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Decline in Taste and Odor Discrimination Abilities with Age, and Relationship between Gustation and Olfaction

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Abstract

It is important to learn about changes in both taste and odor perceptions with increasing age, because the taste of foods we encounter in our daily life is strongly affected by their smell. This study discusses the difference in qualitative taste and odor discrimination between the elderly and the young. Tastants and odorants used in this study were presented not as single stimuli but as a taste mixture (sucrose and tartaric acid) and an odor mixture (β-phenylethyl alcohol and γ-undecalactone). The results showed that quality discrimination abilities of the elderly subjects for both taste and odor were significantly lower than those of the young subjects, indicating a decline in quality discrimination abilities related to age. Also, a moderate but significant correlation was observed between the taste discrimination ability and the odor discrimination ability. We measured thresholds for single-taste and odor components in mixtures and compared them between the elderly and the young to investigate the cause for these findings.

Introduction

Deterioration of gustatory and olfactory perceptions is among the most serious problems in the life of the elderly. Their disability in detecting and identifying gas leaks can endanger public safety; moreover, the tendency toward higher salt and sugar intake in the elderly diet can lead to health-hazardous conditions (Corwin *et al.*, 1995).

A number of studies on age-related changes in gustatory and olfactory sensations have been reported in the past several years. A threshold elevation for various tastants, including NaCl, and various odorants, including isoamyl butyrate, was more prominently observed in the elderly than in the young, and the elderly tend to judge suprathreshold olfactory intensity higher than do the young (Weiffenbach *et al.*, 1982, 1986; Stevens and Cain, 1985; Cain and Stevens, 1989; Cowart, 1989). On the other hand, it has been reported that age reduces the perceived intensity of suprathreshold olfactory sensation to a greater extent than the taste intensity for NaCl, sucrose, citric acid, HCl–quinine and others (Bartoshuk *et al.*, 1986). Stevens and co-workers assessed intensity evaluations for NaCl of five suprathreshold concentration levels and various odorants (Stevens *et al.*, 1984; Stevens and Cain, 1985). However, their study indicated a significant difference in odor intensity evaluation but not in NaCl intensity evaluation between the elderly and the young. It has also been reported that the elderly showed a substantially slower recovery in adaptation to *n*-butanol than did the young. There was, however, only a negligible or no difference in recovery adaptation to NaCl between the two age groups (Stevens and Wellen, 1989; Stevens *et al.*, 1989). Therefore, some researchers have suggested that the age-related deterioration in olfaction is more important than that in gustation.

Nevertheless, the importance of investigating the age-related decline in gustatory perception has been reported in recent years. It has been reported that the elderly require a 2- to 3-fold higher concentration of salt in order to detect it in tomato soup (Stevens *et al.*, 1991). Stevens also demonstrated in a study on the masking effect in taste mixtures that thresholds for tastants in taste mixtures, such as food, were higher than thresholds for single tastants in aqueous solutions (Stevens, 1996). Matsuda and Doty observed a significant decline in detection performance for NaCl in the elderly when a small area on the tip of the tongue was stimulated with NaCl for a short period of time (Matsuda and Doty, 1995). As described above, this age-related decline in gustatory and olfactory thresholds and intensity

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evaluations has been reported. Nevertheless, there have been hardly any studies on discrimination in tastes and odors, except for a report by De Wijk and Cain indicating an age-related decrement in discrimination ability for six odorant samples (De Wijk and Cain, 1994). Further, not many studies have been conducted on the relation between age-related changes in gustation and olfaction.

On the other hand, people do not take in food or beverages with a single taste or odor (McBride, 1989). Discrimination of mixtures with various tastes and odors existing in the daily diet is necessary for pleasantness evaluation of food and beverages. Also, it is extremely important to discriminate and identify a dangerous odor, such as a leaked gas, among other various odors, or to detect a rotten odor or a rotten taste in food with various odors and tastes. Therefore, it is thought that the importance of discrimination and identification in taste and odor mixtures is greater than the thresholds and discrimination and identification of single tastants and odorants.

This report discusses the decline in discriminative abilities for taste and odor qualities with age and the relation between the decline in gustation and olfaction. Also, experiments in this report were designed to measure differences in discrimination abilities for taste and odor mixtures between the elderly and the young, and to compare thresholds for single tastants and odorants in the taste and odor mixtures used for the discrimination experiment in order to explain our results.

Table 1 Mix rates of sucrose and tartaric acid in taste stimuli

Taste set	Stimulus A′		Stimulus A	
	Sucrose (mM)	Tartaric acid (mM)	Sucrose (mM)	Tartaric acid (mM)
T1	189 (3.00)[a]	0 (0)	0 (0)	1.38 (3.00)
T-2	164 (2.83)	0.11 (0.50)	22 (0.50)	1.19 (2.83)
T-3	134 (2.58)	0.18 (0.99)	33 (0.99)	0.92 (2.58)
T-4	99 (2.26)	0.29 (1.46)	50 (1.46)	0.67 (2.26)
T-5	92 (2.18)	0.33 (1.57)	54 (1.57)	0.61 (2.17)
T-6	84 (2.07)	0.37 (1.68)	60 (1.68)	0.55 (2.06)
T-7	79 (2.00)	0.41 (1.78)	65 (1.78)	0.51 (1.99)

[a]The value of the τ scale is shown in the parentheses (Indow, 1966).

Table 2 Mix rates of PA and UL in odor stimuli

Odor set	Stimulus A′		Stimulus A	
	PA (mM)	UL (mM)	PA (mM)	UL (mM)
O-1	650 (3.0)[a]	0 (0)	0 (0)	342 (3.0)
O-2	259 (2.6)	2.98×10^{-3} (0.4)	4.01×10^{-3} (0.4)	54.3 (2.6)
O-3	41.0 (2.2)	2.21×10^{-2} (0.8)	3.33×10^{-2} (0.8)	11.1 (2.2)
O-4	5.05 (1.8)	1.36×10^{-1} (1.2)	2.05×10^{-1} (1.2)	2.02 (1.8)

[a]The psychological intensity from 0 (odorless) to 5.0 (extremely strong) shown in parentheses was determined by psychological intensity function scaled in a pre-test.

Materials and methods

Subjects

The subject group of 'the young' consisted of 20 subjects (10 males and 10 females) aged between 21 and 40 years (average 29 years, SD = 7.13). The subject group of 'the elderly' consisted of 20 subjects (10 males and 10 females) aged between 59 and 75 years (average 67 years, SD = 5.47). The young subjects were university students or ordinary citizens and the elderly subjects were ordinary citizens not living in an old people's home. The education levels of subjects in both groups were at the standard level or above in Japan.

All subjects were healthy at the time the experiments were conducted. All of them were prohibited from intake of food and beverages, except for water, and inhalation of cigarettes for 1 h prior to the experiments.

Stimuli

Stimulus preparation

Taste stimuli were prepared daily by dissolving sucrose and/or tartaric acid in deionized water and kept at 24°C. Odor stimuli were prepared weekly by dissolving β-phenylethyl alcohol (PA), as the smell of rose, and/or γ-undecalactone (UL), as the smell of apricot, in propylene glycol, stored at 4°C and kept at 24°C before each experiment.

Stimuli for determining discrimination abilities

Concentrations of the tastants or odorants in the taste or odor mixtures were established to have psychological intensities almost equal to those in the taste or odor mixtures of 'stimulus A' and 'stimulus A′' (Tables 1 and 2) (Saito *et al.*, 1982; Saito and Hirahata, 1991) and to reach intensities which could be readily perceived. The equality of psychological intensities in the taste or odor sets of 'stimulus A' and 'stimulus A′' was statistically confirmed based on the intensity evaluation tests conducted on the young subject group. The values of the τ scale of taste stimuli (Indow, 1966) and the psychological intensities of odor stimuli are shown in Tables 1 and 2, respectively. Differences in the mix rates of tastes or odors in 'stimulus A' and 'stimulus A′' became smaller as the sets of taste or odor mixtures changed from T-1 to T-7 in Table 1 and from O-1 to O-4 in Table 2 so that discrimination became more difficult for the subjects.

Procedure

General procedure

Before the experiments, a questionaire was presented to the subjects. No statistical difference between the young and the elderly could be observed in preference and familiarity for sweet or sour taste and flower or fruit smell. Each subject participated in the experiments three times. First, the discrimination experiment was conducted for 2 days, and after a break of >2 months the threshold experiment was performed. Each experiment took <1.5 h. The experiments were conducted in a room with a ventilation system to maintain the temperature between 21 and 24°C and the humidity between 40 and 60%.

A three-sample forced-choice method was employed in these experiments. Before the experiments, the subjects learned sufficiently the three-sample forced-choice method by using three pieces of colored paper. Five milliliters of taste solution was presented to the subjects in the taste experiments. The subjects were asked to hold the taste stimulus solution in the mouth for several seconds after rinsing the mouth with deionized water and to expectorate the solution thereafter. The interstimulus interval in each experiment was 20 s or more. The odor stimuli were absorbed on the edge of a paper strip (0.7 × 15.0 cm) and presented to the subjects. The subjects were asked to take a deep breath before each trial, and an interval of 20 s or more was allowed between the odor stimuli.

The subjects were allowed to take notes (upon request) about the characteristics and their liking of each stimulus as a reminder. The subjects could confirm their selection with the residual solution in each taste set or, if they wanted, by an additional smell test in each odor set. The taste trial and the odor trial were alternated, so that an interval of 2 min or more was maintained between subsequent taste or odor experiments to avoid taste and odor adaptation.

Discrimination of taste or odor mixtures

Seven sets of taste stimuli and four sets of odor stimuli were presented randomly to the subjects three times. One set consisted of three stimuli, two with an identical mixing rate and one with a different mixing rate. The subjects were asked to choose one stimulus with a different odorant or tastant from the other two. Correct choices were considered to indicate that the subject successfully discriminated one stimulus with an odorant (or tastant) concentration level different from the other two stimuli.

Detection thresholds for tastes or odors

In order to shorten the duration of the experiment, the lowest detectable concentration using a two-sample forced-choice method was determined for each subject to decide the initial concentration in that experiment. Taste solutions of sucrose (29 mM) and tartaric acid (0.67 mM) and odor solutions of PA (516 mM) and UL (272 mM), which were paired with deionized water or propylene glycol, were presented to the subjects. The subjects were asked to choose one from two stimuli, which facilitated taste or odor perception. A similar experiment was repeatedly administered using a solution diluted 3.16-fold of the original in the case of correct answers until the subject could not detect the taste or odor, and using a solution with a concentration 3.16 times higher than the original in the case of incorrect answers until the subject could detect the taste or odor.

The experiments were then conducted in such a way that a solution with a concentration 3.16-fold greater than the lowest correct concentration in the two-sample forced-choice experiments was used as the initial stimuli of the three-sample forced-choice method. The subjects were asked to choose one from three stimuli, which facilitated taste or odor perception. Experiments were repeated three times for the same concentration. If the subject answered correctly in all three trials, the stimulus of that concentration was considered to be detected, and the trial was repeated using a solution diluted 3.16-fold, until the subject could not answer correctly in all three trials. If the subject gave even one incorrect answer, the sample of that concentration was considered not to be detected, and the experiment was repeated using a solution with a 3.16 times higher concentration until the subject answered correctly in all three trials. The lowest detected concentration was concluded to be the threshold for that subject.

Results

Qualitative discrimination and threshold of taste

In a three-sample forced-choice method, only the subjects who answered correctly in all three repeated experiments of one taste set were considered statistically valid subjects ($P = (1/3)^3 < 0.05$). Figure 1 shows the percentage of subjects who gave correct answers in discrimination in each taste set. In three sets of taste mixtures (T-1, 2, 3) having concentration differences with which discrimination would be relatively easy, both the elderly and young groups showed a high percentage of correct answers such that no significant difference was observed between the elderly and the young. In taste discrimination sets T-4 and T-5, the percentage of correct answers for the elderly group was significantly lower than that for the young group (T-4: $\phi = 0.427$, $n = 39$, $P < 0.01$; T-5: $\phi = 0.334$, $n = 39$, $P < 0.05$). Also, with T-6 and T-7, both the elderly and young groups showed a low percentage of correct answers; therefore, it was thought that the discriminations in these sets were difficult for both groups. In terms of total percentage of correct answer by each subject for all taste sets, there were no outliers exceeding twice the standard deviation from the average in elderly groups.

The total percentage of correct answers in all taste sets was significantly different between the elderly group and the young group ($\phi = 0.155$, $n = 277$, $P < 0.01$), indicating that fewer in the elderly group successfully discriminated the taste mixtures than in the young group.

It was demonstrated that detection thresholds for tartaric acid were higher for the elderly than for the young (Figure 2). On the other hand, there was no significant difference in

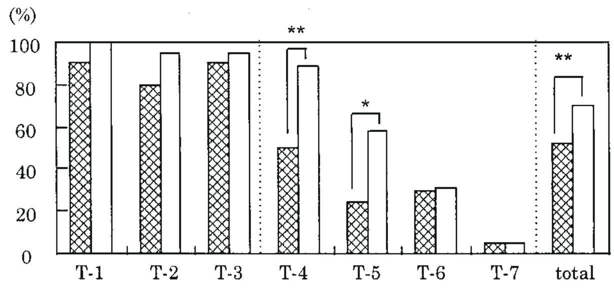

Figure 1 Percentage of persons who gave correct answers in mixed-taste discrimination tests. Mix rates of sucrose and tartaric acid in T-1 to T-7 was as according to Table 1. Hatched boxes, elderly; open boxes, young. *$P < 0.05$; **$P < 0.01$.

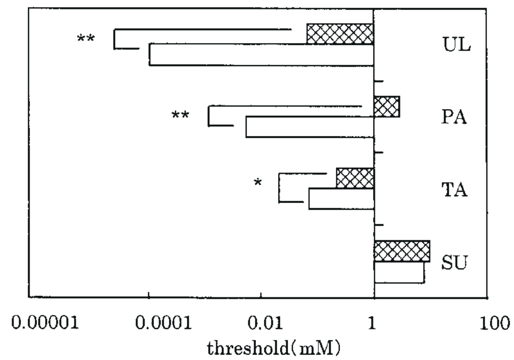

Figure 2 Thresholds of tastes, sucrose (SU) and tartaric acid (TA), and odors, β-phenylethyl alcohol (PA) and γ-undecalactone (UL). Harched boxes, elderly; open boxes, young. * $P < 0.05$; **$P < 0.01$.

detection thresholds for sucrose between the elderly and the young. No effect of gender was observed on discrimination performances and detection thresholds in both groups.

Qualitative discrimination and threshold of odor

The results of discrimination tasks on odor sets O-1, O-2 and O-4 indicated a significant difference between the young group and the elderly group (O-1: $\phi = 0.480$, $n = 40$, $P < 0.01$; O-2: $\phi = 0.436$, $n = 40$, $P < 0.01$; O-4: $\phi = 0.419$, $n = 40$, $P < 0.01$) (Figure 3). In terms of the total percent correct by each subject for all odor sets, there were no outliers exceeding twice the standard deviation from the average in the elderly groups.

The total percentage of correct answers in all sets was significantly different between the young and the elderly ($\phi = 0.364$, $n = 160$, $P < 0.01$), demonstrating that fewer in the elderly group successfully discriminated the odor mixtures than in the young group. Detection thresholds for β-phenylethyl alcohol and γ-undecalactone were higher for the elderly group than for the young group (Figure 2). Gender had no effect on the odor discrimination and detection thresholds.

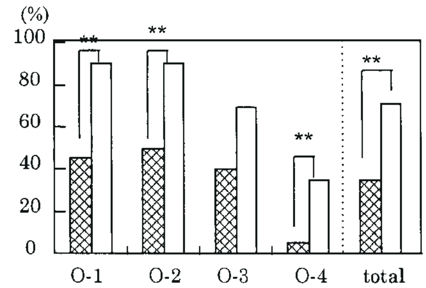

Figure 3 Percentage of persons who gave correct answers in mixed-odor discrimination. Mix rates of β-phenylethyl alcohol and γ-undecalactone in O-1 to O-4 was as according to Table 2. Hatched boxes, elderly; open boxes, young. **$P < 0.01$.

Relation between gustation and olfaction

The total percentage of discriminations in taste mixtures, that is, the percentage of correct answers in each subject for all taste sets, indicated a correlation with the total percentage of discriminations in odor mixtures, that is, the percentage of correct answers in each subject for all odor sets ($r = 0.423$, $n = 39$, $P < 0.01$) (Table 3). The total gustatory detection threshold, which is a sum of the z score of detection thresholds of each subject for sucrose and their z score for tartaric acid, indicated a correlation with the total olfactory detection threshold, which is the sum of the z score of detection thresholds for PA and that for UL ($r = 0.520$, $n = 34$, $P < 0.01$).

Discussion

Changes in gustation or olfaction with age

The lower discrimination ability for the odor mixtures and the taste mixtures indicated that human gustation and olfaction are reduced with age. This hypothesis was also supported by the elevated detection thresholds for tartaric acid, β-phenylethyl alcohol and γ-undecalactone. In this study, there was no significant difference in the detection threshold for sucrose between the elderly and the young. Gilmore and Murphy reported in their study on supra-threshold intensity discrimination for caffeine and sucrose (Gilmore and Murphy, 1989) that the discrimination for caffeine was significantly different between the elderly and the young; however, no significant difference was observed for sucrose. Therefore, they concluded that a qualitative specificity exists in gustatory decrements as a function of age.

The results of several studies on changes in gustatory or olfactory sensations with age have indicated that the decline in olfaction is more important than that in gustation (Stevens *et al.*, 1984; Stevens and Cain, 1985; Schiffman, 1986). However, as described in the Introduction, the importance of the age-related decline in gustation has been reported in recent years. The percentage of correct answers in our study on qualitative discrimination in taste and odor mixture sets as well as the qualitative specificity of taste in

Table 3 Relationship between discrimination rates of mixed tastes and odors and their thresholds

	Threshold				Discrimination rate of mixed tastes	Discrimination rate of mixed odors
	SU	TA	PA	UL		
Threshold						
SU	1.00	0.451*	–	–	–0.209	–
TA		1.00	–	–	–0.413*	–
PA			1.00	0.764**	–	–0.312
UL				1.00	–	–0.509**
Discrimination rate of mixed taste					1.00	0.423*

*$P < 0.05$, **$P < 0.01$.

the detection threshold experiment supported the possibility that the olfactory impairment is more significant than the gustatory impairment. The increased decline in olfaction related to age compared with that in gustation might reflect the elevated detection thresholds for both odor compounds but not for both taste compounds. We plan to conduct further studies whether similar tendencies can be observed for other different taste and odor mixtures.

It has been reported that the age-related decline in olfactory identification and discrimination is more significant in female than in male subjects (Doty *et al.*, 1984; Cowart, 1989; Corwin, 1992; Russell *et al.*, 1993). In this study, gender did not affect both gustatory and olfactory detection thresholds and discrimination. Corwin *et al.* suggested that gender itself was a 'dummy' which disguised the possibility that subjects were exposed to an environment causing the olfactory impairment; they concluded that gender was not the definitive factor in the age-related decline in olfactory function (Corwin *et al.*, 1995). The results of the present study support this conclusion.

Relationship between gustation and olfaction in age-related decline

In our study, a correlation was found between the total mixed-taste discrimination rate and the total mixed-odor discrimination rate in all subjects (Table 3). Also, a positive correlation was observed between the total odor detection threshold and the total taste detection threshold. These findings suggest some sort of relationship between gustation and olfaction in age-related decrements. It is thought that there are several reasons for the age-related decrements in gustation and olfaction, including the above relation.

We should consider the question of why the peripheral functions in gustation and olfaction slow down at the same speed as a function of age. The reasons for the deterioration in peripheral functions can be classified into two hypotheses, morphological (age-related decreases in the number of receptors in the olfactory bulb, mitral cells, taste buds, taste cells) and functional (age-associated declines in functions of the gustatory and olfactory cells at the level of sensory reception and neurotransmission). Nakashima *et al.* have reported that the surface distribution of olfactory mucosa decreased with age (Nakashima *et al.*, 1984). Gradually, the olfactory mucosa became scattered over the respiratory mucosa so that they became dysfunctional at the cellular level. Also, age-related decreases were observed in the size of the olfactory bulb and in the number of mitral cells (Seiden *et al.*, 1985). Mochizuki has reported that a large majority of patients who showed decreases in the circumvallate papillae were elderly (Mochizuki, 1937). On the other hand, according to the study on taste buds in the fungiform papillae, the results showed no diminution of taste receptor density with advancing age (Miller, 1988). The possibilities of morphological changes as reasons for age-related decreases in gustation are still under investigation.

Murphy and Gilmore studied the effect of aging on the perceived intensity for the four taste primaries as a function of age using the method of magnitude matching (Murphy and Gilmore, 1989); their results indicated that the elderly showed lower perception of intensities for sour and bitter tastes. They suggested that the results demonstrated the specificity of taste quality in the age-associated gustatory impairments, as suggested elsewhere (Gilmore and Murphy, 1989). They also suggested that the reason for that specificity of taste quality was functional—the age-related decline in the gustatory functions throughout the transduction process from reception by the peripheral organs to perception by the brain—rather than morphological, such as a decrease in the number of taste buds and taste cells. In that case the effect of the decline in the gustatory functions depended on the taste quality. In our study, only the detection thresholds for sucrose did not indicate a significant difference between the elderly and the young. Furthermore, no correlation was observed between the detection threshold for sucrose and the detection threshold for tartaric acid. These results supported the above suggestions.

There is a possibility that the age-related decline in gustation and olfaction might be caused by performance degradation in both peripheral functions. But this hypothesis cannot successfully explain why the performance of the elderly did not decrease only in the sucrose experiment. Hence, it may be appropriate to conclude that the cause for the correlation between taste and olfaction in the discrimination rates or detection thresholds reflected not only declines in the peripheral functions but also a decrease in the higher brain functions integrating the two sensory systems.

The relationship between olfactory perception decline and brain functions has been widely discussed in recent years. For example, studies have clearly shown that olfactory dysfunction is observed in the early stages of the Alzheimer's disease (Doty, 1991, 1997). Also, it has been shown that the decrements in olfactory sensation in patients with multiple sclerosis is directly caused by plaques in the cortical region related to the olfactory pathway (Doty *et al.*, 1987). In addition, it has been reported that olfactory dysfunction is extremely common among patients with Parkinson's disease (Doty, 1997). In early Parkinson's disease, olfactory dysfunction occurs more often than other basic symptoms (tremor, rigidity, bradykinesia, gait disturbance). Even in subjects who did not suffer from such diseases, human brain functions might be impaired by aging, so that the results of our experiments may explain the declines in brain functions which are shared by gustation and olfaction. The relationship between the age-related decline in gustation or olfaction and brain functions should be studied further.

We addressed the possibility that insufficient understanding of the three-sample forced-choice method by the subjects during the experiments might have affected differences in gustatory and olfactory detection thresholds and discrimination ability between the elderly group and the young group. In these experiments, the subjects were able to learn the three-sample forced-choice method sufficiently and were allowed to confirm their choice by taking notes, smelling and tasting the samples repeatedly. As a result, no significant difference was observed between the elderly and the young in the detection threshold for sucrose and discrimination of relatively easy mixed taste sets (T-1, T-2, T-3). This indicated that both young subjects and elderly subjects sufficiently understood the three-sample forced-choice method so that the age of the subjects did not affect the procedure. A significant correlation was observed between the total olfactory detection threshold and the total odor mixture discrimination rate in all subjects ($r = 0.496$, $n = 34$, $P < 0.01$). There was no significant correlation between the total gustatory detection threshold and the total odor mixture discrimination rate ($r = -0.174$, $n = 34$, n.s.), between the total olfactory detection threshold and the total taste mixture discrimination rate ($r = -0.263$, $n = 34$, n.s.) or between the total taste detection threshold and the total taste mixture discrimination rate ($r = 0.165$, $n = 36$, n.s.). Those results showed that the correlation between discrimination rates for the taste mixtures and the odor mixtures and that between the olfactory and gustatory detection thresholds in these experiments were not affected by the three-sample forced-choice method.

In conclusion, our results suggested the possibility that the age-related decline in gustation and olfaction is due not only to a decrease in the peripheral functions but also to a decrease in performance of the higher functions. In order to clarify the mechanism for the age-related decline in gustatory and olfactory perception, further detailed studies must be conducted on the relationship between gustation, olfaction and brain functions.

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