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Recalling Sweet Taste Intensities in the Presence and Absence of Other Tastes

Mika Vanne, Hely Tuorila and Pentti Laurinen[1]

Department of Food Technology, University of Helsinki, PO Box 27 (Viikki B), FIN-00014 Helsinki and [1]Department of Psychology, University of Helsinki, PO Box 13, FIN-00014 Helsinki, Finland

Correspondence to be sent to: Mika Vanne, Department of Food Technology, University of Helsinki, PO Box 27 (Viikki B), FIN-00014 Helsinki, Finland. e-mail: mika.vanne@helsinki.fi

Abstract

Memory for sweet taste intensities in different media during 125 h was investigated using three concentrations (w/w) of sucrose: 4.21% (0.125 M), 8.28% (0.25 M) and 16.06% (0.5 M). Sucrose was dissolved in four media [water with no tastant and water with 0.73% (0.125 M) sodium chloride, 0.04% (0.002 M) citric acid and 0.04% (0.002 M) caffeine] as standard stimuli. Subjects (n = 39) were assigned into four groups, each group performing the memory task in one medium only. After tasting each standard the subjects reproduced the subjective taste intensity immediately and after 12 min and 1, 5, 25 and 125 h by mixing portions of low (0%) and high (29.75%; 1 M) concentrations (w/w) of sucrose and by tasting and retasting (*ad libitum* procedure). The produced sucrose concentrations increased significantly from the first session to the 125 h time interval. There was a significant difference between immediately reproduced standard concentrations and concentrations produced after all time intervals. Relative differences from standard ($\Delta i/i$) differed only between concentrations produced immediately and after 125 h time interval. The low (4.21%) concentration showed larger differences from standard than the high (16.06%) concentration. The added tastant had no effect on the results.

Introduction

Taste memory has seldom been investigated in memory psychophysical research. One of the earliest taste memory studies was carried out by Barker and Weaver (1983). They asked the subjects to compare the memory image of an earlier presented 15% sucrose concentration after one of four time intervals (1, 5 or 15 min, or 72 h) with one of four sucrose concentrations (5, 10, 15 or 20% in water). The subjects' task was to report if the presented concentration was less sweet, the same or sweeter than the standard. Subjects rated 15% sucrose sweeter than the standard (also 15%) after all time intervals. The number of sweeter responses decreased from the 1 min time interval to the 72 h time interval.

In a study by Algom and Marks (1989) subjects first learned to associate colors with different sucrose concentrations (0.028, 0.083, 0.19, 0.42, and 0.69 M) in water. Those subjects who passed a learning criterion were randomly assigned to either a perceptual or a memory condition after 24 h. In the perceptual condition the subjects rated the intensity of the actual concentrations, and in the memory condition subjects imagined the stimuli and then rated the intensities of the stimuli by using previously learned colors as memory cues. Algom and Marks (1989) calculated exponents of perceptual and memorial power functions and found no significant difference between them. The same method has been used in odor memory studies (Osaka, 1987; Algom and Cain, 1991), with results showing no difference between the exponents of perceptual and memorial power functions, indicating correspondence between perception and memory. The same type of results has been reported also in the studies investigating memory in taste–odor (Algom *et al.*, 1993) and taste–taste (Stevenson and Prescott, 1997) combinations.

The method of adjustment has most often been used in the determination of difference thresholds and absolute sensitivity. Subjects adjust a comparison stimulus until it is just perceptible, until the sensation just disappears or until the stimulus seems equal to some standard stimulus (Gescheider, 1985). In food science, the method of adjustment (*ad libitum* mixing) has been used for assessing optimal preferred levels of tastants in foods with promising results with regard to the reliability and validity of the method (Mattes and Lawless, 1985). Tuorila *et al.* (1996) applied *ad libitum* mixing to investigate people's ability to remember tastes at different time intervals. In the first session subjects matched the intensity of comparison stimulus to the intensity of standard by adding low and high concentrations of taste substance to the comparison stimulus and by tasting and retasting. After time intervals from 1 h to 6 weeks the subjects tried to reproduce the standard without the standard being present. The subjects overestimated the intensity of 8% sucrose in redcurrant juice and 1.2% sodium

chloride in beef broth after time intervals of 24 h, 1 week and 6 weeks. Also the intensity of 3% sucrose was overestimated after 1 week and after 6 weeks.

Some stimuli used in chemosensory memory studies have been single compounds, such as pyridine (Osaka, 1987), sucrose (Barker and Weaver, 1983; Algom and Marks, 1989; Tuorila *et al.*, 1996) and sodium chloride (Tuorila *et al.*, 1996). Combinations of two or more components, such as a mixture of amyl acetate with leaf alcohol (Algom and Cain, 1991), citric acid with sucrose (Stevenson and Prescott, 1997) and orange flavor with sucrose (Algom *et al.*, 1993), have also been employed as stimuli. Taste substances have mostly been presented in water (Barker and Weaver, 1983; Algom and Marks, 1989; Stevenson and Prescott, 1997), but more complex media, such as redcurrant juice and beef broth (Tuorila *et al.*, 1996), have also been used. The effect of the medium on taste memory has not been systematically investigated.

In all earlier studies the results have been calculated using either estimated intensities (Osaka, 1987; Algom and Marks, 1989; Algom and Cain, 1991; Algom *et al.*, 1993; Stevenson and Prescott, 1997) or measured absolute concentrations (Tuorila *et al.*, 1996). In a situation in which different concentrations are compared with each other, the absolute values may be misleading because the discrimination thresholds, as well as the deviations, are necessarily smaller at lower than at higher concentrations.

The aim of this study was to examine the memory for taste intensity of three sucrose concentrations in different media by using *ad libitum* mixing as the testing method. The use of pure water versus sour, salty and bitter tastant enabled the comparison between media.

Materials and methods

Subjects

The subjects were 39 volunteers, 28 females and 11 males, who were staff members and students at the University of Helsinki. Some subjects had previous experience in sensory evaluation but none of them had participated in experiments on taste memory. Subjects were told that the topic of the study was memory for tastes. There were four groups, each group working on one added tastant (no tastant: n = 10, 7 females, 3 males, mean age 33 years, range 24–54 years; sodium chloride (salty): n = 9, 7 females, 2 males, $\bar{x}$ = 32, 26–57; citric acid (sour): n = 10, 7 females, 3 males, $\bar{x}$ = 33, 25–42; caffeine (bitter): n = 10, 7 females, 3 males, $\bar{x}$ = 33, 22–48).

Samples

Sucrose (medical quality according to the standards of Pharmacopea Europe, supplied and analysed by University of Helsinki Pharmacy) was used as a standard stimulus at 4.21% (0.125 M), 8.28% (0.250 M) and 16.06% (0.500 M) concentrations (w/w). Sucrose was dissolved in four media: tap water only (water group) and aqueous solutions with 0.73% (0.125 M) sodium chloride (salty group), 0.04% (0.002 M) citric acid (sour group) and 0.04% (0.002 M) caffeine (bitter group). Perceived intensities of the concentrations of sodium chloride, citric acid and caffeine (all from E. Merck) in water were matched to the perceived intensity of 8.28% sucrose in water in a pilot test.

All samples were presented at room temperature (21°C). The three standard stimuli (30 ml each) were presented in 50 ml beakers. The low 0% and high 29.75% (1 M) concentrations (w/w) of sucrose for mixing, 80 ml each, were presented in 100 ml beakers. The subjects were instructed to ask for more solutions if they needed them. The prefills (20 ml), from which the comparison stimuli were produced, were presented in 110 ml plastic cups.

Four prefill concentrations were used with each standard sucrose concentration. The prefills were two and four Weber ratios lower and two and four Weber ratios higher than the target concentration (Lundgren *et al.*, 1976). The Weber ratio was used to ensure the perceptually equal difference between the prefills. A total of 48 prefills (12 concentrations and four media) were used. The concentrations of the standards and the prefills are shown in Table 1. In each group all stimuli, including the prefills, contained the same concentration of salty, sour or bitter substance.

The samples produced by the subjects were kept frozen at –20°C until all sessions were completed to prevent the evaporation of the water. The sucrose concentrations were analyzed refractometrically at 20°C temperature. The refractive indices were transformed to sucrose concentrations (w/w) using reference tables (AOAC, 1990). Added tastants

Table 1 Sucrose concentrations of standards and prefills used in the study

Stimulus	Moles	Percentage (w/w)
Prefill 1	0.093	3.14
Prefill 2	0.108	3.64
Standard 1	**0.125**	**4.21**
Prefill 3	0.145	4.87
Prefill 4	0.168	5.63
Prefill 5	0.186	6.21
Prefill 6	0.216	7.17
Standard 2	**0.250**	**8.28**
Prefill 7	0.290	9.55
Prefill 8	0.336	11.00
Prefill 9	0.372	12.10
Prefill 10	0.431	13.92
Standard 3	**0.500**	**16.06**
Prefill 11	0.580	18.35
Prefill 12	0.673	21.00

Prefills 1–4 were used randomly with standard 1, prefills 5–8 with standard 2 and prefills 9–12 with standard 3.

(without sucrose) were also analyzed refractometrically to examine whether they influenced the refractive indices. Only sodium chloride added to the refractive index (0.637%) and this value was subtracted from the total sucrose concentration.

Procedure

Ad libitum mixing was used as the testing method. Six sessions were run. In the first session the subjects received low and high concentrations of sucrose for mixing, all three standards in randomized order and two cups of randomly selected prefills for each standard. One of the prefills had a lower and the other had a higher sucrose concentration than the standard. The subjects were first asked to taste the low and high concentrations for mixing and to rinse their mouths with water after tasting. Subsequently they tasted the first standard and swallowed some. Subjects were instructed to pay special attention to the sweetness intensity of the standard, as they would need this knowledge later in the experiment. After tasting the first standard the subjects tried to reproduce the intensity of the standard by mixing low and high concentrations of the taste substance into the cup. The subjects put a lid on the cup when they were ready and handed it to the experimenter. At the beginning of 1 min break between each mixing, the subjects rinsed their mouths for 15 s with tap water. After both cups for the first standard had been produced, the second and finally the third standard was tasted and two replications were made in a similar way. The following five sessions were held 12 min and 1, 5, 25 and 125 h after the end of the first session. The same method was used without the presence of the standards. The order in which the standards were presented in the first session was repeated orally to the subjects before the beginning of the second session. The prefills were used to prevent the subjects from memorizing the quantity of low and high concentrations needed for a successful mix.

Testing was carried out in a sensory laboratory with partitioned tasting booths and with the possibility to spit out the samples and rinse the mouth with tap water. At the beginning of each session the subjects received instructions and were asked to read them carefully. The subjects were encouraged to ask for further information if needed.

Data analysis

Repeated measures analysis of variance was used to determine main effects and interactions over media. Time (six sessions), sucrose concentration (three concentrations) and replication (two replications) were used as a sources of variance. Dunnett's test (e.g. O'Mahony, 1986) was used to compare subjects' performance between the first session and the following sessions. All the data analyses were carried out using both absolute concentrations % (w/w) and relative differences from standard {[mixed concentration % (w/w) – standard % (w/w)]/standard % (w/w)}. The absolute concentrations were used to compare the present results to earlier results.

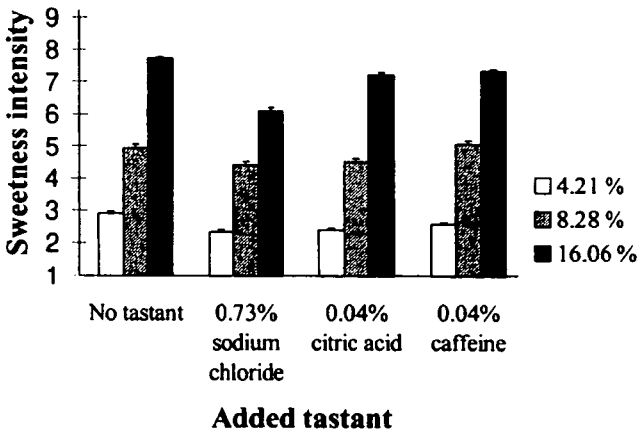

Figure 1 Ratings of sweetness intensity at different sucrose concentrations (w/w) + standard error of measurement with all added tastants (n = 39).

Auxiliary experiment

An auxiliary experiment was conducted to confirm perceptual differences of samples. After the last session all subjects rated sweetness, saltiness, sourness and bitterness of the 12 standards (three sucrose concentrations in four media) at room temperature (21°C) on nine-point scales (anchored at ends, e.g. not sweet at all–extremely sweet). The two-way ANOVA showed an increase in sweetness intensity due to the increase of the sucrose concentration [$F(2,456) = 255.98$, $P < 0.001$] (Figure 1). The medium also showed a significant main effect [$F(3,456) = 18.50$, $P < 0.001$]. However, the increasing trend of sweetness intensity was similar in all media [*sucrose concentration* × *medium* $F(6,456) = 1.16$, $P = 0.33$]. One-way ANOVA showed a decrease of saltiness ratings in salty samples [$F(2,116) = 3.41$, $P < 0.05$] and sourness ratings in the sour samples [$F(2,116) = 3.34$, $P < 0.05$] when the sucrose concentration increased. The bitterness ratings in bitter samples did not differ significantly in different sucrose concentrations.

Results

Absolute concentrations

Repeated measures ANOVA across all groups showed that the sucrose concentrations produced after different time intervals were higher than the sucrose concentrations produced in the first session [$F(5,175) = 3.81$, $P < 0.01$] (Figure 2). Sucrose concentrations produced after each time interval were higher than in the first session (Dunnett's test, $P < 0.01$). The concentration of the standard had a significant main effect [$F(2,70) = 223.70$, $P < 0.001$] on the produced concentrations. Added tastant (medium) did not affect the reproduction of sweetness intensity [the main

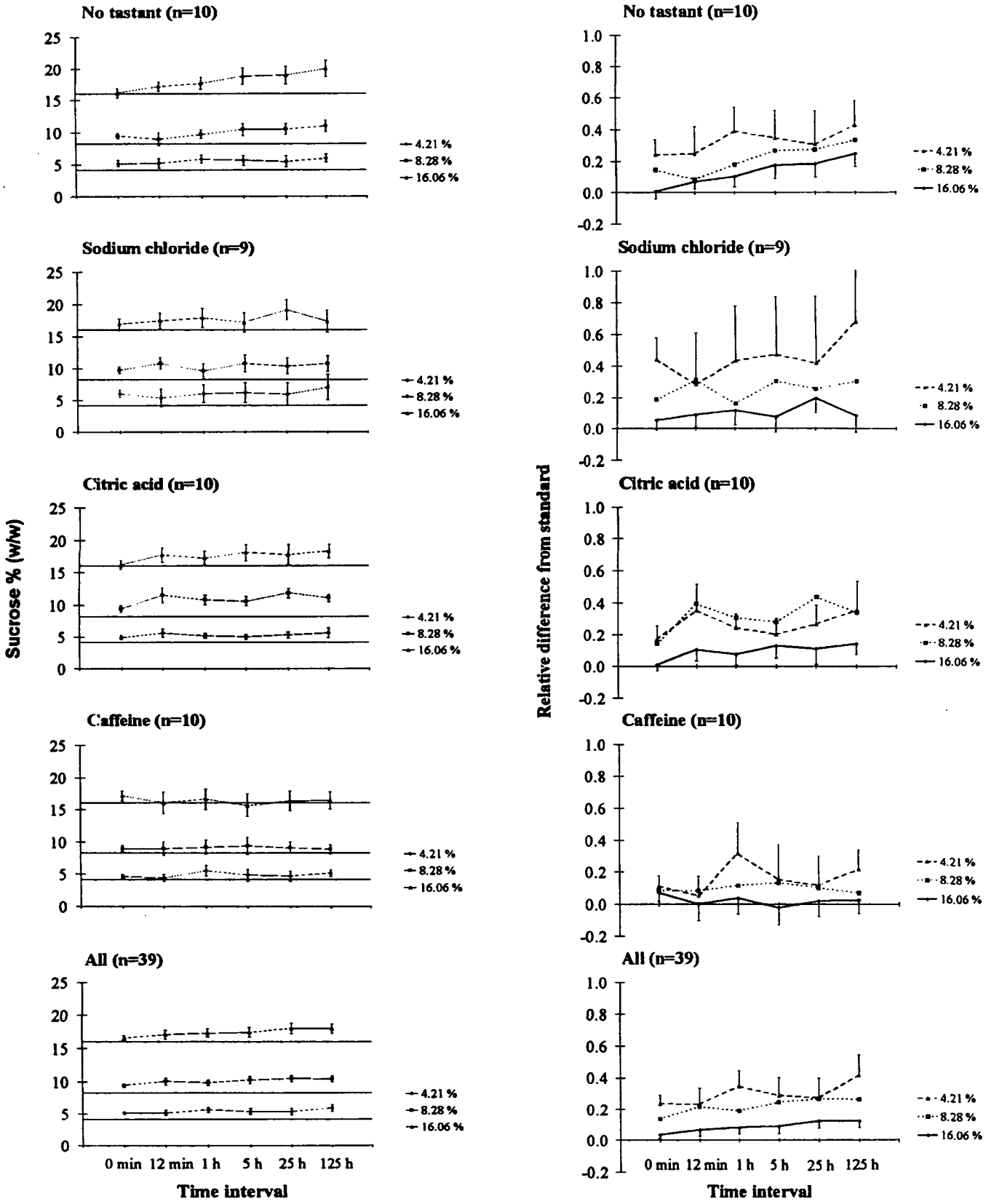

Figure 2 Mean absolute concentrations + standard error of measurement (left) and relative differences from standard (right) with three sucrose concentrations at different time intervals in all four groups separated and together.

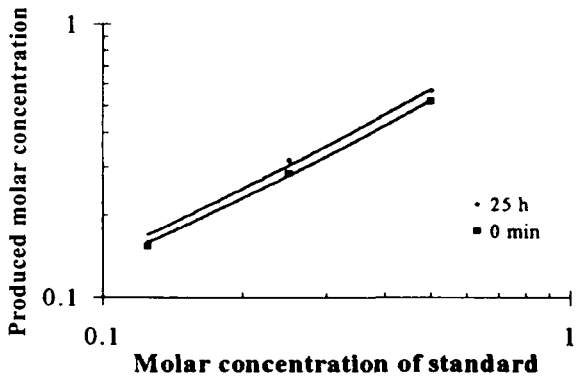

Figure 3 Perceptual (0 min) and memorial (25 h) power functions (from water group only, n = 10).

effect of group was non-significant; $F(3,35) = 1.82$, $P = 0.16$]. No effect of replication was observed.

In order to compare the present results with earlier results from Algom and Marks (1989) a picture of the perceptual and memorial (25 h) power functions (Figure 3) for the water group was drawn for absolute sucrose concentrations.

Relative differences

Repeated measures ANOVA across all groups showed that the produced sucrose concentrations were higher after a certain time interval than the sucrose concentrations reproduced in the presence of standard [$F(5,175) = 2.75$, $P < 0.05$] (Figure 2). However, only after 125 h were the produced sucrose concentrations significantly higher than those produced in the first session (Dunnett's test, $P < 0.05$). The sucrose concentration of the standard showed a significant main effect [$F(2,70) = 3.69$, $P < 0.05$] on the produced concentrations. Groups with different taste substances did not differ from each other [$F(3,35) = 1.11$, $P = 0.358$]. No effect of replication was observed.

Regardless of the non-significant interaction between time and concentration, Tukey's test showed higher relative differences from the standard at the low (4.21%) than at the high (16.06%) concentration [$P < 0.05$ (0 min, 12 min and 5 h); $P < 0.01$ (1 and 125 h). Figure 4 shows the differences after 125 h.

Discussion

The tendency to recall taste intensities as more intense than the reference was observed in this study. The absolute concentrations produced after all time intervals and the relative differences after 125 h were significantly higher than those produced initially in the presence of the standard. The difference between produced concentrations and the standard was higher at the low (4.21%) than at the high (16.06%) sucrose concentration. The added taste substances had no significant effect on recalling sweetness.

Recalling sweet taste intensities (absolute concentrations) as stronger after different time intervals than in the first

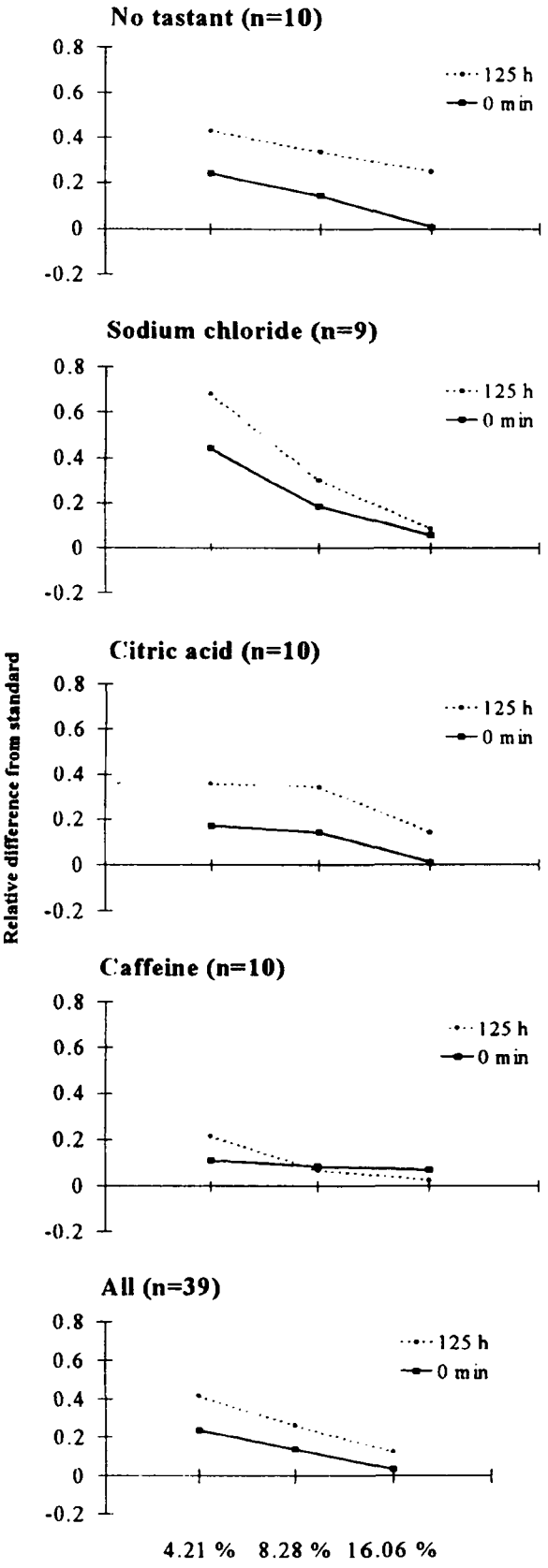

Figure 4 Relative differences from standard at the first session and after 125 h time interval in different sucrose concentrations.

session, where the standard was present, is in line with results by Tuorila *et al.* (1996). The higher concentrations of 3 and 8% sucrose after 24 h (8% only), 1 week and 6 weeks than in the immediate mixing concurs with the reproduced concentrations of sucrose being stronger than the standard at all time intervals in the present study. The effect seems to be contradictory to the underestimation of 15% sucrose reported by Barker and Weaver (1983). However, according to their study the subjects reported 15% sucrose presented after different time intervals to be sweeter than the 15% sucrose presented as the standard. This corresponds with our results, in which subjects produced higher than standard concentrations after time intervals. Barker and Weaver's observation, that the number of sweeter responses was highest after 1 min and decreased over time, may be explained by a saltine cracker eaten for mouth-cleaning purposes after tasting the standard. The decrease of perceived sweetness in the presence of saltiness has been observed in the literature (e.g. Frank and Archambo, 1986; Kroeze, 1989) and also in the auxiliary experiment of the present study (Figure 1).

There was a clear difference in the magnitude of the time-effect depending on the values used in data analysis. Based on the absolute concentrations, the difference between standard and reproduced concentrations can be seen much earlier than when it is based on relative differences. All perceptions are relative, and the use of absolute concentrations can be misleading and result in too large effects. The small difference from the standard at the high concentration compared with the low concentration indicates that the relative mistakes at the low concentration were greater than at the high concentration. One possible interpretation could be the difference of the psychophysical function for sucrose in the used concentration range. However, all concentrations used in our study are in the linear part of the psychophysical function of sucrose (McBride, 1989), so the psychophysical function does not explain the difference between concentrations.

According to Algom and Marks (1989) the slopes of the perceptual and memorial power functions of sucrose in water do not differ from each other, and as a consequence the chemosensory perceptual and memorial functions are more equal than corresponding functions in other modalities (Algom and Marks, 1989). Figure 3 shows the means of produced concentrations as a function of the standard concentration level. The slopes of these power functions seem to be quite similar, which means that the effect of concentration do not differ on perception and memory-based mixing. However, the role of time can be seen in our results, showing that the vertical location of power function depends on the time interval between the perceptual and memory conditions.

Mattes and Lawless (1985) found a difference in *ad libitum* mixing between trials in which the initial samples were concentrated versus those in which they were diluted. This difference was not caused by adaptation (Mattes and Lawless, 1985). Tuorila *et al.* (1996) used prefills to avoid the adjustment error and the visual cues. They did not find a significant effect of prefills, but there was some upward tendency in *ad libitum* concentrations, possibly due to the upward bias in concentrations of the prefills. By using prefills randomly from both sides of the memorable concentration, the potential biasing of the prefills was avoided in the present study.

No effect of added tastant was observed. However, some inconsistency was observed in relative differences from the standard. Subjects working with sodium chloride or caffeine seemed to mix differently than subjects working with no tastant or with citric acid. A high standard error of measurement at the low concentration of sucrose with sodium chloride may be due to individual differences in tasting a mixture of NaCl and sucrose. The enhancement of sweetness by low NaCl concentrations (Beebe-Center *et al.*, 1959; Pangborn, 1962) is also possible with the NaCl concentrations used in the present study. The occurrence of subjects tasting either enhancement or suppression of sweetness could have caused the large differences in the group working with NaCl. The near zero-level results from subjects working with caffeine could depend on the suppression of sweetness by caffeine (Calviño *et al.*, 1990). The slightly suppressive effect of citric acid on the sweetness of sucrose (McBride, 1989; Schifferstein and Frijters, 1990) explains the similar results between subjects working with citric acid and with no tastant.

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