

Effects of Various Taste Stimuli on Heart Rate in Humans

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Abstract

Relationships between taste stimuli and heart rate were evaluated in 29 healthy university students. The test solutions were sucrose, NaCl, citric acid, quinine-HCl and monosodium glutamate (MSG). Heart rate increased by 7.1–13.6% for all the taste stimuli after use as compared with pre-stimuli values. The maximum increases in heart rate came ~25 s after the taste stimuli. After the increases, heart rate returned to pre-stimuli levels after between 80 and 100 s. Heart rate reached its maximum with citric acid. Recovery from the heart-rate increase was more delayed for quinine-HCl and MSG than for the other stimuli. Except for sucrose, increases in heart rate and the hedonic scale values of the taste solutions showed significant negative correlation. These findings show that the taste stimuli solutions increased the heart rate and that the increase differed with the concentration and taste solution used.

Introduction

Food and beverage taste stimuli induce pleasure, displeasure, or both, when various physiological responses occur. Taste stimulation induces salivary secretion (Pangborn and Chung, 1981, Horio and Kawamura, 1989, Matsuo and Yamamoto, 1989), secretion of pancreatic juice in the dog (Naim *et al.*, 1979, 1991; Ohara *et al.*, 1979, 1988), insulin secretion in the rat (Steffens, 1976; Berthoud *et al.*, 1980), change of facial expression in human neonates (Steiner, 1973) and movement of the tongue, jaw and mouth in rats (Grill and Norgren, 1978; Yamamoto *et al.*, 1982).

We have studied the effects of various taste stimuli on human heart rate. Preliminary results were reported in part elsewhere (Horio, 1997).

Materials and methods

Twenty-nine healthy Japanese university students aged 19–21 were tested. They were ordered not to take any food or drink for at least 1 h prior to the test. The test solutions used were 0.07, 0.28 and 1.12 M sucrose (sweet; Wako Pure Chemical Industries Ltd); 0.04, 0.16 and 0.64 M NaCl (salty; Wako Pure Chemical Industries Ltd); 0.02, 0.08 and 0.32 M monosodium glutamate (MSG, umami taste; Ajinomoto Co. Ltd); and 0.0025 M quinine-HCl (bitter; Ishizu Pharmaceutical Co. Ltd). All the solutions were prepared with deionized water and kept at 20°C in a thermostatically controlled bath to ensure constant temperature. The deionized water (Wako Pure Chemical Industries Ltd) used was odorless and contained <2 p.p.m. residue after evaporation. Ten milliliters of a test solution was applied over the entire oral area and left for 10 s, after which it was

expectorated. Deionized water was used twice for oral rinsing between trials, 120 s after the test solution had been given. The samples of the concentrations of the solutions were given in random order, but quinine-HCl was always last. After each trial, the subjects reported the taste hedonic tone. The inter-trial interval was 90 s.

A five-rating scale for taste hedonic tone was used in the preference test: +2, extremely pleasant; +1, slightly pleasant; 0, neither pleasant nor unpleasant; -1, slightly unpleasant; -2, extremely unpleasant. Tests were conducted at room temperature, $22 \pm 3^\circ\text{C}$, and a humidity of $52 \pm 10\%$. Heart rate was monitored with a heart rate monitor (Vantage XL; Cannon Co. Ltd) every 5 s for 30 s before presentation of the various taste solutions and for 120 s afterwards.

A comparison of the values for each solution was made by a two-way ANOVA with repeated measures using the SPSS program. A post-hoc test was conducted using the paired *t*-test.

Results

Heart rate

The mean heart rate at rest was 69.8 ± 0.5 beats/s (mean \pm SE, $n = 29$) for 30 s before presentation of the taste solution. This value was considered 100%. Increases in heart rate after presentation of the solutions are shown in Figure 1.

Heart rate increased during the 10 s presentation of a taste solution, and the peak heart rate for all the solutions tested came 25 s after presentation. Heart rate generally returned to the pre-stimulation level between 80 and 100 s

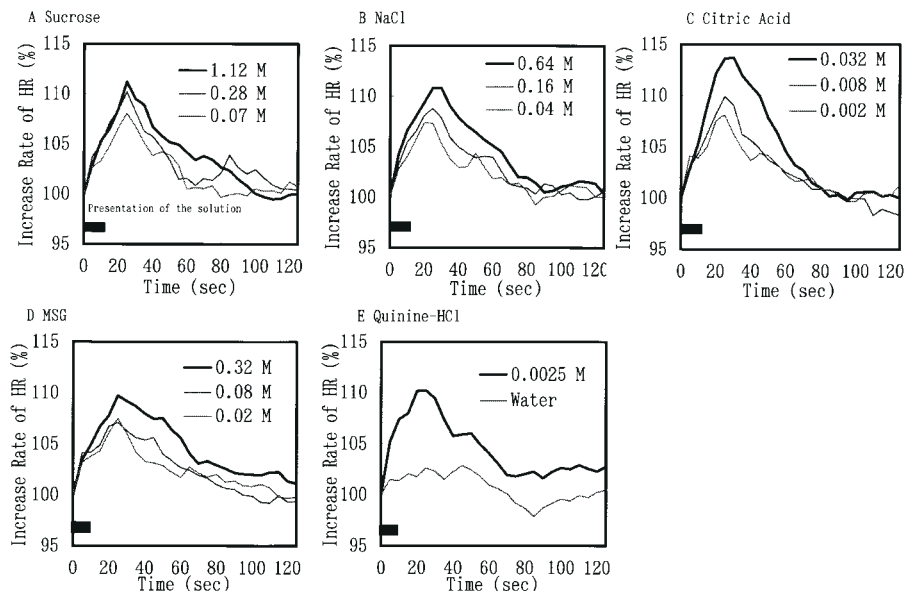


Figure 1 Increases in heart rate elicited by various taste solutions. (A) Sucrose. (B) NaCl. (C) Citric acid. (D) Monosodium glutamate (MSG). (E) Quinine-HCl, and water (HR = heart rate).

after the stimuli, but the increases for 0.32 M MSG and 0.0025 M quinine-HCl were not reversed even 120 s after stimulation.

The heart rate peaks were compared with the mean level for the 30 s period before presentation of the sucrose solutions (Figure 1A). A two-way ANOVA with repeated measures (taste \times concentration) showed significant effects of taste [$F(1,28) = 67.44$, $P < 0.01$], concentration [$F(2,56) = 3.26$, $P < 0.05$], and exercise \times concentration interaction [$F(2,56) = 3.26$, $P < 0.05$]. The maximum increases in heart rate were 108.0 ($t = 5.82$, $P < 0.01$), 110.2 ($t = 7.38$, $P < 0.01$) and 111.2% ($t = 7.59$, $P < 0.01$) for 0.07, 0.028 and 1.12 M sucrose, which were higher than those before the presentation. Post-hoc analyses of the data by the t -test showed that the values for 1.12 M were significantly higher than the values for 0.07 M ($t = 3.42$, $P < 0.01$).

The peak heart rate was compared with the value before the presentation of NaCl solutions (Figure 1B). A two-way ANOVA with repeated measures (taste \times concentration) showed significant effects of taste [$F(1,28) = 67.01$, $P < 0.01$], concentration [$F(2,56) = 3.46$, $P < 0.05$], and exercise \times concentration interaction [$F(2,56) = 3.46$, $P < 0.05$]. The respective maximum increases in heart rate were 107.3 ($t = 5.63$, $P < 0.01$), 108.7 ($t = 6.10$, $P < 0.01$) and 110.8% ($t = 8.46$, $P < 0.01$) for 0.04, 0.16 and 0.64 M NaCl, which were higher than the heart rate value before presentation. Post-hoc analyses of the data by the t -test showed that for 0.64 M the value was significantly higher than that for 0.04 M ($t = 2.72$, $P < 0.05$).

The peak heart rate was compared with the value before presentation of the citric acid solutions (Figure 1C). A two-way ANOVA with repeated measures (taste \times concen-

tration) showed significant effects of taste [$F(1,28) = 91.02$, $P < 0.01$], concentration [$F(2,56) = 9.06$, $P < 0.01$] and the exercise \times concentration interaction [$F(2,56) = 9.06$, $P < 0.01$]. Respective maximum increases in heart rate were 108.1% ($t = 6.00$, $P < 0.01$), 109.9% ($t = 7.20$, $P < 0.01$) and 113.6% ($t = 10.54$, $P < 0.01$) for 0.002, 0.008 and 0.032 M citric acid, which were higher than the heart rate value before presentation. Post-hoc analyses of the data by the t -test showed that the value for 0.032 M ($P < 0.01$) was significantly higher than that for 0.002 M ($t = 4.08$, $P < 0.01$). The rate for 0.032 M was also higher than that for 0.008 M ($t = 3.07$, $P < 0.01$).

The peak heart rate was compared with the value before presentation of the MSG solutions (Figure 1D). A two-way ANOVA with repeated measures (taste \times concentration) showed a significant effect of taste [$F(1,28) = 59.17$, $P < 0.01$], but concentration [$F(2,56) = 2.39$] and the exercise \times concentration interaction [$F(2,56) = 2.39$] were not significant. Respective maximum increases in heart rate were 107.5 ($t = 5.07$, $P < 0.01$), 107.1 ($t = 6.91$, $P < 0.01$) and 109.7% ($t = 7.18$, $P < 0.01$) for 0.02, 0.08 and 0.32 M citric acid, which were higher than the heart rate value before presentation. There was no difference among the concentrations.

The maximum increase in heart rate was 110.2% for 0.0025 M quinine-HCl (Figure 1E, $t = 7.44$, $P < 0.01$), which was higher than the value before presentation. Higher maximum increase rates were obtained with the higher concentrations of each taste solution. The maximum increase in heart rate was 102.6% for deionized water (Figure 1E; $t = 2.39$, $P < 0.05$), which was higher than the value before presentation.

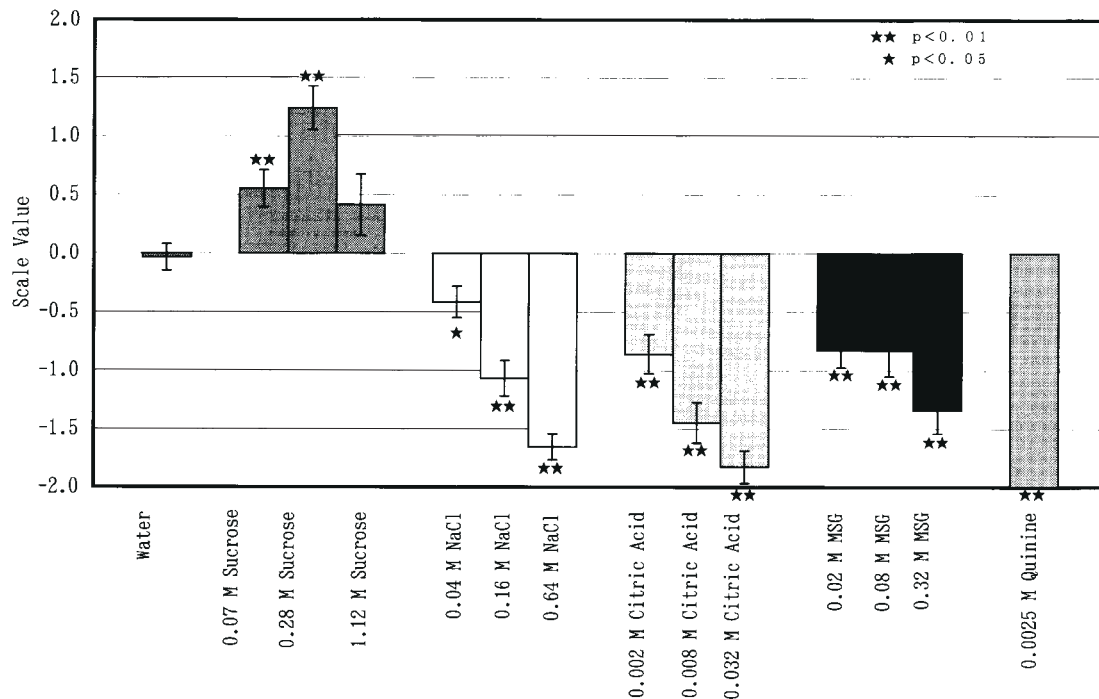


Figure 2 Comparison of preference scale values for various taste solutions. Asterisks indicate significant differences between water and the taste solutions: * $P < 0.05$, ** $P < 0.01$.

The maximum increased rate for water was significantly low compared with the values of the different taste solutions: 0.07 ($t = 4.05$, $P < 0.01$), 0.28 ($t = 4.36$, $P < 0.01$) and 1.12 M ($t = 6.16$, $P < 0.01$) sucrose; 0.04 ($t = 3.45$, $P < 0.01$), 0.16 ($t = 3.88$, $P < 0.01$) and 0.64 M ($t = 5.15$, $P < 0.01$) NaCl; 0.002 ($t = 3.48$, $P < 0.05$), 0.008 ($t = 5.60$, $P < 0.01$) and 0.032 M ($t = 6.67$, $P < 0.01$) citric acid; 0.02 ($t = 2.66$, $P < 0.05$), 0.08 ($t = 3.14$, $P < 0.01$) and 0.32 M ($t = 4.27$, $P < 0.01$) MSG; and 0.0025 M ($t = 5.41$, $P < 0.01$) quinine-HCl. The maximum increased rate for 0.032 M citric acid was significantly higher than that for: water ($t = 6.67$, $P < 0.01$); 0.07 M ($t = 3.20$, $P < 0.01$) sucrose; 0.04 ($t = 4.04$, $P < 0.01$), 0.16 ($t = 2.83$, $P < 0.01$) and 0.64 M ($t = 2.13$, $P < 0.05$) NaCl; 0.02 ($t = 3.53$, $P < 0.01$), 0.08 ($t = 5.17$, $P < 0.01$) and 0.32 M ($t = 2.30$, $P < 0.05$) MSG; and 0.0025 M ($t = 2.56$, $P < 0.05$) quinine-HCl.

Relationship between heart rate and taste solution preference

Figure 2 shows the scores for a five-rating test scale of taste hedonic tone. A one-way ANOVA with repeated measures showed a significant effect [$F(13,364) = 38.03$, $P < 0.01$]. Post-hoc analyses of the data by the t -test showed that the preference scale value for water did not differ from that for 1.12 M sucrose, but did differ significantly from the values for the other taste solutions. Except for sucrose, the scale values for the taste solutions were negative. The scale value for 0.28 M sucrose was higher than the values for 0.07 ($t = 3.99$, $P < 0.01$) and 1.12 M ($t = 2.90$, $P < 0.01$) sucrose. The

scale values for 0.64 M NaCl were lower than for 0.04 ($t = 7.66$, $P < 0.01$) and 0.16 M NaCl ($t = 3.83$, $P < 0.01$). The values for 0.032 M citric acid were significantly lower than those for 0.002 ($t = 7.11$, $P < 0.01$) and 0.008 M ($t = 3.32$, $P < 0.01$) citric acid. The value for 0.0025 M quinine-HCl was the lower than the values for the other taste solutions tested, except 0.032 M citric acid.

Figure 3 shows the correlation between the preference scale values and the increase in heart rate. The correlation coefficient was -0.91 ($P < 0.01$). Except for sucrose, increases in heart rate and the hedonic scale values of the taste solutions showed significant negative correlation.

Discussion

For all the taste solutions, heart rate increased from 7.1 to 13.6% after stimuli, compared with the pre-stimuli value. The citric acid heart rate showed the maximum increase. The strength of citric acid was greater as a stimulus than the strengths of the other taste solutions used. Our findings show that taste stimuli increased heart rate and that the increase differed with the concentration and taste solution.

Parotid secretion is induced by NaCl and MSG (Pangborn and Chung, 1981), oral gustatory administration caused canine pancreatic secretion (Ohara *et al.*, 1979, 1988; Naim *et al.*, 1979, 1991). Sucrose was shown to be a better stimulus than MSG or NaCl. Oral saccharin stimulation caused a rapid rise in the peripheral plasma insulin level without significant change in glycemia (Berthoud *et al.*, 1980). Tap water also induced transient elevation in

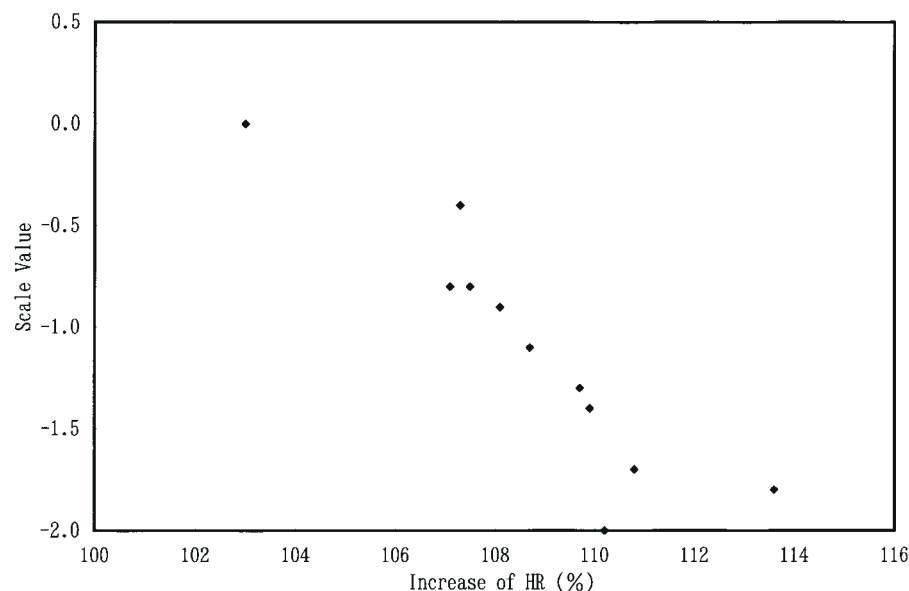


Figure 3 Relationship between preference scale values and the increase in heart rate (HR = heart rate).

insulinemia in rats (Berthoud *et al.*, 1980). Nijjima and co-workers (Nijjima *et al.*, 1990; Nijjima, 1991) reported that in rats sucrose and MSG increased the efferent activity of the hepatic and pancreatic branches of the vagus nerve and that NaCl inhibited them. Gustatory and other oral sensory signals act as triggers for neurally mediated reflexes. Increases in heart rates produced by taste stimuli may be induced through the autonomic nerve system.

The greatest increase in heart rate in our study was induced by citric acid. It has also been reported (Horio and Kawamura, 1989; Matsuo and Yamamoto, 1989) that maximum salivary secretion occurred after sour stimulation, and rat neonatal heart rate responses increased after stimulation with lemon (Smotherman *et al.*, 1991). HCl and NaCl, but neither quinine nor sucrose, were effective in increasing heart rate in rats (Yonemura *et al.*, 1989), and whereas 1.0 M sucrose and 0.9% NaCl were ineffective in changing heart rate, 1.0 M NaCl, 0.03 M quinine-HCl and H₂O strongly affected it (Hanamori and Ishiko, 1993).

Heart rate increased to a maximum ~25 s after taste stimuli were given and returned to the pre-stimuli level after between 80 and 100 s. Human newborns showed rapid onset and offset for contact-induced behavioral changes, slower onset and offset being induced by taste (Blass and Ciaramitaro, 1994). In one study, the reaction times to the strongest solutions used were ~400 ms for NaCl and tartaric acid and ~700 ms for sucrose and quinine (Yamamoto and Kawamura, 1981). Latency to the central nerve system from the oral structure may be very short and voluntary movement might occur for a short time. Involuntary response related to heart rate might be later and continue longer than voluntary movement.

In our study, the return of the heart rate was delayed for

quinine-HCl and MSG as compared with the other taste stimuli used. The durations of after-taste for quinine-HCl and MSG were longer than for sucrose, HCl and NaCl (Horio and Kawamura, 1990).

The increases in heart rate and the hedonic scale values of the taste solutions, except for sucrose, showed significant negative correlation in our study. The heart rate for water, which was neither pleasant nor unpleasant, was higher than that before stimulation. The heart rate for sucrose also increased more than that for water. The heart rate might increase not only with displeasure, but also with pleasure. Licking patterns and electromyogram activities of rat masticatory muscles are characterized by the hedonic aspect of taste (Yamamoto *et al.*, 1982). Heart rate therefore may provide an index of hedonic tone for food and/or beverages.

Acknowledgement

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