and not over time) and during shorter stimuli (e.g., 10 s) with varied salt delivery profiles within the stimulus. This would be more representative of real consumption conditions of products.

The food matrix or microstructure affects the temporal release profile of tastants and aroma, which in turn has an impact on perception (Taylor 1996; Wilson and Brown 1997; Taylor et al. 2001; Wright and Hills 2003; Busch et al. 2008). Studies with the gustometer, such as the current study, can be very useful for the definition of design rules for release profiles that lead to a higher perception with the same tastant or aroma composition. Ultimately, this should provide input for product design.

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References

Alberts B, Bray D, Lewis J, Raff M, Roberts K, Watson JD. 1994. Cell signalling. In: Alberts B, Bray D, Lewis J, Raff M, Roberts K, Watson JD, editors. Molecular biology of the cell. New York: Garland Publishing Inc. p. 721–785.

Bornstein BL, Wiet SG, Pombo M. 1993. Sweetness adaptation of some carbohydrate and high potency sweeteners. J Food Sci. 58:595–598.

Bult JHF, de Wijk RA, Hummel T. 2007. Investigations on multimodal sensory integration: texture, taste, and ortho- and retronasal olfactory stimuli in concert. Neurosci Lett. 411:6–10.

Busch JLHC, Keulemans C, van den Oever GJ, Reckweg F. 2008. Food composition. International patent application. WO 2008/074606.

Cliff M, Noble AC. 1990. Time-intensity evaluation of sweetness and fruitiness and their interaction in a model solution. J Food Sci. 55: 450–454.

Cobcroft M, Tikellis K, Busch JLHC. 2008. Salt reduction—a technical overview. Food Aust. 60:26–30.

Gent JF, McBurney DH. 1978. Time course of gustatory adaptation. Percept Psychophys. 23:171–175.

Guinard J-X, Pangborn RM, Lewis MJ. 1986. Effect of repeated ingestion on temporal perception of bitterness in beer. J Am Soc Brew Chem. 44: 28–32.

Halpern BP, Meiselman HL. 1980. Taste psychophysics based on a simulation of human drinking. Chem Senses. 5:279–293.

Hort J, Hollowood TA. 2004. Controlled continuous flow delivery system for investigating taste-aroma interactions. J Agric Food Chem. 52: 4834–4843.

Kelling ST, Halpern BP. 1983. Taste flashes: reaction times, intensity, and quality. Science. 219:412–414.

Kilcast D, den Ridder C. 2007. Sensory issues in reducing salt in food products. In: Kilcast D, Angus F, editors. Reducing salt in foods: practical strategies. Cambridge: Woodhead Publishing Limited. p. 201–220.

Lee WE III, Pangborn RM. 1986. Time-intensity: the temporal aspects of sensory perception. Food Technol. 40:71–82.

Linforth RST, Pearson KSK, Taylor AJ. 2007. In vivo flavor release from gelatin-sucrose gels containing droplets of flavor compounds. J Agric Food Chem. 55:7859–7863.

Marowitz LA, Halpern BP. 1977. Gustatory neural response of the chorda tympani to lick duration stimuli. Chem Senses Flav. 2:457–485.

Matsuo R, Yamamoto T. 1992. Effects of inorganic constituents of saliva on taste responses of the rat chorda tympani nerve. Brain Res. 583:71–80.

McBurney DH. 1985. Taste and olfaction: sensory discrimination. In: Brookhart JM, Mountcastle VB, editors. Handbook of physiology: section I, Vol. II. Sensory processes. Bethesda, MD: Physiological Society. p. 1067–1086.

Meiselman HL. 1968. Magnitude estimation of the course of gustatory adaptation. Percept Psychophys. 4:193–196.

Meiselman HL. 1972. Human taste perception. Crit Rev Food Technol. 3:89–119.

Meiselman HL, Halpern BP. 1973. Enhancement of taste intensity through pulsatile stimulation. Physiol Behav. 11:713–716.

O'Mahony M. 1972. The interstimulus interval for taste. 1. The efficiency of expectoration and mouthrinsing in clearing the mouth of salt residuals. Perception. 1:209–215.

O'Mahony M. 1984. Alternative explanations for procedural effects on magnitude-estimation exponents for taste, invoking adaptation, context, and volume effects. Perception. 13:67–73.

Sacks FM, Svetkey LP, Vollmer WM, Appel LJ, Bray GA, Harsha D, Obarzanek E, Conlin PR, Miller ER, Simons-Morton DG, et al. 2001. Effects on blood pressure of reduced dietary sodium and the dietary approaches to stop hypertension (DASH) diet. DASH-Sodium Collaborative Research Group. N Engl J Med. 344:3–10.

Schifferstein HNJ, Oudejans IM. 1996. Determinants of cumulative successive contrast in saltiness intensity judgements. Percept Psychophys. 58:713–724.

Schiffman SS, Pecore SD, Booth BJ, Losee ML, Carr BT, Sattely-Miller E, Graham BG, Warwick ZS. 1994. Adaptation of sweeteners in water and in tannic acid solutions. Physiol Behav. 55:547–559.

Schiffman SS, Sattely-Miller EA, Brevick GG, Zervakis J, Butchko HH, Stargel WW. 2003. Effect of repeated presentation on sweetness intensity of binary and ternary mixtures of sweeteners. Chem Senses. 28:219–229.

Smith DV, Bealer SL. 1975. Sensitivity of the rat gustatory system to the rate of stimulus onset. Physiol Behav. 15:303–314.

Smith DV, Bealer SL, van Buskirk RL. 1978. Adaptation and recovery of the rat chorda tympani responses to NaCl. Physiol Behav. 20:629–636.

Taylor AJ. 1996. Volatile flavor release from foods during eating. Crit Rev Food Sci Nutr. 36:765–784.

Taylor AJ, Besnard S, Puaud M, Linforth RS. 2001. In vivo measurement of flavour release from mixed phase gels. Biomol Eng. 17:143–150.

Thompson RF, Spencer WA. 1966. Habituation: a model phenomenon for the study of neuronal substrates of behavior. Psychol Rev. 73:16–43.

Wilson CE, Brown WE. 1997. Influence of food matrix structure and oral breakdown during mastication on temporal perception of flavour. J Sens Stud. 12:69–86.

World Health Organisation. 2007. Report of a WHO Forum and Technical Meeting. Geneva: WHO Document Production Services.

Wright KM, Hills BP. 2003. Modelling flavour release from a chewed bolus in the mouth: part II. The release kinetics. Int J Food Sci Technol. 38: 361–368.

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