Regional Taste Sensitivity to NaCl: Relationship to Subject Age, Tongue Locus and Area of Stimulation

Toshi Matsuda and Richard L. Doty

Smell and Taste Center and Department of Otorhinolaryngology: Head and Neck Surgery, University of Pennsylvania Medical Center, Philadelphia, PA 19104, USA

Correspondence to be sent to: T. Matsuda, Nagoya City University, School of Medicine, Department of Otorhinolaryngology, Kawasumi 1, Mizuho-Cho, Mizuho-Ku, Nagoya, Japan

Abstract

Using a signal detection procedure and a microprocessor-controlled gustometer, sensitivity to three concentrations of NaCl (0.01, 0.1 and 1.0 M) was measured on the tongue tip, and on a region 3.0 cm posterior to the tongue tip in 12 young (20–29 years of age) and 12 elderly (70–79 years of age) subjects. Stimulus duration was 2 s; the sizes of the tongue areas stimulated were 12.5, 25 and 50 mm². On average, the young subjects were more sensitive to NaCl on the tongue tip than on the more posterior stimulation site and exhibited, at both tongue loci, an increase in detection performance as stimulus concentration increased. The elderly subjects, on the other hand, performed at chance level at both tongue loci for all three stimulus sizes and concentrations tested. No sex differences were observed. In the young subjects, the mean R-index increased monotonically as a function of stimulus size for the two highest NaCl concentrations at both tongue loci. A hyperbolic function provided the best fit to these data at the tongue tip, and an exponential function at the more posterior tongue region, implying a different pattern of spatial summation at these two sites. Overall, this study demonstrates that marked age-related changes in regional taste sensitivity to NaCl are present in elderly persons. Chem. Senses 20: 283–290, 1995.

Introduction

Many elderly persons complain of decreased ability to taste. Although a number of such complaints can be explained on the basis of the loss of flavor sensations derived from decreased retronasal stimulation of the olfactory receptors (Burdach and Doty, 1987; Doty et al., 1984), decreased taste perception of sweet, sour, bitter and salty substances also occurs, as measured by both threshold and suprathreshold psychophysical tests (for reviews, see Corso, 1971; Murphy, 1979; Schiffman, 1979; Baker et al., 1983; Bartoshuk et al., 1986; Weiffenbach et al., 1986).

Although the reasons for age-related taste losses are poorly understood, decreases in the number of taste buds has been suggested as one cause (e.g. see Arey et al., 1935; Mochizuki, 1937; Moses et al., 1967). However, this point is controversial, as recent studies have failed to find clear decreases in the number of lingual taste buds in fungiform papillae as a function of age (Arvidson, 1979; Miller, 1988) and, importantly, have observed marked variation in taste bud numbers among individuals of all ages (Miller, 1988).

Compared to age-related decreases observed in the sense of smell (for review, see Doty, 1991), most age-related changes in taste perception are relatively small. This may be due, in part, to the general use of test procedures (e.g. whole-mouth, 'sip and spit' methods) which optimize the opportunity for neural summation and recruitment by stimulating, sometimes simultaneously, large numbers of taste...
buds from several neuronal populations, including ones on the soft palate, tongue, pharynx, larynx and esophagus. Therefore, age-related changes may appear more robust when smaller regions of the oral cavity are evaluated.

Regional differences in taste threshold sensitivity to NaCl, the stimulant used in this study, have been reported in non-elderly persons, although differences in findings are present among studies. In his classic experiment, Hänig (1901) used a fine brush to test localized regions of the tongue and reported greater recognition threshold sensitivity to NaCl on the tongue’s tip than on its edge or rear. Collings (1974), using 4-mm diameter pieces of filter paper, also found greater recognition threshold sensitivity at the tip of the tongue than in other regions tested, although the difference was not statistically significant between the tongue tip and a region 2.5 cm behind the tip on the tongue’s edge. Recently, Linschoten and Kroeze (1992), using filter paper, found no differences in threshold sensitivity to NaCl between medial and lateral locations on the same side of the tongue. However, when both sides of the tongue were stimulated simultaneously, lateral—lateral stimulation resulted in lower thresholds than medial—medial stimulation.

Unlike the case with her threshold findings, Collings reported that suprathreshold build-up in taste sensation to NaCl, as measured by magnitude estimation, was greater for the rear of the tongue (i.e. region of vallate papillae) than for other regions within the oral cavity, including the tongue tip and soft palate. In contrast, Bartoshuk et al. (1987), using magnitude estimation and a Q-tip to present the NaCl stimuli, found magnitude estimate functions to be essentially equivalent for the back and front of the tongue. More recently, Salata et al. (1991) used a cross-modal matching procedure to explore regional differences in sensitivity to electric current (possibly stimulating the taste cells by iontophoresis of Na⁺; see Herness, 1985). The tip of the tongue was more sensitive than the back and anterior sides of the tongue, as well as the soft palate, as indicated by both the slope and relative position of the matching functions.

The present study had several main goals: first, to evaluate age-related changes in NaCl sensitivity on two regions of the tongue known to differ in taste bud density; second, to determine if such age-related sensitivity is influenced by the sex of the subject; and third, to determine if such sensitivity is related to the size of the tongue regions stimulated. To achieve these goals, we developed and incorporated a unique microprocessor-controlled gustometer which allowed for accurate temporally- and spatially-defined stimulation of small regions of the tongue. In addition, we utilized a sensitive non-parametric signal detection procedure which provided a test measure unconfounded by response bias.

Materials and methods

Subjects

Six men and six women between the ages of 20 and 29 years (mean = 23.75 years) comprised the ‘young’ study group; most were students at the University of Pennsylvania. The ‘elderly’ study group consisted of six men and six women between 70 and 79 years of age (mean = 75.08 years) who were recruited from senior citizen centers in the Philadelphia area. All subjects were non-smokers in good health at the time of testing. Among the elderly, eight were receiving no medications; three received medications for mild hypertension and one for mild hypothyroidism. While formal testing for cognitive dysfunction was not performed, the elderly participants were active community-dwelling volunteers who had no evidence or history of dementia and who reported, on their own cognizance, to the center for testing. Prior to testing, each of these individuals evidenced a clear understanding of the task to be performed. All subjects were asked to refrain from eating or drinking (with the exception of water) during the hour preceding their participation.

Taste stimuli

The tastants of this study were three concentrations of reagent-grade sodium chloride (Fisher Scientific, King of Prussia, PA) dissolved in distilled water and presented at room temperature: 0.01, 0.10 and 1.00 M. These concentrations were chosen because they were within the general perithreshold region of humans (see Bartoshuk et al., 1986). Distilled water alone served as the blank stimuli.

Apparatus

The microprocessor-controlled gustometry system developed for this study made it possible to present temporally and spatially discrete stimuli to small regions of the tongue. Components of this system, which is pictured in Figure 1, include (i) a chin rest mounted on a table whose height could be varied electrically to accommodate different subjects, (ii) three Sage Model 355 high-precision syringe pumps (Sage Instruments, Cambridge, MA), (iii) a microprocessor control unit (ATCOM TM Interactive Controller 64; Automatic Timing & Controls Company, Inc., King of Prussia, PA), (iv) glass and Tygon connectors, and (v) a set of glass stimulation devices (Figures 2 and 3). Each glass stimulation...
device was held to the tongue by a vacuum surround (37–85 mmHg) calibrated using a DWYER Minihelic-2 differential pressure gauge. The center section of each stimulation device confined the stimulus, rinse and air flush dispersions to well-circumscribed tongue regions (12.5 mm², 25 mm² and 50 mm²) (Figure 3).

Testing procedure
Each subject participated in three test sessions (one for each stimulus size) lasting from 1 to 2 h in duration. To minimize fatigue or inattention, all subjects were allowed to take periodic rest breaks at their discretion. In the case of the elderly subjects, five returned for an additional session to complete the study, and one came for two additional test sessions. In the case of the young subjects, two came back for an additional test session.

A test trial consisted of (i) the presentation of distilled water for 4 s (termed the rinse period), (ii) a 3-s air flush period and (iii) a 2-s presentation of distilled water or one of the NaCl stimulus concentrations. One-hundred-and-twenty test trials (60 of distilled water and 20 each of the three NaCl concentrations) were presented to the right tongue tip, and an area 1.5 cm right of the midline and 3 cm posterior to the tip during each of these sessions (total number of trials/session = 240). The test sessions for the tongue tip and the more posterior tongue region were separated from one another by a minimum of 15 min. The order of the test sessions was systematically counterbalanced using Latin squares (Zimney, 1961).

Following the 2-s stimulus presentation period of a given trial, the subject indicated his or her degree of certainty that a stimulus was presented or not presented by pointing to one of four response categories located on a chart: (1) Absolutely Not Present; (2) Probably Not Present; (3)
 Probably Present; and (4) Absolutely Present. The hit and false alarm rates, derived from these ratings, were converted to Brown's R-index (Brown, 1974), a non-parametric signal detection measure of sensory sensitivity, according to the following formula:

\[ R = \frac{d(e + f + g) + c(e + f) + 0.50(af + bf + cg + dh)}{(a + b + c + d)(e + f + g + h)}. \]

where the components of the formula are as follows:

- \(a\): stimulus presented, subject indicates category 1 (absolutely not present).
- \(b\): stimulus presented, subject indicates category 2 (probably not present).
- \(c\): stimulus presented, subject indicates category 3 (probably present).
- \(d\): stimulus presented, subject indicates category 4 (absolutely present).
- \(e\): water presented, subject indicates category 1 (absolutely not present).
- \(f\): water presented, subject indicates category 2 (probably not present).
- \(g\): water presented, subject indicates category 3 (probably present).
- \(h\): water presented, subject indicates category 4 (absolutely present).

The \(R\)-value is analogous to \(d'\) in parametric signal detection analysis, in that it reflects true discrimination rather than the subject's willingness to guess, but requires no distributional assumptions.

**Results**

The mean (+SEM) \(R\)-values for the test groups and conditions are presented in Figure 4. These data were subjected to an overall analysis of variance (ANOVA) with between-group factors of age group (young, elderly) and gender (male, female) and within-group factors of stimulus size (12.5, 25 and 50 mm\(^2\)), tongue locus (tip, more posterior) and tastant concentration (0.01, 0.10 and 1.00 M) (Wilkinson, 1991). The main effects of age group \([F(1,20) = 41.43, P < 0.0001]\), tongue locus \([F(1,20) = 9.44, P = 0.006]\), and tastant concentration \([F(1,40) = 5.26, P = 0.009]\) were significant, as were the interactions between age group and tongue locus \([F(1,20) = 6.59, P = 0.018]\) and age group and tastant concentration \([F(2,40) = 6.51, P = 0.004]\).

Given the small number of elderly subjects that were taking antihypertension medications, this was not included in our formal statistical analyses. However, inspection of the raw data indicated that no systematic differences were present between the \(R\)-values of the three elderly subjects taking hypertensive medication and the other nine elderly subjects.

ANOVARs (gender \(\times\) stimulus size \(\times\) tongue locus \(\times\) tastant concentration) were performed separately on the data of the elderly and young subjects. In the case of the elderly subjects, no significant main effects or interactions were present (\(p > 0.10\)), suggesting, as would be expected from the data shown in Figure 4, that their tongues, when regionally tested, are relatively insensitive to changes in stimulus concentration, area of stimulation and stimulus location. This was not true for the young subjects. Thus, significant effects were found for the main effects of tongue locus \([F(2,20) = 8.66, P = 0.015]\) and stimulus concentration \([F(2,20) = 10.03, P = 0.001]\), as well as the interaction between stimulus locus and concentration \([F(2,20) = 3.68, P = 0.044]\). It is clear from Figure 5 that the younger persons were more sensitive to NaCl on the tip.
of their tongues than on the more posterior region, and that their sensitivity increased as NaCl concentration increased, particularly on the tip of the tongue.

Although stimulus size was not a significant main effect ($P = 0.21$) or component of any interaction (all $ps > 0.20$), the mean $R$-index increased monotonically as a function of stimulus size for the two highest NaCl concentrations in the young subjects (Figure 4). This phenomenon was more pronounced for the tongue tip than for the more posterior tongue region, and suggested that a different pattern of spatial summation occurred at each tongue site. This was confirmed by the fact that a hyperbolic function fitted the $R$-index data better than an exponential function for these NaCl concentrations at the tip of the tongue, whereas the reverse was true at the more posterior region of the tongue (Table 1) (see McBurney, 1969).

**Discussion**

The present study indicates that, on average, older persons have a significant deficit in the ability to taste NaCl on at least two circumscribed regions of the anterior tongue. The deficit is profound; indeed, most of the subjects of this study evidenced chance or near-chance performance on the

![Stimulus Concentration:](image)

**Figure 4** The $R$-index values as a function of subject age group, stimulus size and stimulus concentration. Size 1 = 12.5 mm$^2$; Size 2 = 25 mm$^2$; Size 3 = 50 mm$^2$. Since no sex differences were apparent in the data, this factor was omitted from the figure to simplify data presentation. Error bars represent $+1$ SEM. See text for details.

**Table 1** Goodness of fit measures for hyperbolic and exponential functions fitted to taste sensitivity ($R$-index) data obtained from the tongue tip and a region 3.0 cm posterior to the tongue tip. Functions were fitted for the two highest concentrations of NaCl (0.1 and 1.0 M) presented across three stimulus areas (12.5, 25 and 50 mm$^2$). Exponential goodness of fit measure represents the square of the Pearson correlation coefficient computed between area stimulated and log NaCl concentration. Hyperbolic goodness of fit measure represents analogous coefficient computed between log area stimulated and log NaCl concentration.

<table>
<thead>
<tr>
<th></th>
<th>Exponential $r^2$</th>
<th>Hyperbolic $r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tongue tip, 0.10 M NaCl</td>
<td>0.876</td>
<td>0.972</td>
</tr>
<tr>
<td>Tongue tip, 1.00 M NaCl</td>
<td>0.867</td>
<td>0.966</td>
</tr>
<tr>
<td>3.00 cm posterior to tip, 0.10 M NaCl</td>
<td>0.925</td>
<td></td>
</tr>
<tr>
<td>3.00 cm posterior to tip, 1.00 M NaCl</td>
<td>0.992</td>
<td></td>
</tr>
</tbody>
</table>
the observed effects are due to alterations in peripheral Having lived a long life (e.g. cumulative effects of viral As with the case of many age-related phenomena, the relative number or integrity of taste buds, number of taste cells/taste observed in the elderly subjects of this study is unknown. The basis for the decrease in regional taste function observed in the elderly subjects of this study is unknown. As with the case of many age-related phenomena, the relative contribution of aging, per se, and factors associated with having lived a long life (e.g. cumulative effects of viral infections) are difficult to disentangle. It is conceivable that the observed effects are due to alterations in peripheral neural mechanisms (e.g. neural responsiveness of taste cells, number or integrity of taste buds, number of taste cells/taste bud), particularly in light of the fact that taste receptors, like olfactory receptors, are exposed rather directly to the vagaries of the external environment (cf. Hinds and McNelly, 1981). Interestingly, taste buds on circumvallate papillae, which are innervated by fibers from the glossopharyngeal nerve (CN IX), appear to decrease with age. Thus, Arey et al. (1935) noted such decreases in a study of 152 circumvallate papillae from 51 individuals, of whom 13 (25%) were between 74 and 85 years of age. Mochizuki (1937) also noted such decrements in 254 circumvallate papillae from 128 tongues, with 52 (41%) of the tongues coming from persons older than 60 years. On the other hand, more recent studies of taste buds on fungiform papillae, which are innervated by fibers from the chorda tympani branch of the facial nerve (CN VII), find no evidence of age-related changes in taste bud number and, importantly, report large variability in the number of buds among tongues of all ages (Arvidson, 1979; Miller, 1986, 1988). Although these studies are technically excellent, they are based on smaller numbers of subjects than those used in the circumvallate work. For example, Miller (1986) evaluated fungiform taste buds from 10 subjects, four of whom were over the age of 60. In his 1988 paper, he evaluated the tongues of eight subjects over the age of 60, six of whom were over the age of 70. Of the 22 subjects evaluated by Arvidson (1979), only five were over the age of 60 and considerable effort was made to select ‘normal’ tongues for study. Thus, it is conceivable that larger samples might reveal age-related changes in fungiform taste bud numbers. On the other hand, given the high quality of these studies and the fact that their data provide no evidence for even a trend in age-related decreases in taste bud number, it is quite possible that, unlike circumvallate taste buds, taste buds on the anterior tongue do not decrease in number with age. If this is true, other factors must be responsible for the perceptual alterations observed in the present study.

In non-elderly persons, it is well established that a relationship exists between the density or number of taste buds on the tongue and the degree of taste function, as measured psychophysically. This relationship provides a reasonable explanation for the difference in sensitivity noted in the young subjects of this study between the tongue tip and the more posterior tongue locus (since taste buds are more numerous in the tongue tip). Thus, Smith (1971) demonstrated that the perceived intensity of several tastants applied to the anterior tongue, including NaCl, is proportional to the number of fungiform papillae stimulated (fungiform papillae are the sole papillae on the anterior surface of the tongue that harbor taste buds). Arvidson and Friberg (1980) found that the number of basic taste qualities registered by single human papillae is related to the number of taste buds borne by these papillae, and Miller and Reedy (1990) demonstrated that subjects with higher fungiform taste bud densities also reported the tastes of NaCl, sucrose and 6-n-propyl-2 thiouracil as more intense than did subjects with fewer fungiform taste buds (see also Zuniga et al., 1993).

Despite the fact, noted above, that the tongue tip of the young subjects of our study was found to be more sensitive to NaCl than the more posterior tongue region, some individual differences were present in this regard. Thus, taste sensitivity was greater in two of the 12 young subjects on the more posterior tongue region than on the tongue tip, and one young subject evidenced similar sensitivity at both stimulation sites. Such findings conceivably reflect individual differences in the distribution of taste receptors. Miller (1986), for example, reported that one of the 10 tongues he examined (from a 22-year-old man) had a lower density of taste buds on its tip than on its more posterior region, a finding that would be in accord with such psychophysical observations.

There was a tendency for some elderly subjects in this study to exhibit an R-value consistently below 0.50 (i.e. below chance performance). In other words, these subjects reliably reported the water stimulus as more intense than
the NaCl stimulus. The basis for this phenomenon is unknown. One possible explanation is that under normal conditions water produces, in some elderly subjects, a slight taste (perhaps only after removal of saliva) and that the addition of small amounts of a solute such as NaCl to water actually masks or adapts the tongue to this slight taste (L.M. Bartoshuk, personal communication). Another possibility is that at low stimulus levels (and brief stimulus presentations to small tongue regions), pure water and water containing NaCl are actually similar in intensity, yet are able to be discerned. Some subjects may therefore simply focus on one of these sensations as being the strongest on a disproportionate number of trials, thereby producing an R-value below 0.50.

While it seems most likely that the poor detection performance of the older subjects of this study reflects decreased function of the taste system proper, one cannot rule out the possibility that elements of the test procedure may also have contributed to the poor performance. For example, stimulation of small tongue regions may have encouraged adaptation (which would be particularly evident if elements of the taste system were already impaired). Since, however, the R-values did not decrease across the test sessions, it is unlikely that adaptation alone explains the general inability to detect the stimuli. Similarly, the slight vacuum which held the stimulator onto the tongue may have somehow differentially influenced the taste function of the young and elderly subjects within its annular stimulation region (e.g. by altering the vascularity of the region of stimulation). Again, however, this would appear to be an unlikely cause of the marked age-related decrement in detection performance, in that the tongues of the elderly subjects appeared healthy upon physical examination and the elderly subjects uniformly demonstrated major taste loss relative to the young subjects.

In summary, the present study suggests that the ability to taste NaCl is markedly decreased in elderly persons when small regions of the anterior tongue are tested for brief periods of time. Although the degree to which such localized deficits influence everyday taste function in humans requires further study (particularly in light of recent studies demonstrating that considerable compensation can occur for localized loss of taste), it would seem likely that such alterations would contribute, along with decreased olfactory function (e.g. Doty et al., 1984; Deems et al., 1991), to the experience reported by many older persons that food lacks flavor. Additional research is needed to determine whether localized NaCl taste losses of the elderly are related to the salty and sour dysgeusias commonly observed in older populations.

ACKNOWLEDGEMENTS

We wish to thank Mr James Graham and Mr William Irby for their technical contributions to the project (namely, the development of the glass stimulators and microprocessor controlled test system, respectively). Without their service, a gustometer system could not have been developed. In addition, we thank Mr Donald McKeown for assistance in performing the statistical analyses of the project, and Drs Inglis Miller and Linda Bartoshuk for providing comment on several of the observations of this study. Dr Joel Maruniak kindly provided us with one of the syringe pumps used in this work. This study was supported by NIDCD Grant PO 00161 awarded to R.L.D.

REFERENCES


Corso, F. (1971) Sensory processes and age effects in normal...


Received on April 17, 1994; accepted on November 1, 1994