



# Effects of Tongue-Hold Swallows on Suprahyoid Muscle Activation According to the Relative Tongue Protrusion Length in the Elderly Individuals

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## Abstract

This study investigated differences in suprahyoid muscle activity in elderly adults during tongue-hold swallowing (THS) according to tongue protrusion length to determine the most effective tongue protrusion length during THS. A total of 52 healthy participants (34 females and 18 males) aged 69–92 years were included. Changes in suprahyoid muscle activation during normal swallowing and THS with 1/3rd and 2/3rd tongue protrusions using surface electromyography were observed. Suprahyoid muscle activation significantly increased with the increasing tongue protrusion length ( $p < 0.05$ ). Depending on the responses of the participants based on tongue protrusion length, participants were categorized into the increase group [increased suprahyoid muscle activity with tongue protrusion,  $n = 36$  (1/3rd THS compared to normal swallowing) or 38 (2/3rd THS compared to normal swallowing)] or decrease group [decreased suprahyoid muscle activity with tongue protrusion,  $n = 16$  (1/3rd THS compared to normal swallowing) or 14 (2/3rd THS compared to normal swallowing)]. The functional reserve of the increase group was significantly higher than that of the decrease group ( $p < 0.05$ ). Many elderly people were found to have increased activation of the suprahyoid muscle during THS; however, others showed the opposite. Therefore, it is necessary to confirm the degree of suprahyoid muscle activation during THS so that the patient can perform the exercise at the tongue protrusion length that can maximize the effect of the exercise. For individuals who cannot overcome even a small amount of tongue protrusion (e.g., 1/3rd MTPL), replacing THS with another exercise may be considered.

**Keywords** Deglutition · Deglutition disorders · Electromyography · Exercise · Tongue

## Introduction

Tongue-hold swallowing (THS), also known as the Masako maneuver, is designed to strengthen the posterior pharyngeal muscles [1]. During normal swallowing, contact between the base of the tongue and the posterior pharyngeal wall plays a crucial role in moving the bolus down into the esophagus [2, 3]. THS is performed by trying to swallow with the tongue protruded between the teeth. During THS, the contact between the base of the tongue

and the posterior pharyngeal wall becomes difficult and to compensate for it, the posterior pharyngeal wall moves further forward [1, 4]. Therefore, holding the tongue acts as resistance during swallowing [5, 6].

To the best of our knowledge, only two studies have assessed the long-term application of THS. Oh et al. [7] enrolled ten healthy subjects to evaluate the effects of THS as an exercise for improving swallowing. THS was implemented according to the original instructions (protrude the tongue maximally but comfortably, hold it between the front teeth, and swallow saliva) [4]. Participants performed THS every 5 s for 20 min (a total of 240 repetitions per session), 5 days a week, for 4 weeks. After 4 weeks of the exercise, there was no biomechanical change in the degree of hyolaryngeal elevation, anterior movement of the posterior pharyngeal wall, and pharyngeal constriction ratio during normal swallowing as measured

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by videofluoroscopy (VFS) [7]. Woo et al. [8] enrolled 14 healthy subjects to evaluate the effects of THS as a long-term exercise program. Their protocol was similar to that used by Oh et al. However, the number of sessions per day was increased threefold, i.e., three sessions per day, and the total duration was 8 weeks. After completion of the training, the subjects showed significantly higher suprahyoid and infrahyoid muscle activities during normal swallowing as measured by surface electromyography (sEMG) during swallowing compared with the control group [8]. These two studies differ in the number of sessions per day, the total duration of the exercise, and the method used to identify the effects of the exercise, making it difficult to conclude the long-term effects of THS exercise. Therefore, as suggested by Fujiu and Logemann [4], it is necessary to appropriately implement THS and find a suitable target group of participants in whom the strengthening effect of the posterior pharyngeal wall, which is the original purpose, can be observed. This strengthening effect can be estimated through the process of confirming the physiological changes in the short-term application of various THS methods before the long-term application of THS.

Four previous studies have examined physiological changes during THS according to the protrusion length of the tongue. Fujiu-Kuarchi et al. [9] examined changes in the intraoral pressure during THS according to different degrees of tongue protrusion in young healthy adults. They concluded that those with longer maximal tongue protrusion length (MTPL) had sufficient extra length of the tongue needed for swallowing, while those with shorter MTPL demonstrated low pressure when swallowing because they did not have enough extra length of the tongue. Thus, MTPL should be considered when determining the tongue length during THS [9]. Hammer et al. [10] found that the activities of the suprahyoid, genioglossus, and superior pharyngeal constrictor muscles significantly increased during saliva swallowing with the tip of the tongue at the lip, as well as during swallowing of saliva with THS maneuver, compared with the normal swallowing without the maneuver; however, the pharyngeal pressure during swallowing did not change in all conditions. They suggested that the relatively stable pressures across tasks may be due to the increased activity of the superior pharyngeal constrictor in the absence of posterior tongue movement. However, this study did not directly compare the differences in THS between the tip of the tongue at the lips and maximal protrusion of the tongue [10]. Oh [11] evaluated the changes in suprahyoid muscle activation between three conditions during THS in young healthy adults and reported that the greater the protrusion of the tongue, the greater the suprahyoid muscle activation during swallowing, indicating that the tongue should be maximally protruded to achieve the greatest therapeutic effect.

Similarly, Fujiwara et al. [12] found that a decrease in the intraoral pressure during THS was inversely associated with increased suprahyoid muscle activation; therefore, they also suggested maximal protrusion of the tongue to maximize the effectiveness of THS exercise. Thus, the longer the tongue, the greater is the required protrusion to maximize the therapeutic effects of THS [12].

The conclusions of previous studies that suggest maximal protrusion of the tongue for better effects of THS are based on studies in healthy young adults who do not have a problem with swallowing. Furthermore, these findings have not been validated in those with muscle weakness associated with swallowing who are the target population for this exercise. Clinically, it has been reported that several patients with dysphagia cannot perform the original THS because it is very difficult to swallow with the tongue protruded [11]. Therefore, in order to find out if the effects of THS can be achieved in those who are unable to swallow according to the original THS guidelines, we compared the physiological changes with a certain proportion of the tongue protruded relative to its maximum length rather than a fixed length, as tongue length can vary between individuals [9, 11, 12].

Previous studies have used absolute values (tongue protrusion lengths) to assess physiologic changes during THS without considering individual characteristics. However, a person with a shorter tongue will face greater resistance when attempting to swallow with the same length of the tongue protruded compared to a person with a longer tongue. As THS is an exercise developed to strengthen the pharyngeal constrictor muscle, it is necessary to gradually increase the resistance [5]. In individuals with a short tongue, the length of the tongue may be insufficient to further increase the resistance beyond a certain point. Therefore, we used relative 1/3rd and 2/3rd protrusion lengths, as their feasibility has been proven in a preliminary study in healthy adults [11]. The aim of this method was to confirm the relative length of the tongue necessary to perform THS most efficiently and effectively according to the characteristics of an individual.

The present study investigated the changes in suprahyoid muscle activation during swallowing according to the relative tongue protrusion length in an elderly cohort aged over 65 years to assess the applicability of THS as a strength training exercise in the elderly. We hypothesized that suprahyoid muscle activation would increase with the increasing relative tongue protrusion lengths.

## Methods

### Participants

This study included 52 volunteers (age  $77.31 \pm 4.30$  years; range 69–92) without a reported history of speech or swallowing deficits, all of whom were able to perform THS (Table 1). None of the participants reported drug use that could affect swallowing or neurological function, or having engaged in any swallowing-related strength training program for at least 1 year prior to this study. All participants passed a clinical swallowing screening test (Gugging swallowing screen) administered by an occupational therapist who majored in dysphagia therapy [13]. Before conducting the study, all participants received complete explanation of the purpose, risks, and procedures, and all participants provided written informed consent. This study was approved by the Institutional Review Board.

### Maximal Tongue Protrusion Length (MTPL)

At complete protrusion, the distance from the tip of the tongue to the upper incisor was defined as MTPL [9]. MTPL was measured thrice in each participant and the mean value was used for the analyses. To avoid the effect of variations between individuals in the width and tone of the tongue on swallowing, all participants were instructed to protrude their tongue maximally and maintain a flat tongue [11].

### Experimental Procedures

Each participant performed four tasks with three repetitions for each: (1) saliva swallow without tongue protrusion, (2) saliva effortful swallow with no-tongue protrusion, (3) THS with 1/3rd tongue protrusion, and (4) THS with 2/3rd tongue protrusion. The participants were instructed to protrude the tongue to the predetermined length and

maintain it flat. The examiner evaluated the length in mm using a transparent plastic ruler [11]. The participants were provided time to familiarize themselves with the tasks prior to the measurements; after practicing, they rested for at least 15 min before the measurements [9]. The measurements were preceded by a familiarization session to exclude the effects of a learning curve and improve the reliability of the measurements. The measurements were repeated thrice with 120 s of rest between the trials. The order of the tasks was randomized. The participants swallowed their saliva normally in each task.

### Electrophysiological Evaluation

Prior to the measurements, the submental area of each participant was wiped with alcohol and allowed to dry for approximately 30 s. During the examination, the participants were instructed to sit on a chair and hold their trunk in a neutral upright position. sEMG data were collected using Noraxon TeleMyo-DTS (Noraxon, Inc., Scottsdale, AZ, USA) and analyzed using Noraxon MyoResearch 1.07 XP software. The sEMG signals were amplified, bandpass filtered (10 and 500 Hz), and notch filtered (60 Hz) before digitally recording at 1000 Hz and converting into their root mean squares. For recording the activity of the suprahyoid muscle complex (mylohyoid, geniohyoid, and anterior digastric muscles), wireless sEMG electrodes were placed at distance of 1 cm on the skin on both sides of the midline under the chin [14]. The participants then performed the four tasks mentioned above. The onset and offset signals that represent the effort of the participant for each task were identified, and the signals in between these two were analyzed to obtain the peak values (peak amplitude). For each task, the mean values of three trials were used to calculate the peak value.

### Additional Procedures

An additional tongue pressure-related parameter was measured to determine the characteristics of the subjects. The tongue pressure measurements were performed thrice using the Iowa Oral Performance Instrument (IOPI Pro system 2.3, IOPI Medical, Redmond, WA, USA) by the same evaluator and under the same conditions.

### Tongue Tip Pressure

Anterior lingual elevation strength was assessed with the tongue bulb positioned longitudinally 10 mm posterior to the tip [15]. After placing the bulb in the correct position, the connecting tube was painted with a permanent marker at the point where it meets the front teeth to allow placement of the bulb in the same position for every

**Table 1** Demographic characteristics of the participants

	Number ( <i>n</i> )	Percent (%)
Gender		
Male	18	34.6
Female	34	65.4
Age group (years)		
60–69	2	3.85
70–79	36	69.23
80–89	13	25
90–99	1	1.92

measurement. The participants were instructed to push the tongue up against the bulb with maximum effort. Three trials were performed, with the maximum pressure (kPa) across the three trials recorded as the tongue tip strength [16].

### Tongue Base Pressure

Posterior lingual elevation strength was assessed with the tongue bulb positioned 10 mm anterior to the most posterior circumvallate papilla [15]. The participants were instructed to push the tongue up against the bulb with maximum effort. Three trials were performed, with the maximum pressure (kPa) across the three trials recorded as the tongue base strength [16].

### Tongue Endurance

After measuring the tongue strength, the bulb was placed at the tongue tip pressure measurement location to measure the endurance. In the tongue base pressure measurement position, the bulb slides on the tongue if it is pressed for a long time due to saliva; therefore, we only measured the endurance of the front of the tongue. The target value of the endurance measurement was set at 50% of the premeasured maximum tongue tip strength. The participants were required to maintain the target value for as long as possible. When the target value is reached, the green light at top of the device turns on. The participants were able to monitor their performance through the LED window throughout the endurance measurements. Endurance was measured only once [17].

The order of measurement was the same for all participants. Tongue tip strength was assessed first, followed by the tongue base strength and endurance. Rest periods of 2 min were provided between measurements to avoid fatigue.

### Statistical Analysis

All data were analyzed with SPSS (version 23.0) for Windows (IBM Inc., Armonk, NY, USA). sEMG data were logarithmically transformed to normalize the data distribution. Raw data were used for analyzing the tongue pressure. Data are reported as mean  $\pm$  standard deviation (SD). Descriptive statistics and tests for normality (Shapiro–Wilks test) were performed for all outcome variables. The differences in the tasks were analyzed using repeated measure analysis of variance (ANOVA). When the  $F$  value was significant, post hoc mean comparisons were analyzed with the least significant difference multiple comparisons test. Bonferroni adjustments for multiple comparisons were used.

Next, the participants were categorized according to individual responses for further analysis. The participants were divided into two groups according to the changes in their sEMG data, to allow for comparison between individual characteristics and THS performance; one group with increased suprahyoid muscle activation when swallowing with 1/3rd or 2/3rd tongue protrusion compared with normal swallowing (increase group) and the other group with decreased suprahyoid muscle activation when swallowing similarly (decrease group). Independent  $t$  test was performed to compare the characteristics of these two groups. The significance level was set at  $p < 0.05$ .

## Results

All participants successfully completed the study. The mean values of MTPL, 1/3rd MTPL, and 2/3rd MTPL were  $23.40 \pm 6.50$  mm (range 6–36),  $7.80 \pm 2.17$  mm (range 2–12), and  $15.60 \pm 4.33$  mm (range 4–24), respectively.

### Changes in sEMG Activation During Relative THS

The sEMG amplitudes during the tasks are presented in Table 2. There was a significant effect of the task on the amplitude of the suprahyoid muscle activity [ $F(1.605, 81.836) = 8.424$ ,  $p = 0.001$ ,  $\eta^2 = 0.142$ ]. The peak suprahyoid muscle activation value was significantly higher during THS with 1/3rd tongue protrusion and THS with 2/3rd tongue protrusion than during normal swallowing. The peak suprahyoid muscle activation estimated value was higher during THS with 2/3rd tongue protrusion than that during THS with 1/3rd tongue protrusion; however, the significance level suggests that the values may not be different (Table 2, Fig. 1).

### Increase or Decrease Group (Suprahyoid Muscle Activation at 1/3rd THS Compared to Normal Swallowing)

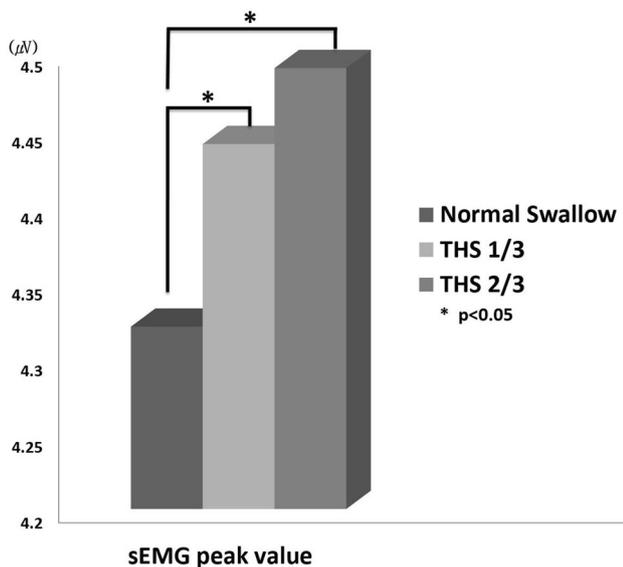
All participants were classified into the increase group (mean age  $76.92 \pm 4.42$  years; 26 females, 10 males) or decrease group (mean age  $78.19 \pm 4.04$  years; 13 females, 3 males) depending on whether the suprahyoid muscle activation increased or decreased during 1/3rd THS in comparison with normal swallowing. Figure 2 shows the changes in suprahyoid muscle activation of these groups in three swallowing conditions. The increase group showed significantly higher muscle activation than normal swallowing in 1/3rd THS and 2/3rd THS, whereas the decrease group showed significantly lower muscle activation than normal swallowing in 1/3rd THS. In the increase group, the Effortful–Normal ratio [(suprahyoid muscle activation in

**Table 2** Maximum sEMG values (logarithmically transformed) of tasks compared to normal swallowing

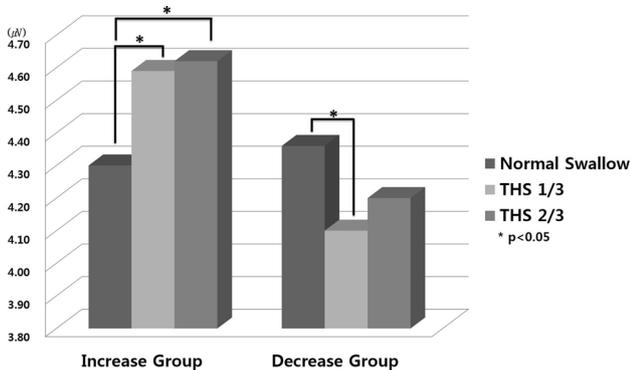
	sEMG peak value Mean $\pm$ SD	95% CI		<i>p</i> value
		Lower bound	Upper bound	
Normal swallow	4.32 $\pm$ 0.42	4.20	4.43	–
THS–1/3rd tongue protrusion	4.44 $\pm$ 0.47	4.31	4.57	0.028*
THS–2/3rd tongue protrusion	4.49 $\pm$ 0.42	4.38	4.61	0.004*

THS tongue-hold swallow

\*Significant difference versus normal swallowing ( $p < 0.05$ )



**Fig. 1** Comparison of sEMG values of suprahyoid muscle activity during the three tasks



**Fig. 2** Comparison between the increase and the decrease groups in suprahyoid muscle activation [classification criteria: 1/3rd tongue-hold swallow (THS) in contrast to normal swallowing]

effortful swallow/suprahyoid muscle activation in normal swallow)  $\times 100$ ] was significantly higher than that in the decrease group ( $p < 0.05$ ). The estimated values of tongue tip pressure, tongue base pressure, and tongue tip endurance were higher in the increase group than those in the

decrease group; however, the significance level suggests that the values may not be different (Table 3).

### Increase or Decrease Group (Suprahyoid Muscle Activation at 2/3rd THS Compared to Normal Swallowing)

The participants were also classified into a separate increase (mean age  $77.26 \pm 4.57$  years; 23 females, 15 males) or decrease muscle activation group (mean age  $77.43 \pm 3.63$  years; 11 females, 3 males) depending on whether the suprahyoid muscle activation increased or decreased during 2/3rd THS compared to normal swallowing. Figure 3 shows the changes in suprahyoid muscle activation of these groups in three swallowing conditions. The increase group showed significantly higher muscle activation than normal swallowing in 1/3rd THS and 2/3rd THS. Additionally, the group also showed significantly higher muscle activation in 2/3rd THS than in 1/3rd THS. However, the decrease group showed significantly lower muscle activation than normal swallowing in 2/3rd THS.

In the increase group, the Effortful–Normal ratio and 2/3rd THS versus 1/3rd THS ratio [(suprahyoid muscle activation in 2/3rd THS/suprahyoid muscle activation in 1/3rd THS)  $\times 100$ ] was significantly higher than that in the decrease group ( $p < 0.05$ ). The estimated values of tongue tip pressure, tongue base pressure, and tongue tip endurance were higher in the increase group than those in the decrease group; however, the significance level suggests that the values may not be different (Table 4).

## Discussion

This study is the first to identify changes in the activity of the suprahyoid muscles in elderly adults during THS according to the relative tongue protrusion length. In this study, 52 healthy people aged 69–92 years were assessed to determine the effective tongue protrusion length during THS. The mean MTPL length was  $23.40 \pm 6.50$  mm (range 6–36), which is different from that reported in young adults (range 23–48 mm) [9, 11].

**Table 3** Comparison between the increase and the decrease groups (classification criteria: suprahyoid muscle activation during 1/3rd THS in contrast to normal swallowing)

	Increase group (n = 36)	Decrease group (n = 16)	p value
Effortful-normal ratio <sup>a</sup>	5.07 ± 0.25	4.90 ± 0.21	0.027 <sup>b</sup>
2/3 THS-1/3 THS ratio <sup>a</sup>	4.63 ± 0.22	4.70 ± 0.25	0.315
Tongue tip pressure (kPa)	41.56 ± 15.04	34.63 ± 14.87	0.130
Tongue base pressure (kPa)	39.56 ± 14.03	37.56 ± 15.09	0.646
Tongue endurance (s) <sup>a</sup>	2.11 ± 1.21	2.03 ± 1.14	0.842
Tongue length (mm)	24.10 ± 6.10	21.90 ± 7.30	0.282
Age (years)	76.92 ± 4.42	78.19 ± 4.04	0.331

Effortful-Normal ratio: (suprahyoid muscle activation in effortful swallow/suprahyoid muscle activation in normal swallow) × 100

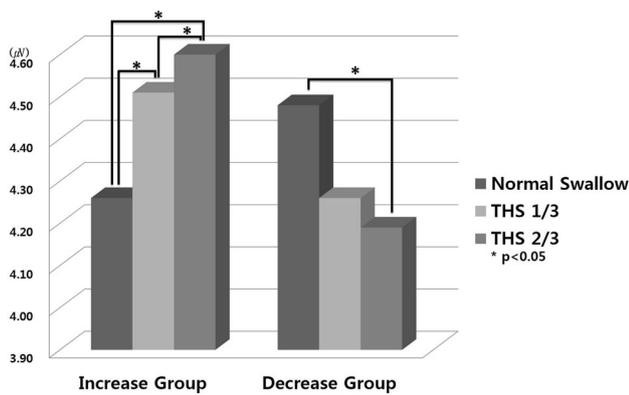
2/3 THS-1/3 THS ratio: (suprahyoid muscle activation in 2/3 THS/suprahyoid muscle activation in 1/3 THS) × 100

Increase group: suprahyoid muscle activation was greater in 1/3 THS compared to normal swallow

Decrease group: suprahyoid muscle activation was less in 1/3 THS compared to normal swallow

<sup>a</sup>Log-transformed variable

<sup>b</sup>Significant difference between two groups (p < 0.05)



**Fig. 3** Comparison between the increase and the decrease groups in suprahyoid muscle activation (classification criteria: 2/3rd tongue-hold swallow [THS] in contrast to normal swallowing)

**Table 4** Comparison between increase and decrease group (classification criteria: suprahyoid muscle activation during 2/3rd THS in contrast to normal swallowing)

	Increase group (n = 38)	Decrease group (n = 14)	p value
Effortful-normal ratio <sup>a</sup>	5.07 ± 0.25	4.86 ± 0.17	0.006 <sup>b</sup>
2/3 THS-1/3 THS ratio <sup>a</sup>	4.70 ± 0.20	4.53 ± 0.26	0.018 <sup>b</sup>
Tongue tip pressure (kPa)	39.79 ± 15.44	38.43 ± 14.99	0.778
Tongue base pressure (kPa)	39.11 ± 14.52	38.50 ± 13.98	0.893
Tongue endurance (s) <sup>a</sup>	2.17 ± 1.17	1.83 ± 1.22	0.377
Tongue length (mm)	23.20 ± 6.30	23.90 ± 7.40	0.728
Age (years)	77.26 ± 4.57	77.43 ± 3.63	0.904

Effortful-Normal ratio: (suprahyoid muscle activation in effortful swallow/suprahyoid muscle activation in normal swallow) × 100

2/3 THS-1/3 THS ratio: (suprahyoid muscle activation in 2/3 THS/suprahyoid muscle activation in 1/3 THS) × 100

Increase group: suprahyoid muscle activation was greater in 1/3 THS compared to normal swallow

Decrease group: suprahyoid muscle activation was less in 1/3 THS compared to normal swallow

<sup>a</sup>Log transformed variable

<sup>b</sup>Significant difference between two groups (p < 0.05)

In this study, we used submental sEMG to estimate variations in resistance to the pharyngeal constrictors at relative tongue protrusion lengths. In the pharyngeal stage of swallowing, the hyoid bone and larynx elevate in the anterosuperior direction, the epiglottis inverts and blocks the laryngeal entrance, and the tongue base and posterior pharyngeal wall make contact with each other, creating pressure to push the bolus down the pharynx [18]. The origin of the middle pharyngeal constrictor includes the superior surface of the greater horn of the hyoid bone, the lesser horn, and the lower part of the stylohyoid ligament. Additionally, the middle pharyngeal constrictor also receives fibers from the back of the tongue and the mylohyoid line of the mandible [19]. Thus, the movements of the hyoid bone and tongue and contraction of the

pharyngeal constrictors are closely related in swallowing, and the protrusion of the tongue during swallowing has a close relationship with the movement of the hyoid bone and contraction of the pharyngeal constrictors. The suprahyoid muscle activation as measured by sEMG was correlated with the movement of the hyoid bone, pharyngeal contraction, and opening and closing of the upper esophageal sphincter as confirmed by VFS, and suprahyoid muscle activation was found to precede these events [20, 21]. Increase in the degree of suprahyoid muscle activation during THS implies that greater force is needed to bring the tongue base and pharyngeal wall into contact in order to lower the bolus into the pharynx. This greater resistance when trying to swallow with a protruded tongue is the basis of applying THS as a strengthening exercise [12].

Burkhead et al. [5] stated that as with Mendelsohn maneuver and effortful swallowing, it is difficult to increase the progressive physiologic load in the training program due to the nature of the THS exercise. However, the present study indirectly confirmed that resistance was increased based on tongue protrusion lengths during THS by observing changes in activity of the suprahyoid muscles. This was also confirmed in previous studies that assessed changes in tongue protrusion lengths during THS [9–12]. Therefore, THS could be applied as a progressive strengthening exercise by controlling tongue protrusion length.

However, not all participants demonstrated similar patterns. This study referred to the method of analysis used by Fujiwara et al. [12]; we confirmed the characteristics of those who demonstrated differences from the whole cohort. Thus, the participants were divided into increase and decrease groups. In this study, the ‘Effortful–Normal ratio’ was generated using the variables ‘suprahyoid muscle activation during normal swallowing’ and ‘suprahyoid muscle activation during effortful swallowing’. This ratio is similar to the concept of ‘functional reserve’ [5], which is the term used to describe the difference in the maximal strengths of the muscles compared with the strengths used in normal swallowing tasks [22]. Functional reserve is known to gradually decrease with age [23]. In this study, we analyzed the increase group and the decrease group using two different criteria (1/3rd THS vs. normal swallowing; 2/3rd THS vs. normal swallowing). In both cases, a common finding was that the functional reserves (Effortful–Normal ratio) were significantly higher in the increase groups compared with the decrease groups ( $p < 0.05$ ) (Table 4). Furthermore, the 2/3rd THS–1/3rd THS ratio in the increase group was significantly higher than that in the decrease group ( $p < 0.05$ ) (Table 4). In the increase group, the muscle activity increased with the increasing tongue protrusion, while in the decrease group, the suprahyoid

muscle activity decreased with the increasing tongue protrusion (Fig. 3).

A study that used manometry reported that pressure in the pharynx during THS did not change significantly when compared with normal swallowing in healthy adults. THS would have caused the posterior pharyngeal wall to contract more than usual and induce an offset effect in order to overcome the resistance due to the limited movement of the tongue during swallowing [24]. In another study, both young and elderly adults were found to have significantly lower oropharynx and hypopharynx pressures in THS than that during normal swallowing [25]. Unlike the participants in the former study, the subjects in the latter study seem to have failed to produce the pressure between the tongue base and pharyngeal constrictor that they had demonstrated in normal swallowing by overcoming the resistance induced by tongue holding. Those two studies performed under similar conditions using similar measuring equipment showed different results. This may be because the positions of the sensors in manometry may demonstrate large variation during THS [6] and the individual characteristics of the subjects participating in each study might be different. These conflicting results may also be related to the two types of responses (increase group, decrease group) presented by the subjects in this study.

In this study, activation of suprahyoid muscle was measured using sEMG to identify physiological changes in THS in the elderly population. The sEMG measured from the suprahyoid muscle does not directly confirm activation change of the pharyngeal constrictor, which is the main target of THS exercise. However, previous studies have shown a correlation between suprahyoid muscle activation and pharyngeal constrictor contraction during swallowing [20, 21]. Hammer et al. found that suprahyoid muscle activation measured by sEMG and pharyngeal constrictor activation measured by needle EMG were significantly higher during THS than those in normal swallowing without performing THS [10]. Suprahyoid muscles would exhibit higher activity along with pharyngeal constrictor muscles in swallowing situations that require more force than usual, such as in effortful swallowing and viscous food. The needle EMG is the method used to directly measure activation of the pharyngeal constrictor muscle. However, this is an invasive method, which can cause considerable inconvenience to the subject. Thus, this study used sEMG, which is commonly used in exploratory research [26, 27], to identify the feasibility and physiological changes of relative THS in the elderly population.

To improve muscle strength, a significantly greater amount of resistance than the load applied in routine activities should be applied [5]. Elderly individuals with a high functional reserve might gain gradual strengthening of the muscles by adjusting the tongue protrusion length

during THS exercise. On the other hand, elderly persons with a low functional reserve would not be able to overcome the resistance and may even exhibit decreased muscle activity during THS than that in normal swallowing; thus, the benefit of the resistance exercise would not be as high as those with a high functional reserve (increase group). In these cases, it would be better to protrude the tongue only to the extent where they can overcome it. As the muscle strength increases due to the effect of a strengthening exercise, the tongue protrusion lengths can be adjusted gradually. The desired effect could be achieved through other exercises. This might be equally applicable to patients with dysphagia. If THS is not feasible due to low functional reserve, clinicians may choose to try THS after strengthening swallowing-related muscles using another exercise, such as effortful swallowing. Doeltgen et al. [6] suggested that although some individuals could not produce a sufficient compensatory movement of the posterior pharyngeal wall during THS, repetitions of THS exercises may enhance muscle strength to consequently overcome the initial reduced pressure [6]. However, to apply THS as a progressive strengthening exercise more efficiently and safely, it would be necessary to first check whether the subject can overcome the resistance. This can be confirmed indirectly by determining whether THS can result in greater suprahyoid muscle activity in comparison with normal swallowing.

This study has several limitations. First, this study was conducted in healthy elderly people over 65 years old who voluntarily participated. In general, THS would be applied in patients with dysphagia with weakness of the pharyngeal constrictors. Therefore, further studies are needed with such patients prior to large-scale applications in clinical practice. Second, in this study, the activation of the pharyngeal constrictor, the main target muscle of THS exercise, was not directly examined by nature of the equipment used. Due to this limitation, we could not obtain a definitive conclusion about the activity of the pharyngeal constrictor muscle during THS. It was only possible to assume that the activation of the pharyngeal constrictor occurred due to activation of the suprahyoid muscle, as both are activated together during swallowing. In subsequent studies, simultaneous measurement of suprahyoid muscle activation and pharyngeal contraction will provide more information on the physiology of swallowing during THS.

## Conclusions

This study was the first to identify changes in the activity of the suprahyoid muscles in an elderly population during THS according to relative tongue protrusion length. Many elderly people showed an increased activation of the

suprahyoid muscles during THS, while others showed the opposite. Therefore, it is necessary to perform the exercise at a tongue protrusion length that can maximize the effect of the exercise by confirming the degree of suprahyoid muscle activation of each subject during THS. For those who cannot overcome even a small amount of tongue protrusion (e.g., 1/3rd MTPL), another exercise that can replace THS may be considered.

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## Compliance with Ethical Standards

**Conflict of interest** The authors declare that there are no competing interests.

**Ethical Approval** All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committees and the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All the participants provided informed consents to participate in this study.

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