Table 2 Order of stimulus presentation of foods with four taste qualities

Trial	Stimuli	Taste qualities	
1st	DW[a]	none	SS[g]
2nd	0.01 M MSG[b]	umami	CS[h]
3rd	0.1 M NaCl[c]	salty	CS
4th	0.0005 M QHCl[d]	bitter	CS
5th	DW	none	SS
6th	0.02 M HCl[e]	sour	CS
7th	0.5 M Suc[f]	sweet	CS
8th	0.1 M HCl	sour	CS
9th	DW	none	SS
10th	0.05 M MSG	umami	CS
11th	0.1 M Suc	sweet	CS
12th	0.5 M NaCl	salty	CS
13th	0.0001 M QHCl bitter	bitter	CS
14th	DW	none	SS

The order of stimulus presentation was the same in 1st and 3rd sessions and the reverse in 2nd session. [a]distilled water, [b]monosodium glutamate, [c]sodium chloride, [d]quinine hydrochloride, [e]hydrochloric acid, and [f]sucrose. [g]standard stimulus, [h]comparative stimuli. See text for details.

transportation to the posterior oral cavity and pharynx. According to the SH EMG activity and the laryngeal movement, three durations were used to evaluate swallowing movement. The duration of the oral phase (DOP) was defined as the time from the second SH burst to just before the pharyngeal phase which was determined by elevation of the larynx (from b to c in Fig. 1). Laryngeal elevation was approximately concomitant with the peak activity of the third SH burst (Burst 2) [19]. Technically, the duration of the oropharyngeal phase (DOPP) was first measured to determine the total time of the oropharyngeal events associated with swallowing, and then the duration of the pharyngeal phase (DPP) was estimated by subtracting DOP from DOPP, because the peak activity of Burst 2 was sometimes an easier measure of the start of laryngeal elevation than the laryngeal movement curve (b in Fig. 1).

In addition to the three durations (DOP, DOPP, and DPP), which were used as temporal parameters for swallowing movement, the maximum amplitude of the third SH burst (Burst 2) was measured to evaluate the strength of motor activity, since SH burst activity was presumed to be relevant to a reflex component in swallowing. The strength of responses to the CS was expressed as the relative amplitude to the SS, i.e., foods at 35°C in Exp. I and those distilled with DW in Exp. II.

Data Analysis

In sensory data, medians and quartiles were calculated for the sensory evaluation scores, and Friedman's test for repeated measures was applied, followed by Tukey's multiple-comparison tests for further analysis. Kendall's rank correlation coefficients for the scores between pairs of sessions (first vs. second and second vs. third) were calculated to evaluate the reliability (or concordance) of the scores. The calculation was done for a pair of sessions by using all 40 medians (4 temperatures × 10 subjects) in Exp. I and all 60 medians (6 tastes including DW × 10 subjects) in Exp. II. In motor data, means and standard errors of means (SEM) were calculated for the three durations and the peak EMG activity of the SH muscles. For the three durations, significance of differences was examined by two-factor repeated-measure analysis of variance (ANOVA) with temperature and session as factors in Exp. I and taste and session as factors in Exp. II. For SH muscle activity, one-factor ANOVA was applied with temperature as a factor in Exp. I and taste as a factor in Exp. II. The level at $p < 0.05$ was assumed to indicate significant differences.

Experiment I: Materials and Methods

Stimuli and Stimulation

The syringes packed with the prepared foods were kept in water adjusted to 5°C, 20°C, 35°C, and 50°C by thermoregulators. The core temperatures of the SS and CS were checked throughout the experiments. The food at 35°C was used as the SS in Exp. I because the temperature was close to the temperature in the mouth and was presumed to be the least stimulating to the oropharyngeal tissues. The measured hardness of the prepared foods (about 3300 N/m^2 at 35°C) tended to decrease with an increase in temperature, but the hardness did not differ significantly among the four food temperatures.

Each session consisted of 13 trials that evaluated four SS and nine CS (Table 1). Two of the four SS were assigned to the first and last trials. The CS at 5°C, 20°C, and 50°C were delivered three times in each session. The order of delivery was the same in the three sessions as well as for all of the subjects. Before the first trial of the first session, each subject was asked whether the CS at 5°C and/or 50°C was uncomfortable or harmful for him/her. No subject reported uncomfortable or harmful sensations associated with the foods at these temperatures.

Results

Sensory Aspect

Medians and quartiles of SDS of the SS and CS at four temperatures are depicted in Figure 2 for individual sessions. The SDS was highest (i.e., most difficult to swallow) for the foods at the lowest temperature of 5°C and decreased with an increase in food temperature up to 50°C. All of the medians of SDS at 35°C in the three sessions were zero, suggesting that the SDS of the SS was consistent throughout these sessions of the experiment. Statistically significant differences among temperatures were found in the second ($\chi^2 = 18.548$, $p < 0.001$) and third ($\chi^2 = 12.742$, $p < 0.01$) sessions, while no significant difference was observed in the first session. Further analysis with Tukey's test showed that in both the second and third sessions (1) the difference in SDS between the CS at 5°C and at 50°C was significant ($p < 0.01$), and (2) the difference between the CS at 20°C and at 50°C was also significant ($p < 0.01$ in the second session and $p < 0.05$ in the third session). Kendall's rank correlation

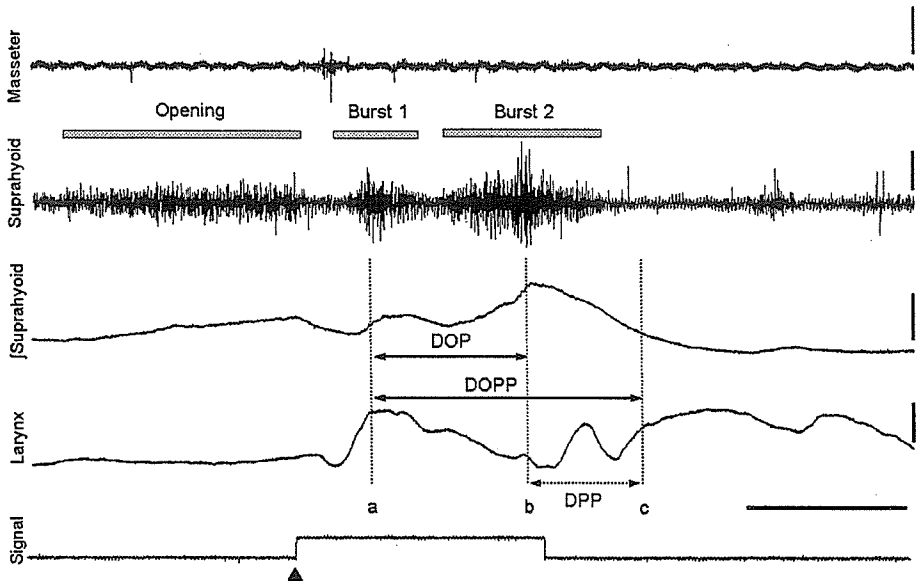

Fig. 1. Masseter and suprahyoid activities with motion of the thyroid cartilage were recorded during swallowing of food (20°C). Suprahyoid and ∫Suprahyoid: original and integrated activities of the suprahyoid muscles, Larynx: movement of the thyroid cartilage, and Signal: signal for swallowing. Horizontal bar between Larynx and Signal indicates a time scale of 1.0 s. Vertical bars on the right side indicate 200 μV for Masseter, 400 μV for ∫Suprahyoid, 400 μV for ∫Suprahyoid, and 0.5 mm for Larynx. Closed triangle shows the delivery of food. DOP = duration of oral phase (from a to b), DOPP = duration of oropharyngeal phase (from a to c), DPP = duration of pharyngeal phase (from b to c; DOPP minus DOP). See text for details.

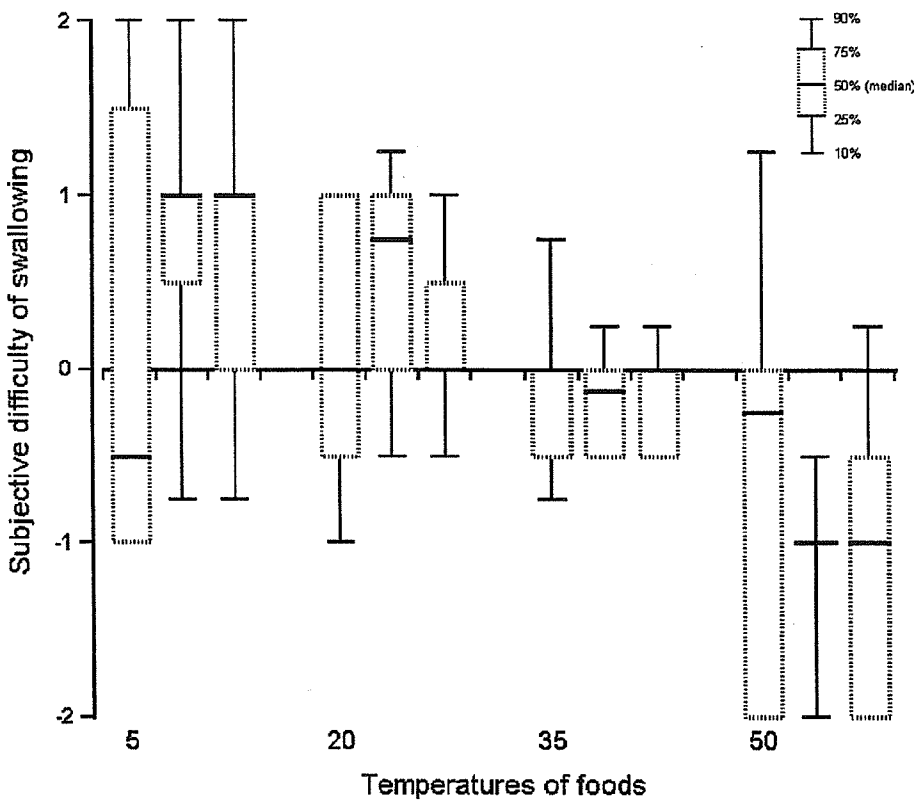

Fig. 2. Changes in subjective difficulty of swallowing evaluated with foods at four temperatures (5°C, 20°C, 35°C, and 50°C). The three bars for each temperature indicate the three different sessions (left bar, first session; middle bar, second session; and right bar, third session). In the upper-right corner, columns and error bars indicate 10% (upper error bars), 25% (upper lines of columns), 50% (medians, solid bars), 75% (lower lines of columns), and 90% (lower error bars) of responses. Numbers below individual columns show the temperatures of the foods. See text for details.

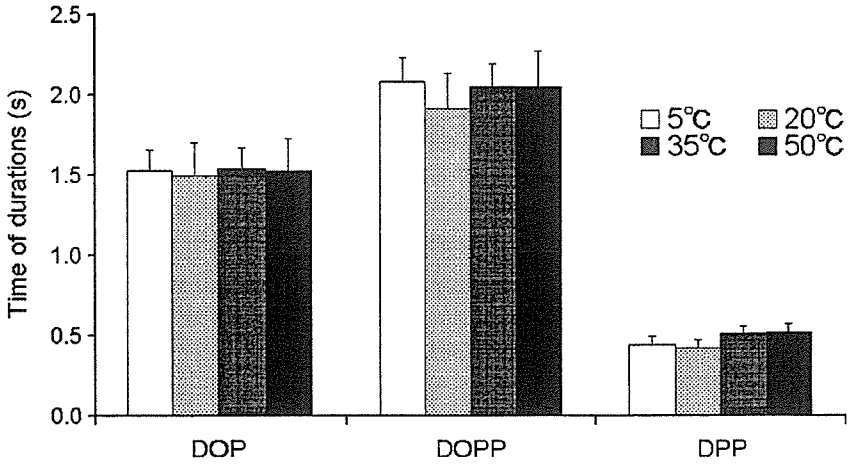

Fig. 3. Three kinds of durations were measured in subjects swallowing foods of four temperatures (5°C, 20°C, 35°C, and 50°C). DOP = duration of oral phase, DOPP = duration of oropharyngeal phase, DPP = duration of pharyngeal phase. See text for details and also Figure 1. Values are means + SEM. These three durations were obtained from the three sessions.

coefficient calculated between the first and second sessions ($\tau = 0.241$, $p < 0.05$) and between the second and third sessions ($\tau = 0.596$, $p < 0.001$) was significant.

Motor Aspect

Durations of Swallowing

The DOP and DOPP measured in three individual sessions are shown in Figure 3. The DOP examined at the four temperatures varied among the three sessions from 1.31 s (50°C, third session) to 1.73 s (50°C, first session), and the overall average was 1.53 ± 0.09 s. The DOPP also varied among the three sessions from 1.82 s (50°C, third session) to 2.22 s (50°C, first session), and the overall average was 2.08 ± 0.10 s. No consistent relationships were observed between the four food temperatures and DOP and DOPP (Fig. 3). ANOVA confirmed that no statistically significant differences were found in the DOP and DOPP among the four food temperatures. Since the DOPP of swallowing consisted of the DOP and the duration of the pharyngeal phase (DPP), the overall average of DPP was estimated as 0.55 s (i.e., 2.08 s minus 1.53 s; Fig. 3). The DPP varied from 0.49 s (5°C, first session) to 0.63 s (5°C, second session), and the range calculated at 0.14 s was 25. Five percent of the overall estimated value of 0.55 s.

Swallowing Muscle Activities

The peak amplitudes of SH EMGs for three CS (5°C, 20°C, 50°C) were standardized with those for SS (35°C), since absolute amplitudes of SH EMGs varied considerably among subjects and trials. Relative peak amplitudes of SH EMGs are shown in Figure 4. The relative peak amplitudes were largest at 20°C, second largest at 5°C, and smallest at 50°C in all three sessions. ANOVA revealed that the differences in the first ($F = 5.190$, $p < 0.05$) and second ($F = 3.975$, $p < 0.05$) sessions were statistically significant, but not in the third session. Further analysis also revealed that the differences in the peak amplitudes between 20°C and 50°C were significant in both the first ($p < 0.05$) and second ($p < 0.05$) sessions, respectively.

Discussion

First, the appropriateness of the stimuli used in Exp. I and the method used for sensory evaluation must be considered. In Exp. I, food at 35°C was used as the standard stimulus (SS; see Table 1 and Materials and Methods) and the other foods at 5°C, 20°C, and 50°C (CS) were compared with the SS. The oral cavity temperature is close to 35°C, where the SS was placed. It is assumed that the similarity in temperature of the food and the food application region is minimally stimulating to the oropharyngeal tissues. The adopted range of temperatures is thought to be the widest for safe experimentation because (1) foods at temperatures below 5°C and above 50°C may be harmful to oral and other tissues, (2) food hardness would probably differ over a wider range of temperatures, and (3) harder foods may make the manipulation of stimulation more difficult.

The subjects in Exp. I were required to estimate the SDS of the CS compared with that of the SS, and conventional methods for sensory evaluation [20] were not used. If methods of paired comparisons were used, for example, many more trials for each subject would be necessary. The subjects would thus swallow larger amounts of food in more trials, and the increased amount of ingested foods may affect the SDS because of sensory information from the abdominal organs such as the stomach. Therefore,

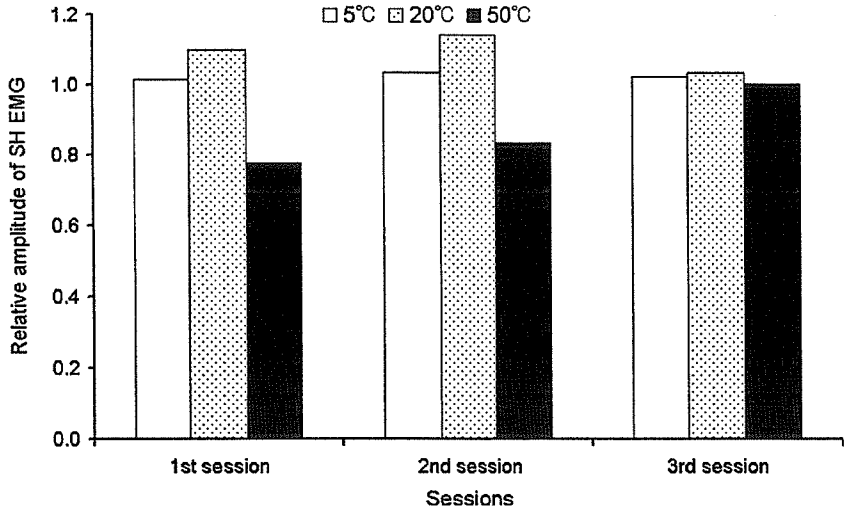

Fig. 4. Relative amplitudes of suprahyoid muscle activities in swallowing of foods of four temperatures (5°C, 20°C, 35°C, and 50°C). In each session the amplitudes of suprahyoid muscle activity were compared with amplitudes measured while swallowing the standard stimulus at 35°C and expressed as ratios of the suprahyoid muscle activity for the standard stimulus.

the stimuli and method used here for sensory evaluation appear to be most appropriate.

Second, these results demonstrate that a higher food temperature (50°C) reduces the subjective difficulty of swallowing (Fig. 2). Previous psychophysical reports may be related to the present finding: (1) the tongue (at least its tip) is highly sensitive to both warmth and cold [21], and (2) the oral cavity as a whole perceives warming more readily than cooling [22]. The first report [21] suggests that the tongue is the initial sensor responsible for the change in the subjective difficulty of swallowing (Fig. 2). Three cranial nerves innervating the tongue contain fibers highly responsive to warm and cold stimulation [23–25]. The second report [22] also suggests that the oral cavity, including the tongue, is a better sensor of warmth than of cold. The following fact may also be related to the present finding that spatial summation occurs under warm rather than cold oral cavity conditions [26]. The lingual (trigeminal) nerve conveys thermal sensation of the tongue to the central nervous system (CNS). According to animal experiments, the lingual mucosa contains both warm and cold responsive fibers [23,25]. In the CNS, cold responsive neurons predominate at least in the medulla [27]. Thus, this finding is difficult to explain by neurophysiologic and psychophysical studies. Another possible explanation may be the differences in sensitivities of the test foods between the texture sensation in humans and the texture measured by the texturometer. If human sensitivity is much greater than texturometer sensitivity, the subjects may have judged slight textural differences among the four kinds of foods, which influenced their sensory evaluation. The present experiment suggests that food warmth in the oral cavity facilitates swallowing, although the responsible neural mechanism remains unclear.

Third, the present study shows that a higher food temperature at 50°C reduces the activity of the suprahyoid (SH) muscles during swallowing (Fig. 4). Probably because of clinical limitations, previous studies investigating thermal stimulation and swallowing focused mainly on the influences and physiologic mechanism of cold, rather than warm, stimuli on elicitation, rather than performance, of swallowing [13,15,28]. Videofluorographic analysis of liquid temperature on oropharyngeal swallowing indicated that 1 ml of cold liquid causes longer (compared to control) pharyngeal response times and longer (compared to control) laryngeal elevation in normal subjects [11]. Unfortunately, liquids warmer than the oral temperature were not tested. The present study examined activity of the SH muscles electromyographically and laryngeal movement kinesiologically during swallowing. Since the SH muscles together with the thyrohyoid muscle serve as elevators for the hyoid bone and larynx [1], augmentation of SH activity may reflect an increased effort for the elevation. Anatomically, the SH muscles consist of three components: the geniohyoid muscle, the myohyoid muscle, and the anterior belly of the digastric muscle. A series of previous studies analyzed individual activities of these three muscles during swallowing in normal subjects and suggested that the laryngeal elevation system with the three muscles is an adaptive function rather than an immutable action [29]. The present finding may support the laryngeal elevation system hypothesis, i.e., the laryngeal elevation system functions more flexibly during swallowing than generally believed.

We conclude from Exp. I that food temperatures affect both sensory and motor aspects of swal-

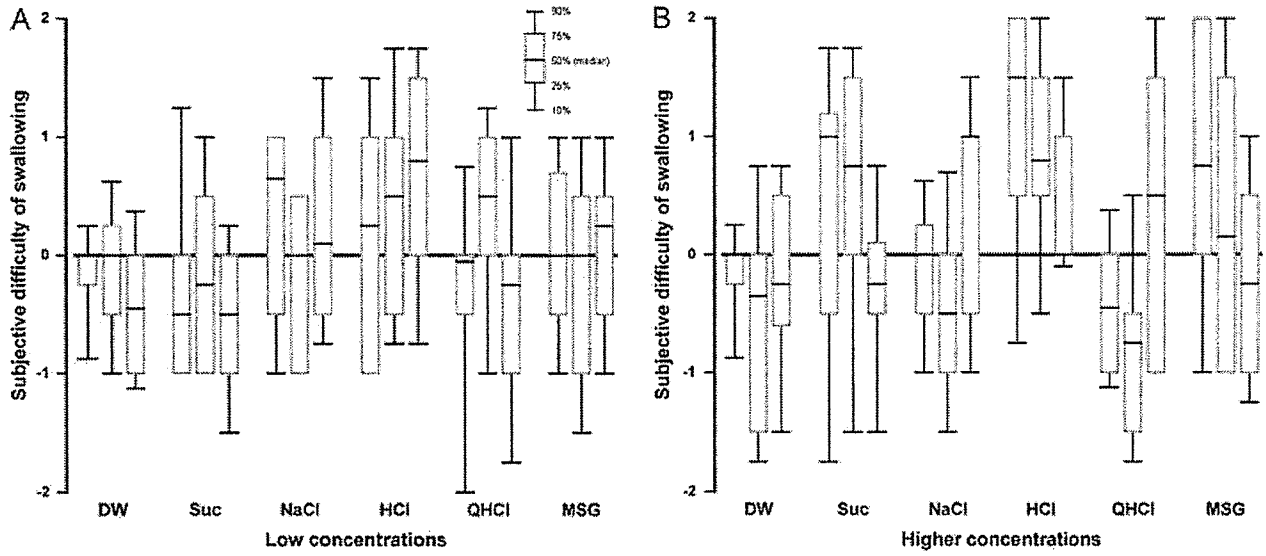

Fig. 5. Changes in subjective difficulty of swallowing evaluated with foods containing five taste qualities at low (A) and high (B) concentrations. The three bars for each taste quality indicate the three different sessions (left bar, first session; middle bar, second session; and right bar, third session). In the upper right corner of panel A, columns and error bars indicate 10% (upper error bars), 25% (upper lines of columns), 50% (medians, solid bars), 75% (lower lines of columns), and 90% (lower error bars) of responses. Food taste samples were as follows: DW = distilled water, Suc = sucrose, NaCl = sodium chloride, HCl = hydrochloric acid, QHCl = quinine hydrochloride, and MSG = monosodium glutamate. See text for details.

lowing, and a higher temperature of 50°C appears to facilitate swallowing.

Experiment II: Materials and Methods

Stimuli and Stimulation

A thickening agent dissolved in distilled water (DW) was used as the standard food stimulus (SS) in Exp. II, and five taste substances were used as the comparative stimuli (CS): (1) sucrose (Suc), (2) sodium chloride (NaCl), (3) hydrochloric acid (HCl), (4) quinine hydrochloride (QHCl), and (5) monosodium glutamate (MSG). The test concentrations are indicated in Table 2. The hardness of the foods (about 4100 N/m^2 in SS) varied, but not with statistical significance.

The SS was delivered to individual subjects four times, always as the first and last trials. Each CS (one of the five basic taste qualities) was tested twice (low and higher concentrations) in each session. As shown in Table 2, the delivery order of the SS and CS was the same in the first and third sessions and was reversed in the second session. Because Kruskal–Wallis one-way ANOVA indicated no significant differences in the four SDS of the SS among the three sessions, the medians of four SDS of DW in each subject for individual sessions were used to apply the Tukey's test followed by ANOVA.

Results

Sensory Aspect

Medians of SDS of the four SS and ten CS are shown in Figure 5. Although SDS values varied among the subjects and among the three sessions, SDS of the CS dissolved in Suc tended to be high, while those of QHCl or HCl tended to be low, i.e., sweet tasting foods were easier for the subjects to swallow, while bitter- or sour-tasting foods were more difficult to swallow. Statistical analysis using Friedman's test revealed that (1) in low concentration series there was a significant difference among the SS and five CS ($\chi^2 = 12.180$, $p < 0.05$) only in the second session and (2) in higher concentration series the differences in all three sessions were significant ($\chi^2 = 16.909$, $p < 0.01$; $\chi^2 = 15.997$, $p < 0.01$; $\chi^2 = 12.667$, $p < 0.05$, respectively). Further analysis using Tukey's test showed that in the first and second sessions the following two pairs of differences in SDS were significant: (1) between SS (with DW) and CS with HCl ($p < 0.05$) and (2) between CS with HCl and CS with QHCl (first session, $p < 0.01$; second session, $p < 0.05$). Kendall's rank correlation coefficient calculated between the first and second sessions was not significant ($\tau = 0.181$), but that between the second and third sessions was significant ($\tau = 0.263$, $p < 0.01$).

Motor Aspect

Durations of Swallowing

As described in Exp. I, three characteristic bursts were observed in the SH EMGs associated with

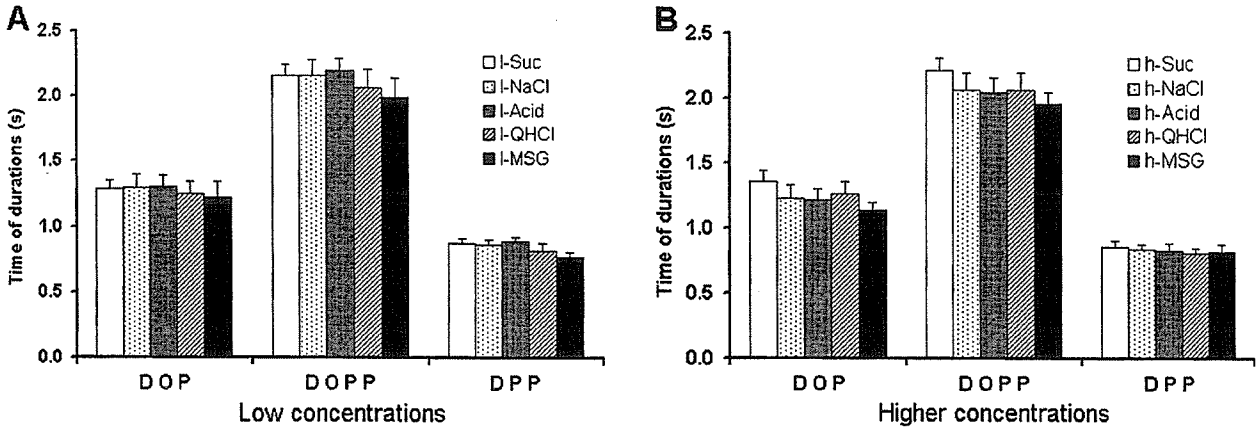

Fig. 6. Three kinds of durations were measured in subjects swallowing foods containing five taste qualities at low (l-; A) and higher (h-; B) concentrations. DOP = duration of oral phase, DOPP = duration of oropharyngeal phase, DPP = duration of pharyngeal phase. See text for details and also Figure 1. Values of DOP and DOPP are means + SEM. These three durations were obtained from the three sessions. Food taste samples were as follows: DW = distilled water, Suc = sucrose, NaCl = sodium chloride, HCl = hydrochloric acid, QHCl = quinine hydrochloride, and MSG = monosodium glutamate.

swallowing (see General Materials and Methods, Fig. 1). First, the DOP for the SS (dissolved in DW) ranged from 1.28 ± 0.115 s (14th trial, see Table 2) to 1.37 ± 0.083 s (1st trial). The DOP for the five low-concentration taste solutions showed negligible variation from the shortest DOP (1.22 ± 0.103 s for MSG CS) to the longest DOP (1.31 ± 0.127 s for the Acid CS) (Fig. 6A). Second, the DOPP for SS ranged from 2.12 ± 0.136 s (14th trial) to 2.19 ± 0.089 s (1st trial). The DOPP for higher-concentration taste solutions showed small variation from the shortest DOPP (1.99 ± 0.125 s for the MSG CS) to the longest DOPP (2.20 ± 0.150 s for the Acid CS) (Fig. 6B). Statistical analyses with ANOVA of DOP, DOPP, and DPP in low- and high-concentration solutions detected no significant differences between tastes (i.e., the SS and five CS) and sessions. Finally, the overall average of the DPP for the SS was estimated as 0.82 s. The DPP ranged from 0.77 ± 0.042 s for the MSG CS to 0.89 ± 0.041 s for the Acid CS at low concentrations (Fig. 6A) and ranged from 0.81 ± 0.057 s for the QHCl CS to 0.86 ± 0.064 s for the Suc CS at higher concentrations (Fig. 6B).

Swallowing Muscle Activities

Amplitudes of SH EMGs were measured during swallowing of the CS with low and higher concentrations of the five taste qualities. Relative amplitudes of the peak SH activities after swallowing the SS are shown in Figure 7. Changes were not observed among the low concentrations of the five CS throughout the three sessions (Fig. 7A). At the higher concentrations, the peak SH amplitudes tended to decrease when the food taste qualities were added in the first and second sessions, but not in the third (Fig. 7B). Thus, no consistent tendency throughout the three sessions was observed. Statistically, significant differences were not found among the SS and the five CS either in the low or higher concentrations.

Discussion

In Exp. II, significant differences were found in the subjective difficulty of swallowing (SDS) of the CS and SS (Fig. 5). The present result confirms previous reports [9,12,15,17,30] showing that food taste can modify swallowing. The result suggests that the modification is more prominent in the sensory aspect than in the motor aspect. The concentrations of the five taste substances (Table 2) appeared to be sufficient for effective stimulation of taste receptors, since even the lower concentrations used are equal to or greater than the cognitive thresholds examined by the whole-mouth method [31].

Anatomically, multiple cranical nerves innervate taste receptors in the oral cavity and the pharynx, and taste thresholds are different in these regions [32,34–34]. Because the epiglottis and the nearby larynx region are stimulated when a bolus is swallowed, taste receptors not only in the oral cavity and pharynx but also in the larynx appear to be stimulated. Consequently, at least four taste nerves may be responsible for the obtained results: the chorda tympani, glossopharyngeal (GP), superficial petrosal (SP), and superior laryngeal (SL) nerves. Each subject in Exp. II was required to pay special attention to the throat when he/she evaluated SDS. Considering this requirement together with the innervation of the

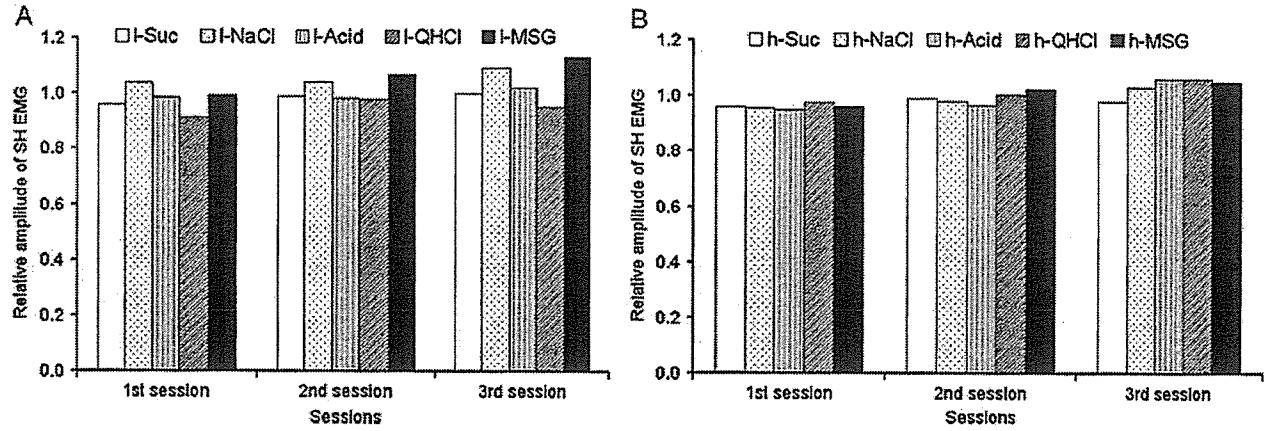

Fig. 7. Relative amplitudes of suprahyoid muscle activities in swallowing foods with five taste qualities at low (l-; A) and higher (h-; B) concentrations. In each session the amplitudes of suprahyoid muscle activity were compared with amplitudes measured during swallowing of the standard stimulus which was dissolved in distilled water (DW) and expressed as ratios of the suprahyoid muscle activity for the standard stimulus. Food taste samples were as follows: Suc = sucrose, NaCl = sodium chloride, HCl = hydrochloric acid, QHCl = quinine hydrochloride, and MSG = monosodium glutamate.

throat, neural information through the SL nerve may play a more important role in the evaluation of SDS than the other nerves innervating the oral cavity and pharynx. In animal experiments, these gustatory nerves have different responsiveness to solutions of the four basic taste qualities [33,34]. The SL nerve exhibits high responsiveness to HCl and water and much lower responsiveness to Suc and QHCl. The sweet-tasting foods were easier for the subjects to swallow, while the bitter- or sour-tasting foods were more difficult to swallow (Fig. 5). The present result seems inconsistent with the response characteristics of the SL nerve [33,34], suggesting that the preference for sweet foods and aversion to sour and bitter foods, which are generally recognized, directly determine SDS, although neural information through the other nerves, like the GP and SP innervating the posterior oral cavity, may be largely responsible.

According to previous studies, sour taste facilitates swallowing in patients with neurogenic dysphagia [12] as well as in animals [17]. Patients who suffered stroke or other neurogenic disorders [12] indicated improved oral onset of swallowing (i.e., shortening of latency for swallowing) of a sour bolus compared with nonsour boluses. Alternatively, healthy humans had a prolonged latency for swallowing following application of sour solutions to the posterior oral cavity and pharynx [9]. The solution amount for each application was as small as 0.3 ml [9]. This report suggests that not only taste of the stimuli but also the volume of the stimuli (i.e., boluses vs. small amounts of solutions) affect swallowing. These previous reports [9,12,17], at any rate, indicate that sourness can modify swallowing when the taste stimulus is delivered to the area from the posterior oral cavity to the pharynx and larynx. Unfortunately, the present study did not measure latency of swallowing. The duration of the oral phase (DOP) of swallowing was not significantly different among the foods representing the five taste qualities (Fig. 6), suggesting that sourness does not affect DOP. In Exp. II, the foods swallowed were presumed to stimulate sensory receptors on the upper alimentary canal (i.e., anterior and posterior areas of the oral cavity, pharynx, larynx, and esophagus). Considering previous findings [9,12,17] and the present result, food taste is sensed by receptors on the posterior oral cavity, pharynx, and larynx, which affect swallowing in normal humans, while receptors on the upper alimentary canal do not affect swallowing.

General Discussion

Two methodologic points are discussed: definitions of swallowing phases and reliability of the data. For the first point, deglutition has been generally divided into four consecutive phases (or stages): oral preparatory, oral, pharyngeal, and esophageal [1]. In the present study, we focused on the oral and pharyngeal phases and instructed the participants to swallow test foods without chewing, suggesting that oral preparation can be negligible. We defined the oral and pharyngeal phases by suprahyoid (SH) muscle activity and laryngeal movement associated with swallowing (see Swallowing Movement section of General Materials

and Methods and Fig. 1). According to previous studies [18,19,35], the SH muscles of humans exhibit maximum activity associated with swallowing just before the start of laryngeal elevation (i.e., the pharyngeal phase), although the temporal relationship depends to some degree on the volume and consistency of foods. Thus, SH muscle activity and laryngeal movement seem to be suitable determinants for the oral and pharyngeal phases. For the second point, the SDS scores of sensory data were consistent during the three sessions in Exp. I (Fig. 2) and the latter two sessions in Exp. II (Fig. 5). These results suggest that the sensory data are reliable in both experiments. As for the three durations of motor data, no significant differences were detected among the three sessions with respect to Exp. I and Exp. II. We considered it to be inappropriate to measure amplitude parameters of muscle activity on different experimental days because the recording of the amplitude of muscle activity using surface electrodes is generally recognized to result in wide fluctuations between experimental sessions (especially on different days) and among subjects because of the positioning of the electrodes [36] and differences in cutaneous and subcutaneous conditions [37].

The present study separately examined the effects of two sensory modalities, temperature and taste, of foods on swallowing in Exp. I and Exp. II, respectively. Previous studies examined the influences in normal and dysphagic patients (e.g., temperature, [11,14]; taste, [12,15,30]), but these studies focused on motor parameters only. On the contrary, the present study examined the effect of both the sensory aspect and the motor aspect of swallowing in individual subjects. Psychophysical studies of taste in humans have revealed that the temperature of taste solutions affects their thresholds differentially among the taste qualities tested [38–40]. Previous experiments in animals also revealed that sensory receptors innervating the tongue respond to both taste and thermal stimuli [24,25], and that neural signals from the receptors of both modalities converge at the medulla and cortex [41,42]. These previous studies in humans and animals suggest that these two sensory modalities in foods must be considered together when evaluating effects on swallowing. According to the present study, food at a high temperature of 50°C is easier for subjects to swallow (Fig. 2). Consequently, foods at lower temperatures can be excluded in the next study. To consider interactions between the two sensory modalities, the sensory and motor aspects of swallowing foods at 50°C, for example, should be evaluated with respect to the five basic taste qualities.

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Research Article

(J Oral Rehabil)

Influences of body posture on duration of oral swallowing in normal young adults

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Running head: Body posture and duration of oral swallowing

Key words: body posture, duration, oral swallowing, anterior tongue, suprahyoid, electromyogram, normal subject

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Abstract

The primary purpose of this study was to determine whether body posture altered or not the duration of oral phase of swallowing. To answer the question, the present authors recorded electromyograms from the anterior tongue and suprahyoid muscles together with laryngeal movement associated with swallowing in normal young subjects. The subjects swallowed a test food just after a signal at four postures set randomly: the upright, two inclined (60° and 30° to the horizontal), and supine positions. We measured six durations, including the duration of oral phase, from these electromyograms and defined the duration of oral phase by the integrated suprahyoid electromyogram and by the laryngeal movement. The average duration of oral phase decreased by lying down from the upright to the inclined and supine positions. The decrease in the duration reached the statistically significant level we set ($p < 0.05$) and was consistent among three experimental sessions conducted. A duration from start to peak of the integrated anterior tongue electromyogram during swallowing also decreased by lying down, but the decrease failed to be significant ($p < 0.07$). The postural changes unaffected the remaining four durations measured. The decrease in the duration of oral phase by lying down suggests that the gravitational force acted on the test food facilitates elicitation of the swallowing reflex (i.e., the pharyngeal phase of swallowing). Large variation in the anterior tongue activity during swallowing across the subjects is attributable to the statistically negative result of the decrease in the duration of anterior tongue.

1. Introduction

Inclined body posture (e.g., 60° from vertical) are often used to help swallowing of dysphagic patients in clinical sites (e.g., (Logemann, 1998). Several physiological studies have evaluated influences of body posture on swallowing in normal subjects and dysphagic patients. A previous study analyzed changes in nasal pressure during swallowing and found functional correspondences of the pressure changes to sequential events shown in swallowing (Gramiak & Kelley, 1966). Then, the authors examined the pressure changes at the upright and supine positions using an enough number of normal subjects (N = 1,219) and showed that the nasal pressure complexes corresponded to the oral phase of swallowing did not differ between the two positions with a small (spoonful) amount of barium, but prolonged at the supine position with more amounts (10 to 30 mL) of barium and water (Gramiak, Kelley & Gravina, 1967). A later study analyzed electromyogram (EMG) activities of the lateral pterygoid and digastric muscles during swallowing of saliva and documented that these muscles started firing earlier (30-100 ms) at the 45° inclined and supine positions than the upright, suggesting that lying body posture down shortens the oral phase of swallowing (Moller, Lund & Nishiyama, 1971). In contrast, a recent analysis of EMG recorded from the suprahyoid (SH) muscles during swallowing of 5 mL of water revealed that the SH EMG at the inclined position (60° reclining from vertical with 60° chin-tuck) was longer than the upright and inclined (30° reclining from vertical with 30° chin-tuck) positions, suggesting that inclining body posture to 60° prolongs the oral phase of swallowing (Ayuse *et al.*, 2006). These previous studies about the influence

of body posture on oral swallowing are inconsistent with each other (unaffected, (Gramiak, Kelley & Gravina, 1967); shortened by lying down (Moller, Lund & Nishiyama, 1971); and prolonged by lying down, (Ayuse *et al.*, 2006), while the influence of body posture on pharyngeal swallowing appears consistently 'negative' among previous reports (Dejaeger *et al.*, 1994; Gramiak, Kelley & Gravina, 1967; Johnsson *et al.*, 1995; Palmer, 1998). Thus, the primary purpose of the present study is to examine influences of body posture on the duration of oral swallowing to resolve the contradictory findings reported.

In swallowing, the tongue plays important roles, especially in transport of bolus from the anterior oral cavity to the pharynx (Hiiemae & Palmer, 2003; Lowe, 1980; Miller, 2002). Previous studies using videofluorography, electropalatography, and ultrasound techniques revealed that the anterior tongue (AT) folds bolus and presses it to the hard palate to propel it into the pharynx (Chi-Fishman & Stone, 1996; Chi-Fishman, Stone & Mccall, 1998; Hiiemae & Palmer, 1999; Hiiemae *et al.*, 2002; Kahrilas *et al.*, 1993; Shawker *et al.*, 1983; Stone & Shawker, 1986). These techniques are sensitive for observation of mass movements of the tongue during swallowing, but less sensitive for analysis of sequences in muscle activity of the AT due to their low temporal resolution. Recording of EMGs is a useful technique for understanding of sequential changes in muscle activities. Despite the important roles of the tongue and the usefulness of the EMG technique, muscle activity of the tongue are not frequently analyzed to explore physiological mechanisms of swallowing in humans (Yoshida *et al.*, 1982) probably because of technical difficulties in recording (Yamada, Yamamura & Inoue, 2005).

Specifically, the following two questions were tested in the present study:

(1) Does body posture during swallowing affect the duration of oral phase?, and (2) Are there any differences between AT and SH muscle activities during swallowing?

2. Materials and Methods

2.1 Subjects

Nine adults (six males and three females; 21 to 30 years old) participated as subjects of the present study. None of the subjects had jaw or oral functional abnormalities. Before the experiment, aim and methods of the experiment were explained individually to the subjects, and informed consent was obtained from them.

2.2 Test food

A tasteless and odorless thickening agent (Mousse-up®, NISSHIN SCIENCE CO.) developed especially for dysphagic patients was adopted as a test food for the present experiment. The test food was prepared at room temperature of around 24.5 °C, and procedures for the preparation was as follows: 1) an amount, 2 g, of the thickening agent was dissolved in 100 mL of distilled water (DW), 2) the dissolved agent was mixed until creamy, and 3) the mixture was filled into needle-less plastic syringes. Physical properties of the test food was measured using a texturometer (Yamaden Inc., RE-3305S) at room temperature, and the measurement was repeated three times. Table 1 shows average values of three physical properties measured in the test food used: hardness, cohesiveness, and adhesiveness, and the hardness of the

present test food (2 g of the agent/100 ml water) was 5.3% (temperature experiment) and 4.2% (taste experiment) of the test foods (8 g of the agent/100 ml water) used in our preceding report (Miyaoka *et al.*, 2006).

TABLE 1 Physical properties of used test food

Hardness	Cohesiveness	Adhesiveness
174.1 ± 27.2	0.81 ± 0.40	5.3 ± 7.1

Values are mean ± S.E.M. Units of hardness and adhesiveness are Pa and J/m^3, respectively.

2.3 Recording

An electromyogram (EMG) of the anterior tongue (AT) was recorded by surface electrodes which we modified on the basis of a previous report (Yoshida *et al.*, 1982). Each subject was instructed to protrude the tongue, and the electrodes were attached on surface of the tongue with an adhesive (KOATSU GAS KOGYO CO.) after applying a paste (NIHON KOHDEN CO.) to the insides of the electrodes (Fig. 1b). The electrodes were located 20 mm posterior from the tongue tip with bilateral symmetry, and an interelectrode distance was 15 mm.

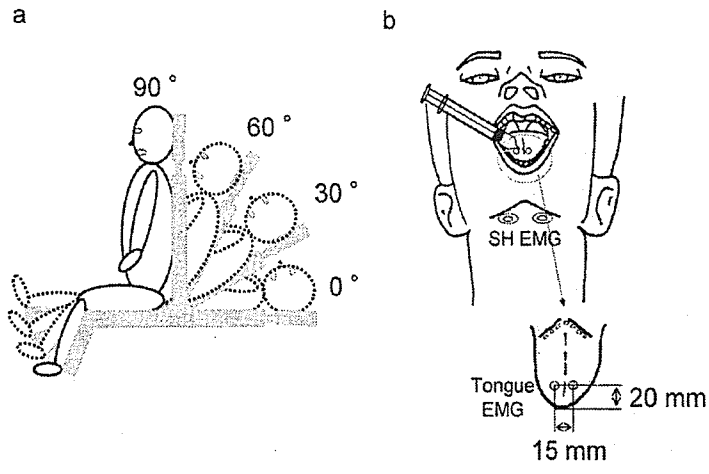

Fig. 1

An EMG of the suprahyoid (SH) muscles was recorded with a pair of adhesive electrodes (Ambu Inc., Blue Sensor), which was adhered to the skin under the chin on both sides of the midline (Fig. 1b).

An electrode was affixed to the left earlobe as the reference electrode. The EMG signals were amplified (ADInstruments CO.), filtered using bandwidth of 10-5,000 Hz, fully rectified, and integrated (time constant, 0.03 s). Laryngeal movement associated with swallowing was monitored with a piezo-electric pulse transducer (MLT1010, ADInstruments Pty Ltd) attached to the skin above the thyroid cartilage. The EMG signals and the laryngeal movement were stored (digital sampling rate, 10 kHz) on a data recorder (ADInstruments CO., PowerLab/8sp) for later analysis.

2.4 Procedures

Recordings were carried out at four different body positions: upright position (90°), 60° supine position (60°), 30° supine position (30°), and horizontal supine position (0°; Fig. 1a). After the setup for EMG recordings, individual subjects were instructed to lie in a dental chair with a head support comfortably in an air-conditioned (24.5°C) room. Body positions were initially adjusted to be horizontal to the Frankfurt plane. Instructions to the subjects were outlined as follows: 1) open the mouth slightly and hold the position for a while, 2) accept 1.0 ml of the test food poured from each syringe onto the tongue surface at the middle of the AT electrodes, 3) close the mouth and let the tongue rest on the floor of mouth, 4) swallow it without chewing immediately by releasing the tongue from the floor of mouth after when facing light is turned on, and 5) rinse the mouth with water if necessary. The used volume, 1.0 ml, was determined after the preliminary experiment. Then, the dental chair was operated randomly to one of the four positions from the 0° to the 90° position. One experimental session using the test food consisted of four trials corresponding to the four body

positions. Three sessions were conducted with each subject, and at least 1 week intervals intervened between sessions. In total, 108 trials (4 trials × 3 repeats × 9 subjects) were conducted in the present experiment.

2.5 Data processing and analysis

The present authors defined the duration of oral phase (DOP) by the SH EMG and laryngeal movement associated with swallowing in our previous reports and documented that the time from the start to the peak of the integrated SH EMG was nearly equal to the DOP (Miyaoka *et al.*, 2006; Takagi *et al.*, 2001). According to the definition, the time of the SH EMG was measured to determine whether or not the DOP was affected by body positions during swallowing. Five other durations were also measured from the two, AT and SH, EMGs during swallowing for further analysis of changes in the DOP (Fig. 2). The six durations measured in this study were as follows:

1) the first duration of the AT EMG ($Duration_{1st\ AT}$): the time from the start to the peak(s) of the integrated AT EMG,
2) the first duration of the SH EMG (i.e., DOP): the time from the start to the peak of the integrated SH EMG,
3) the second duration of the AT EMG ($Duration_{2nd\ AT}$): the time from the peak(s) to the end of the integrated AT EMG,
4) the second duration of the SH EMG ($Duration_{2nd\ SH}$): the time from the peak to the end of the integrated SH EMG,
5) the full duration of the AT EMG ($Duration_{Full\ AT}$): the time from the start to the end of the integrated AT EMG (i.e., $Duration_{Full\ AT}$ equals $Duration_{1st\ AT}$ plus $Duration_{2nd\ AT}$),

and 6) the full duration of the SH EMG ($Duration_{Full\ SH}$): the time from the start to the end of the integrated SH EMG (i.e., $Duration_{Full\ SH}$ equals $Duration_{1st\ SH}$ plus $Duration_{2nd\ SHT}$).

It was easy for us to determine the time showing the peak of the integrated AT and SH EMGs, but not those showing their start and end, so we adopted the following criteria: 1) averages and SD of magnitudes of the integrated EMGs were calculated for 0.5 s before the command of swallowing as the control activities for individual trials, 2) the onset of the integrated EMGs was detected when they deviated from the averages by 2.0 SD, and 3) the offset of the integrated EMGs was recognized when they returned to the control levels. In this study, we regarded a smaller burst in the SH EMG preceding the major one (Fig. 2; 'Burst 1' and 'Burst 2', respectively, in our previous reports (Miyaoka *et al.*, 2006; Takagi *et al.*, 2001) as a part of the major burst, and we applied the same rule to the AT EMG when two bursts were observed, as shown in Fig. 2. According to the procedure, the durations of the AT and SH EMGs recorded were calculated by

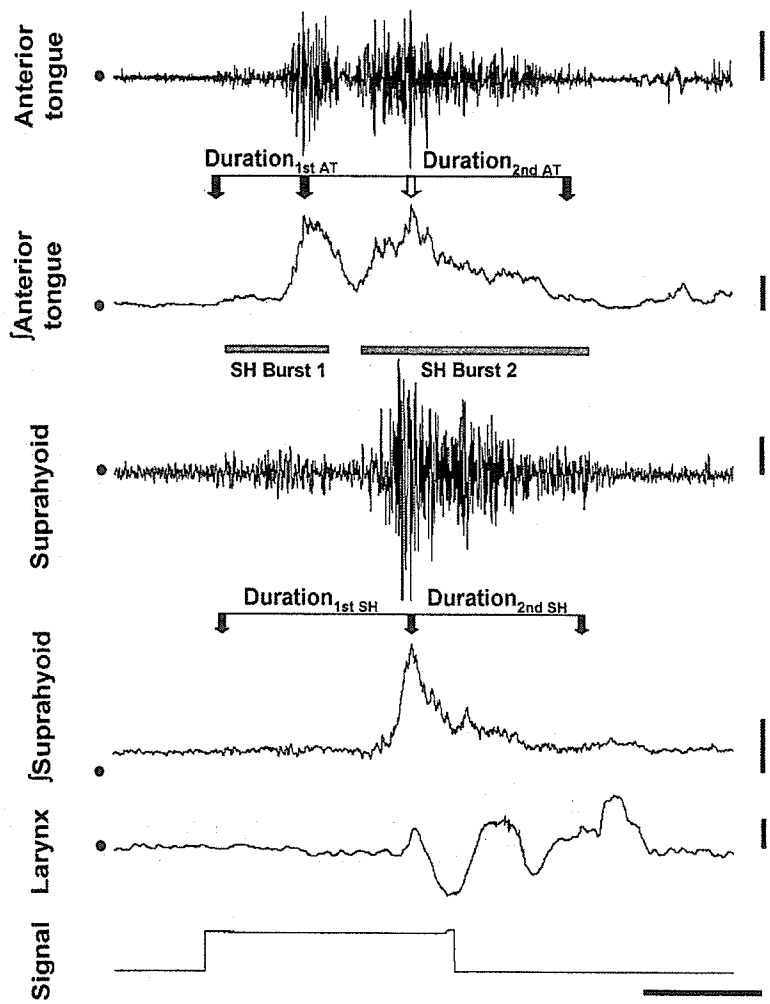

Fig. 2

subtracting the time of start from that of end.

Statistical analysis was performed using two-way analysis of variance (ANOVA) after homogeneity of samples was verified by the Bartlett's test. The Tukey's multiple comparison tests were followed by ANOVA when significant differences were detected. The significant level was assumed to be $p < 0.05$.

3. Results

Figure 2 depicts sample data recorded from the AT and SH muscles during swallowing of a test food at the upright position in a subject. The AT and EMG started bursting just after the command to swallow and lasted for ~1.5 s, while the SH EMG bursted concomitant with or behind the start of the AT EMG (Fig. 2). Changes in the DOP and five additional durations by different body positions during swallowing are summarized as follows: (1) the average DOP decreased consistently by lying posture down from the upright to two (60° and 30°) inclined and supine positions across the three sessions (Fig. 3), and the decrease reached the statistically significant level ($p < 0.05$), (2) the average $\text{Duration}_{\text{Full AT}}$ tended to decrease by lying posture down, but the decrease was inconsistently across the sessions and close to the significant level ($p < 0.07$; Fig. 4B), and (3) the remaining four

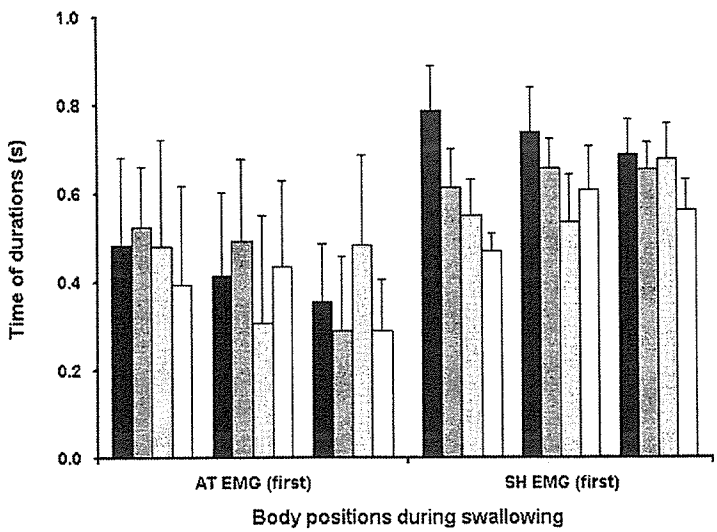

Fig. 3

durations (i.e., $Duration_{1st\ AT}$, $Duration_{2nd\ AT}$, $Duration_{2nd\ SH}$, and $Duration_{Full\ SH}$) showed inconsistent changes across both the four body postions and the the sessions (Figs 3 and 4). Two way analysis of variance (ANOVA) showed that changes in the DOP were significant among the four body postions (as mentioned above) and not among the three sessions, suggesting high reproduceability of the changes observed in the DOP. The Tukey's multiple comparison tests followed by two way analysis of variance showed that the DOP at the upright position was significantly longer than that at the supine position ($p < 0.01$).

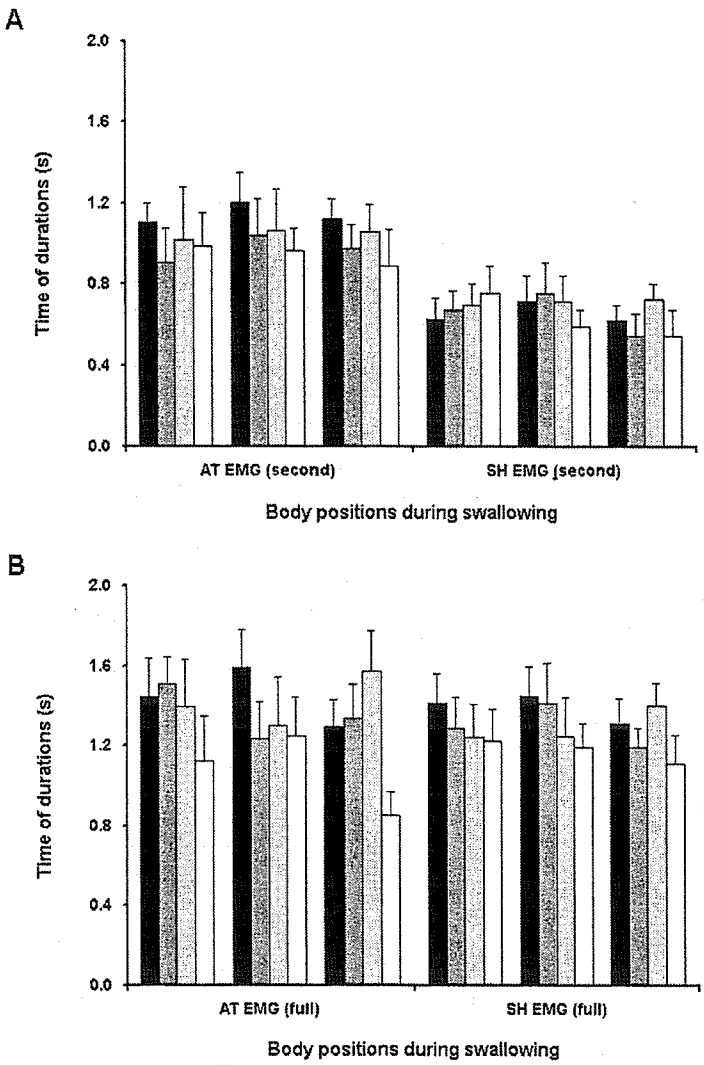

Fig. 4

More than 20% (on average) ranging from 15% (30° inclined position) to 33% (upright position) showed two peaks of the integrated AT EMG, as seen in Fig. 2. Secondary durations, $Duration_{1st\ AT}$ and $Duration_{2nd\ AT}$, were 0.78 ± 0.04 s (mean ± S.E.M) ranging from 0.71 s (mean, supine position) to 0.87 s (upright position) and 0.66 ± 0.03 s ranging from 0.41 s (supine position) to 0.88 s (upright position), respectively. However, the number of samples was too small to perform statistical examination about differences in the durations among