Mouth Movements Diminish Taste Adaptation, but Rate of Mouth Movement does not Affect Adaptation

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Abstract

The degree of adaptation to five concentrations of sucrose was measured. Solutions were kept in the mouth for 25 s; a sweetness judgement was given every 5 s. There were four conditions of mouth movements: no movement, slow, medium and fast mouth movements. It was found that when mouth movements are made there is less adaptation than when there is no mouth movement; however, the *rate* of movement does not appear to influence the degree of adaptation. Furthermore concentration was found to have an effect. In the no-movement condition, the degree of adaptation seems to rise with concentration, whereas in the movement conditions the opposite effect occurs, i.e. a decrease in the degree of adaptation occurs with increasing sucrose concentration. These phenomena might be explained by the stimulated tongue area, or by taste constancy. **Chem. Senses 21: 545–551, 1996.**

Introduction

Taste adaptation can be defined as the gradual decline of the subjective intensity of a gustatory stimulus when it is applied continuously on the tongue. If the sensation disappears totally, this is called complete adaptation. In taste experiments investigating adaptation, complete adaptation is not always obtained. Abrahams *et al.* (1937) and Krakauer and Dallenbach (1937) used a whole mouth flow stimulation procedure to investigate adaptation. The time it took until taste was no longer observed was measured. Although complete adaptation was reached, it took longer when subjects were unable to keep their tongues still. One subject was instructed to move his tongue during the experiments instead of holding it as motionless as possible. This resulted in a consistently longer adaptation time. Von Békésy (1965), investigating adaptation using a flow method, found that irregularities in smooth adaptation curves were caused by tongue movements. In a time–intensity experiment O'Mahony and Wong (1989) found that when chewing movements were made, less adaptation occurred. Meiselman (1968) used a sip-and-spit method to establish the course of adaptation, and asked his subjects to gently move their tongues. A decrease of taste intensity was observed, but no complete adaptation occurred. However, in a study that compared a flow method to a filter paper stimulation procedure, Meiselman and Buffington (1980) did find complete adaptation. More subjects reached complete adaptation in the filter paper condition than in the flow condition. Gent and McBurney (1978) and Ganzevles and Kroeze (1987) also reported complete adaptation using a filter paper method of stimulation. The use of filter paper minimizes the possibility that mouth or tongue movements lead to dispersion of the stimulus on the tongue. It provides the experimenter with improved control over stimulus location and duration. It is therefore not surprising that with this method complete adaptation can be obtained.

From this it can be concluded that mouth or tongue movements may prevent complete adaptation. However, no attempt has been made to investigate systematically the effect of rate of mouth movement on the degree of adaptation. In the present experiment we will test the hypothesis that the rate of mouth movement influences the degree of adaptation: the higher the rate of mouth movement, the less adaptation there will be. When mouth movements are made, there is a continuous movement of the stimulus through the mouth. It may be assumed that as a result there is a process of continuous blocking and deblocking of taste receptor cells. When a receptor cell is blocked, i.e. not accessible to stimuli, recovery from adaptation occurs. Recovery from adaptation is a non-linear process with the fastest rate of recovery immediately after stimulus removal (Hahn, 1934; Bujas *et al.*, 1991b). We could expect that with a higher rate of mouth movement the blocking and deblocking process is faster than in a situation where only slow movements are made. In the latter situation this would lead to less recovery from adaptation, resulting in more adaptation.

There is another line of reasoning which suggests that mouth movements may play a role in adaptation. A few experiments have demonstrated that a high flow rate of the stimulus leads to a stronger sensation (Smith, 1975; Meiselman and Bose, 1977). A high flow rate may mimic mouth movements to a certain degree as the access to the receptor is enhanced in both cases. Ossebaard (1993) obtained higher sweetness intensity estimates with a flow method than with a filter paper method (flow rate is almost zero in a filter paper method). A higher taste intensity, however, resulting from more mouth movements or increased flow, might very well be the result of a changed equilibrium between adaptation and recovery. Adaptation starts at the moment a stimulus is taken in the mouth, and the taste intensity declines quite steeply (e.g. Gent and McBurney, 1978; Ganzevles and Kroeze, 1987; Bujas *et al.*, 1991a). Intensity judgements are generally made after the stimulus has been in the mouth for some seconds [e.g. 5 s in the experiment of Meiselman and Bose (1977)]. During this time, however, adaptation occurs. If it is assumed that more adaptation occurs in no-movement or low-flow conditions, the lower perceived intensity in these conditions could be explained by adaptation. The effect of mouth movements on taste adaptation will be investigated in the present study by imposing different rates of mouth movement.

Materials and methods

Subjects

Twenty paid volunteers, 11 females and 9 males, ranging in age from 18 to 39 years (median age 21 years), served as subjects in this study. All volunteers were students of Utrecht University. Some had had previous experience with psychophysical experiments, but all were naive with respect to the purpose of the present experiment. A preliminary selection test assessed the subjects' ability to differentiate between the five different concentrations of sucrose used in the experiment. Only those who passed the test qualified as subjects.

Stimuli

Solutions of five concentrations of sucrose [0.20 M (S1), 0.28 M (S2), 0.40 M (S3), 0.56 M (S4) and 0.79 M (S5)] in demineralized water (produced by a Millipore Milli-U10 water purification system, resistivity > 10 MΩ·cm) were thickened with carboxymethylcellulose sodium salt (CMC, Fluka Chemica, 21904, ultra high viscosity) to 1400 mPa s. Thickened solutions instead of watery solutions were used because viscous solutions have more resemblance to common foods. Moreover, it is easier to make mouth movements with a viscous than with a watery solution. Viscosity was measured using a Brookfield viscometer (model LVF, spindle 3, 60 r.p.m.). The amounts of CMC required to produce the same viscosity in the different solutions were determined by trial and error. They were 1.14% CMC (w/w) for S1, and 1.11, 1.06, 0.99 and 0.89% CMC for S2–S5 respectively. Solutions were prepared 1 day before use and stored at 4°C for a period of no more than 1 week. Before use they were brought to room temperature (23°C) in a water bath (40°C).

Design

In the experiment four rates of mouth movements were used: no movement, slow movement (0.6 movements/s), medium movement (1.2 movements/s) and fast movement (1.8 movements/s). Since it was not feasible to change the rate of mouth movement during a session, as this could confuse the subjects, in each of the four sessions only one rate of mouth movement was used. The order of the sessions was balanced, with every rate of mouth movement used equally often in each session, and every rate of mouth movement preceded by the other rates an equal number of times. In every session all five stimuli were judged six times. Therefore, 30 stimuli were judged in a session. Stimuli were offered in a random order. Each stimulus was held in the mouth for 25 s and its sweetness was judged every 5 s. Thus there were five sweetness judgements for every stimulus.

Procedure

Subjects were asked to judge the sweetness intensity of the stimuli presented to them. The judgments were expressed on a 150 mm visual analogue scale, with the left end of the scale marked as 'not at all sweet' and the right end marked as 'extremely sweet'. Each judgement was made on a separate sheet.

Subjects were requested to judge the sweetness while making mouth movements at the specified rate. They were asked to keep the solution between the tongue and the palate with the lips closed and make up and down mouth movements. They were told not to chew on the solutions. In the 'no-movement' condition subjects were instructed to keep their mouth as still as possible.

Stimuli were presented in 25 ml polystyrene medicine cups, containing 10 ml of solution. Because the solutions were viscous, ~7.5 ml was taken in the mouth. This amount differed slightly across subjects, but was stable within subjects.

During the procedure, the subjects were continuously cued by a computer program providing sound signals of moderate intensity. At the first signal (a bell-like sound) the subject took the stimulus in her (or his) mouth. She then immediately started to move her mouth at the rate indicated by the computer with 200 Hz sound signals of 40 ms. This movement was continued for 25 s, while every 5 s a sweetness judgement was made. The time of judgement was indicated by another signal from the computer (a 250 ms sound, 700 Hz). The subject was instructed to continue moving her mouth while rating the sweetness. After the last sweetness judgement the solution was expectorated. The subject then rinsed her mouth twice thoroughly with demineralized water, and waited for the next stimulus. The inter-trial interval was 50 s. One session took 45 min.

The experiment was preceded by a training session during which subjects could practise the procedure. In this practice session an identical series of eight sucrose concentrations was offered to all subjects in the same order. The first four concentrations of this series (S3, S4, S5 and S2) were judged using a medium rate of mouth movement; stimuli 5 and 6 (concentrations S1 and S2) were judged while making mouth movements at a high rate; and the last two stimuli (concentrations S5 and S4) were judged under conditions of low-rate mouth movements.

Results

The distance from the left anchor of the visual analogue scale to the slash mark was measured in mm, providing a sweetness rating ranging between 0 (not at all sweet) and 150 (extremely sweet). The mean sweetness rating was calculated over the six replications.

Figure 1 shows the time course of sweetness intensity for all movement conditions, in a separate graph for each concentration. The data shown in these graphs were submitted to a repeated measures analysis of variance with concentration, time and rate of mouth movement as factors (SPSS/PC+, version 5.01). The main effects were tested using multivariate tests of significance, which is recommended when the number of subjects is greater than the number of repeated measures + 10 (Stevens, 1992, pp. 454–456). The interactions were tested with a univariate test of significance because here the number of repeated measures + 10 exceeded the number of subjects. In these tests the degrees of freedom were adjusted according to Stevens (1992, pp. 454–456), i.e. with the Huynh–Feldt epsilon (HFe) if the Greenhouse–Geisser epsilon (GGe) was >0.7, or with the mean of the GGe and the HFe if the GGe was <0.7. As *post-hoc* tests, specified contrasts were tested univariately.

Table 1 shows the results from the analysis of variance. All main effects appear to be significant. The main effect of time indicates that adaptation occurs. In a *post-hoc* test it was shown that the main effect of rate of mouth movement is probably due to the difference between the no-movement condition and the three movement conditions. Some significant interactions were also found. It appeared that the rate of mouth movement × time interaction is significant.

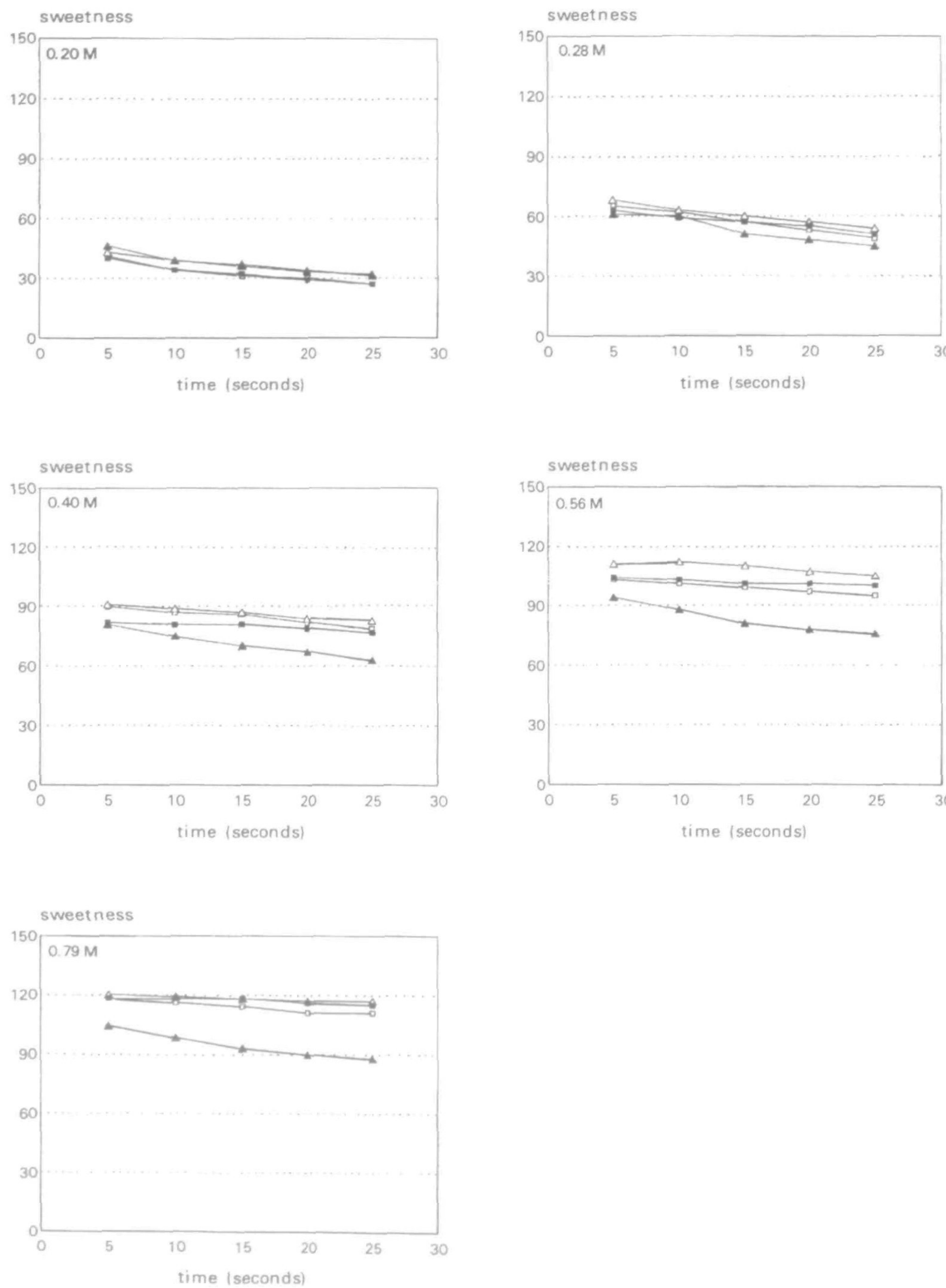

Figure 1 Time course of sweetness intensity with a separate curve for each mouth movement condition. In the left upper corner of each panel the sucrose concentration is shown. Filled triangles represent the no-movement condition, filled squares the low rate of mouth movement, open triangles the medium rate and open squares the high rate of mouth movement.

From Figure 1 it can be seen that this is probably caused by the larger degree of adaptation (i.e the larger decline in sweetness intensity) found in the no-movement condition. The rate of mouth movement × concentration interaction is also significant. The differences between the mouth movement conditions seem to be larger at higher concentrations. Apparently, across all mouth movement conditions, the degree of adaptation is the same at all concentration levels, since there is no significant time × concentration interaction. However, the significant three-way interaction would imply that the differences between the mouth movement conditions with regard to the degree of adaptation are not

Table 1 Results from a repeated measures analyses of variance

Effect	*F*	*P*
Rate of mouth movement (RMM)	4.63	0.015
Concentration	52.5	<0.001
Time	5.77	0.005
RMM × concentration	5.34	<0.01
RMM × time	3.47	$0.01 < P < 0.05$
Time × concentration	2.77	>0.05
RMM × concentration × time	2.40	$0.01 < P < 0.05$

F and *P* values are shown for the main effects and interactions. Main effects are tested with a multivariate test of significance; for the interactions a univariate test is used.

similar for the five concentrations. It seems that more adaptation occurs at high concentrations in the no-movement condition, whereas in the movement conditions more adaptation occurs at low concentrations.

Discussion

The aim of the present experiment was to investigate the effect of rate of mouth movement on the degree of adaptation. It was hypothesized that higher rates of mouth movement would lead to less adaptation. This hypothesis is only partly confirmed: when mouth movements are made there is indeed less adaptation than when there is no mouth movement. However, the *rate* of movement does not appear to influence the degree of adaptation. Furthermore, concentration was found to have an effect. In the no-movement condition the degree of adaptation seems to rise with concentration, whereas in the movement conditions the opposite effect appears to occur, i.e. a decrease in the degree of adaptation occurs with increasing sucrose concentration. Two questions need to be answered. First, why does movement affect adaptation, and does rate of movement have no influence, and second, why is there a differential effect of concentration?

The second question will be discussed first. This concentration effect is puzzling. The only two experiments that used more than one concentration level in an adaptation study are the investigations by Gent and McBurney (1978) who, using filter paper, found that higher concentrations adapted more slowly, and the study by Lawless and Skinner (1979), who reached the same conclusions using both dorsal flow and sip-and-spit methods. In the present experiment we found the opposite: the no-movement condition (which compares best with the methods used by the previous investigators) shows more adaptation at high concentrations (i.e. a faster decline in taste intensity during the time period we used). In the movement conditions, however, we did find a smaller degree of adaptation with rising concentration.

The finding that less adaptation occurs when mouth movements are made is in agreement with previous research (e.g. Von Békésy, 1965; O'Mahony and Wong, 1989). When movements are made stimulus material is moved through the mouth and thus different receptor cells will be stimulated, whereas in the no-movement condition it is more likely that the same receptor cells are continuously stimulated. Temporarily non-stimulated receptor cells will show recovery from adaptation and this will lead to a lower total degree of adaptation over time in the movement conditions. However, rate of mouth movement does not appear to influence the degree of adaptation. Apparently the mere movement, rather than the rate of movement, is sufficient to counteract adaptation, which may be explained in one of the following ways.

O'Mahony and Wong (1989) found that when chewing movements were made, more saliva was produced than when the mouth was held still. Louridis *et al.* (1970) found that the secretion rate of saliva increased with chewing rate. More saliva results in a dilution of the stimulus, and thus in a lower perceived taste intensity. If in the present study more saliva had indeed been produced at high rates of mouth movements, it would be expected that lower taste intensities were produced. However, as can be seen in Figure 1, higher taste intensities were found. Moreover, the effect would have to be more pronounced at the highest rate of mouth movement since at that rate most saliva would be produced. However, no differences were found between the three movement conditions. Therefore either there is no such effect of saliva, or the effect is counteracted by other processes.

It is unlikely that viscosity can explain the absence of an effect of rate of mouth movement, because if viscosity had affected sweetness it would have led to differences between the movement conditions. The reasoning for this is as follows. The thickener used in this experiment is a pseudoplast. This means that physical viscosity decreases with increasing shear rate. If it is supposed that a higher rate of mouth movement has the same effect as an increasing shear rate, it may be expected that at high rates of mouth movement physical viscosity is somewhat lower than at low rates of movement. Since viscosity suppresses sweetness (e.g. Arabie and Moskowitz, 1971; Christensen, 1980) a lower viscosity would lead to slightly higher sweetness intensities. We would thus expect higher sweetness ratings at the high rates of mouth movement. However, as the rate of mouth movement does not seem to influence sweetness intensity, viscosity cannot account for this.

A factor that could possibly explain the differences between the mouth movement conditions is the stimulated area. In the no-movement condition the stimulus remains on the same spot, whereas in the movement conditions stimulus material is probably spread over a larger area. A larger stimulated area may lead to a higher sweetness intensity, as is shown in several experiments (Linschoten and Kroeze, 1994; Bujas *et al.*, 1995). If stimulated area does not depend on the rate at which the movements are made, but solely on the movement *per se*, this could explain the higher intensities and lower degree of adaptation found in the movement conditions, and the absence of an effect of rate of movement.

A final possibility to explain the absence of an effect of rate of mouth movement might be constancy. In olfaction it has been found that odour intensity remains constant, regardless of the vigour of a sniff (Teghtsoonian *et al.*, 1978). If a subject is sniffing vigorously, the flow rate becomes higher. When flow rate is increased artificially, it has been found to increase perceived intensity. However, the olfactory system apparently recognizes this rise in flow rate as occurring from a natural sniff and calibrates the sensation. It is conceivable that rate of mouth movement may have a similar effect, i.e. perceived intensity remains constant, despite differences in the rate of movement.

In conclusion, it appears that with the rather liquid stimuli used in this experiment, mouth movements diminish the degree of adaptation, but rate of movement has no effect. It remains to be established if rate of movement does influence the perception of other, more solid stimuli, or foodstuffs. The finding that movement affects degree of adaptation is in agreement with remarks made by some subjects. They mentioned that they found it hard to judge sweetness in sessions where they were not allowed to move their mouth. This can also be seen in everyday life; if one tries to judge the taste (intensity or quality) of a foodstuff, mouth movements are made for a better judgement.

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