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Effect of the head extension swallowing exercise on suprahyoid muscle activity in elderly individuals

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ABSTRACT

Aging causes motor function deterioration in the elderly population, which in turn can cause weakness in the muscles associated with swallowing. Swallowing-related problems in elderly individuals can be prevented or their symptoms can be improved with strengthening exercises for the muscles involved in swallowing. The existing strengthening exercises for the suprahyoid muscle have their limitations. Therefore, it is necessary to find another exercise that can be performed by individuals whose personal characteristics make it difficult for them to perform the existing exercises. In this study, we investigated the changes in suprahyoid muscle activation, tongue strength, and thickness of the suprahyoid muscle after 8 weeks of the head extension swallowing exercise (HESE). A total of 23 healthy elderly individuals participated in an 8-week exercise program (20 min/session, 2 times/week for 8 weeks). Suprahyoid muscle activation during effortful swallowing and the effortful-normal ratio were significantly increased at 8 weeks compared to the baseline values (p = 0.002, and 0.033, respectively). Tongue tip pressure, tongue base pressure, normal swallowing pressure, effortful swallowing pressure, and tongue tip endurance were significantly increased at 8 weeks compared with baseline (p = 0.014, 0.004, 0.046, 0.009, and 0.004, respectively). The thickness of the digastric muscle and that of the mylohyoid muscle were significantly increased at 8 weeks compared with baseline (p = 0.000 and 0.004, respectively). This study showed that HESE can be a good option for improving the suprahyoid muscle and tongue strength in the elderly population. Additionally, this exercise does not require any additional equipment and has the advantage of being able to be performed anytime and anywhere. A variety of exercise options tailored according to individual characteristics may be helpful in choosing the most appropriate exercise.

1. Introduction

Aging causes deterioration of sensation and the motor swallowing mechanism in elderly individuals (Aslam and Vaezi, 2013). Deterioration of motor function cause weakness in the muscles associated with swallowing. In turn, muscle weakness associated with swallowing can lead to decreased hyoid movement (Logemann et al., 2000), decreased isometric tongue pressure (Robbins et al., 1995), reduced pharyngeal contraction (Tracy et al., 1989), and decreased diameter of the upper esophageal sphincter opening (Shaw et al., 1995). These changes related to aging can affect the efficiency of swallowing, leading to different complications, such as dysphagia and aspiration pneumonia (Di Pede et al., 2016).

These problems caused by aging can be prevented or their symptoms can be improved with strengthening exercises for the muscles involved in swallowing. Robbins et al. (2005) found that the tongue isometric pressure, the pressure of the tongue during swallowing, and the volume of the tongue were significantly increased by tongue strengthening exercise for 8 weeks in healthy elderly subjects. Kraaijenga et al. (2015) showed that suprahyoid muscle mass and tongue strength were significantly increased compared with the pre-exercise levels by applying 3 types of strengthening exercise (jaw opening against resistance, chin tuck against resistance, and effortful swallowing) for 6 weeks in healthy elderly individuals.

Decreased extent of hyoid movement is one of the aging-related phenomena observed in normal elderly people (Logemann et al., 2000). Hyolaryngeal excursion is mainly caused by contraction of the suprahyoid muscles (mylohyoid, geniohyoid, digastric, and stylohyoid muscles) (Pearson et al., 2013; Pearson et al., 2012), and can be improved with the Shaker exercise, Mendelsohn maneuver, jaw opening exercise, and chin tuck against resistance exercise (Kraaijenga et al., 2015; Antunes and Lunet, 2012; McCullough and Kim, 2013; Park et al., 2018). These exercises have limitations, such as the indications of each exercise and the need for special equipment, making them difficult to apply in all elderly individuals (Yoon et al., 2014; Oh, 2016). The Shaker exercise is the most commonly used method for strengthening

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the suprahyoid muscle, and its effect has been verified in various studies. However, this exercise is difficult to perform for an individual with difficulty in postural control because the exercise is performed while lying down. In addition, the action of lying down then lifting the head itself requires considerable effort, resulting in a high dropout rate and an excessive burden on the sternocleidomastoid and abdominal muscles (Park et al., 2018). The Mendelsohn maneuver is a method of deliberately increasing the duration of hyolaryngeal elevation during swallowing, and it is usually applied in patients with limitation in upper esophageal sphincter opening. However, in a study conducted on normal subjects, some subjects did not maintain the motion required by the exercise (Wheeler-Hegland et al., 2008). Moreover, in a study of patients with dysphagia due to stroke, some subjects complained of dizziness during the exercise and stopped the exercise (Bogaardt et al., 2009). To perform the chin tuck versus resistance and jaw opening exercises, a special tool is needed to provide resistance during the performance of the exercise (Kraaijenga et al., 2015). Therefore, it is necessary to find another exercise that can be performed by individuals whose personal characteristics make it difficult for them to perform the existing exercise.

The head extension swallowing exercise (HESE) is an exercise for strengthening the suprahyoid muscles. Subjects sit in an erect posture, look at the ceiling with their head extended, and swallow a small amount of saliva. A previous study reported that the HESE significantly improved the suprahyoid muscle activation and the tongue strength of healthy adults compared with before exercise (Oh, 2016). Originally, head extension swallowing is a compensatory method that is applied in patients with head and neck cancer who generally have problems with the oral transfer of food because of tongue resection or the effects of radiation/chemotherapy (Pauloski, 2008). However, Oh (2016) used the idea of reinforcing the suprahyoid muscle by using this posture to apply resistance, based on the report by Sakuma and Kida, who demonstrated that suprahyoid muscle activation increased significantly when the subjects attempted to swallow with the head extended (Sakuma and Kida, 2010).

Previous study has confirmed the effect of strengthening the suprahyoid muscle and tongue muscles; however, this study was conducted in young healthy adults and that result is difficult to apply to the elderly population. Therefore, in the present study, we investigated the changes in the suprahyoid muscle activation, tongue strength, and thickness of the suprahyoid muscle after 8 weeks of HESE. We hypothesized that the suprahyoid muscle activation, thickness of suprahyoid muscle, and tongue strength would increase as a result of 8 weeks of muscle strengthening exercise.

2. Materials and methods

2.1. Participants

This study included 23 volunteers (mean age, 76.22 ± 4.64 years; range, 66–83 years) without a reported history of speech or swallowing deficits and who could perform the HESE (Table 1). A total of 25 participants were initially recruited; however 2 were excluded from the analysis because they could not attend the final measurement (week 8): 1 subject (female, 74 years) was lost to the final measurement and another subject (female, 70 years) dropped out because of a long overseas trip. Therefore, 23 of 25 participants completed the exercise program. No participant reported drug use that could affect swallowing or neurological function, or having engaged in any type of swallowing-related strength training program for at least 1 year before this study. Before the start of the study, all participants received a complete explanation of the purpose, risks, and procedures, and provided written informed consent. The procedures were in accordance with the ethical standards of the committee on human experimentation at the institution at which the work was conducted. This study was approved by our Institutional Review Board.

Table 1
Demographic characteristics of the participants.

		Number (n)	Percent (%)
Sex	Male	6	26.1
	Female	17	73.9
Age group (years)	65–69	1	4.4
	70–74	7	30.4
	75–79	10	43.5
	80–84	5	21.7

2.2. Experimental procedures

This study was carried out in the following order:

1. Baseline measurement (muscle activation of the suprahyoid muscle during normal and effortful swallowing measured using surface electromyography [sEMG], isometric/swallowing tongue pressure and tongue endurance determined using a tongue pressure measurement system, and muscle thickness of the suprahyoid muscles evaluated using ultrasound);
2. Eight-week exercise program (20 min/session, 2 times/week for a total of 8 weeks);
3. Re-evaluation after 8 weeks (sEMG, tongue pressure, muscle thickness).

Measurements at baseline and at 8 weeks were conducted in the same place, at the same time, and by the same examiner.

2.2.1. Electrophysiological evaluation

Before the measurements, the skin under the chin was wiped with alcohol cotton and dried for 30 s. During the examination, the subjects sat on a chair with armrests and a backrest, maintaining a neutral upright posture. sEMG data were collected using Noraxon TeleMyo-DTS (Noraxon, Inc., Scottsdale, AZ, USA) and analyzed using Noraxon MyoResearch 1.07 XP software (Noraxon Inc.). The sEMG signals were amplified, band-pass filtered (10 and 500 Hz), and notch filtered (60 Hz) before being digitally recorded at 1000 Hz and processed into the root mean square. For recording the activity of the suprahyoid muscle complex (mylohyoid, geniohyoid, and anterior digastric muscles), wireless sEMG electrodes were placed at a distance of 1 cm on the skin on both sides of the midline under the chin (Beckmann et al., 2015). The isometric reference voluntary contraction (RVC) was used to normalize the EMG data. RVCs were used instead of maximum voluntary contraction to decrease the risk of injury. To measure the RVC, the subjects were required to lift their head and look at their feet for 5 s from the supine position. The suprahyoid muscle activity during the first and last seconds was excluded from the measurement of RVC. Therefore, data of the middle 3 s of the 5 s contraction were used for analysis (Hiramatsu et al., 2015). 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 then repeated 3 times, with a 120-s rest period between the trials. During normal swallowing, the participants were given 10 mL water in the mouth by using a syringe and instructed to swallow comfortably. During effortful swallowing, the participants were given 10 mL water in the mouth by using a syringe and instructed as follows: “As you swallow, push really hard with your tongue” (Huckabee and Steele, 2006). The order of measurements was the same for all participants and during all measurements (baseline and 8 weeks). The onset and offset signals representing the effort applied by the participant for each task were identified, and the signals in-between the onset and offset signals were analyzed to obtain the peak values (peak amplitude) for each participant. For each task, the mean values of the 3 trials were used to analyze the peak value. For each subject, the mean value of the sEMG

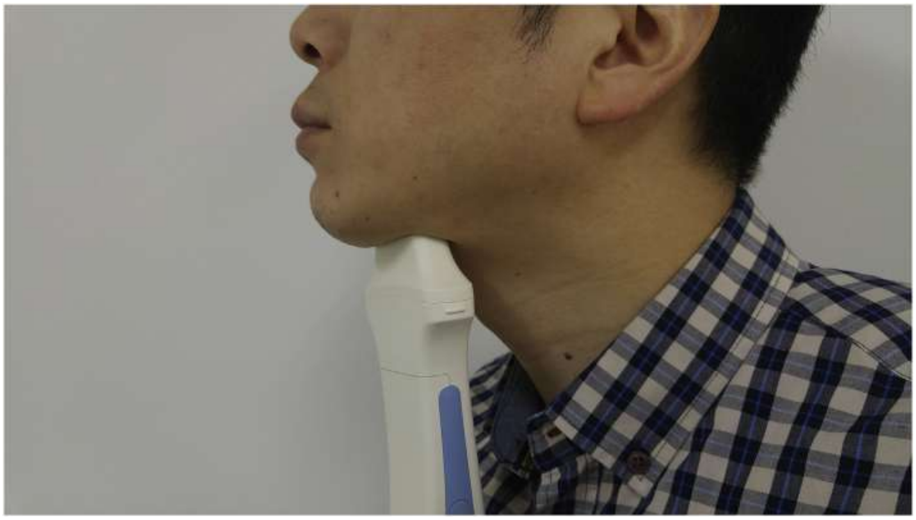

Fig. 1. Ultrasound transducer placement for the suprahyoid muscles.
Transducer and system settings: 10 MHz, depth 4 cm.

signals was expressed as a percentage of the RVC (%RVC) (Hiramatsu et al., 2015).

2.2.2. Tongue pressure measurements

Tongue pressure measurements were performed using the Iowa Oral Performance Instrument (IOPI Pro system 2.3; IOPI Medical, Redmond, WA, USA). The tongue pressure-related parameters, except tongue endurance, were measured 3 times, and the highest value (kPa) was used for the analysis (Robin et al., 1992).

2.2.2.1. Tongue tip pressure. Anterior lingual elevation strength was assessed with the tongue bulb positioned longitudinally 10 mm posterior to the tongue tip (Robbins et al., 2007). After placing the bulb in the correct position, the connecting tube was painted with permanent marker to the point where it met the front teeth to place the bulb in the same position at every measurement. The participants were instructed to push the tongue up against the bulb with maximum effort.

2.2.2.2. Tongue base pressure. Posterior lingual elevation strength was assessed with the tongue bulb positioned 10 mm anterior to the most posterior circumvallate papilla (Robbins et al., 2007). The participants were instructed to push the tongue up against the bulb with maximum effort.

2.2.2.3. Normal swallowing tongue pressure. Maximum tongue pressure during normal swallowing was assessed with the tongue bulb positioned 10 mm anterior to the most posterior circumvallate papilla. The participants were given 3 mL water in the mouth by using a syringe and instructed to swallow comfortably.

2.2.2.4. Effortful swallowing tongue pressure. Maximum tongue pressure during effortful swallowing was assessed with the tongue bulb positioned 10 mm anterior to the most posterior circumvallate papilla. The participants were given 3 mL water in their mouth using a syringe and instructed to squeeze all their mouth and throat muscles as hard as possible and then swallow.

2.2.2.5. Tongue tip endurance. After measuring the tongue strength, the bulb was placed at the measurement location of the tongue tip pressure to measure the endurance. In the tongue base pressure measurement position, the bulb slid on the tongue when the bulb was pressed for a long time because of the 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 pre-measured maximum tongue tip strength. The participants were required to maintain the target value for as long as possible. Time measurement began when the subjects' tongue pressure reached the target value. When the target value was reached, the green light at the top of the built-in LED of the device turned on. The participants were able to monitor their performance through the LED window throughout the endurance measurements. Endurance was measured only once (Adams et al., 2015). In this study, the changes in endurance before (baseline) and after exercise (8 weeks) were measured using absolute endurance according to Clark's recommendation (Clark, 2012). Therefore, the endurance at the absolute force level used at baseline was measured at 8 weeks.

The order of measurements was the same for all participants. The tongue tip strength was measured first; the tongue base strength was assessed next; and then the normal swallowing pressure, effortful swallowing pressure, and finally the endurance of the tongue were measured. Rest periods of 2 min were provided between measurements to avoid fatigue.

2.2.3. Ultrasonographic measurements

All measurements were performed using a wireless linear 10 MHz transducer on a SONON 300 L ultrasound system (Healcerion, Seoul, Korea). During the examination, the participants were instructed to sit on a chair and hold their trunk in a neutral upright position. Sufficient amounts of conductive gel were applied to the transducer, which was then positioned submentally with passive contact in the frontal plane (Fig. 1). Correct transducer placement was determined by the presence of both left and right anterior bellies of the digastric, mylohyoid, and geniohyoid muscles on the ultrasound system screen. The participants were instructed to remain as relaxed as possible and to limit extraneous movements of the head and neck while 3 still images of the submental muscles were captured (Van Den et al., 2012). The mean values of the 3 still images were used to analyze the thickness of each muscle.

2.2.3.1. Measurement of suprahyoid muscle thickness. Muscle thickness was measured with the built-in electronic calipers of the ultrasound equipment. The digastric muscle (left) was measured using the upper and lower borders of the fascia at the most prominent point perpendicular to the mylohyoid muscle. The mylohyoid muscle (left) was measured below the extension of the digastric measurement point (Fig. 2) (Van Den et al., 2012).

All data were analyzed by a single expert trained in both swallowing

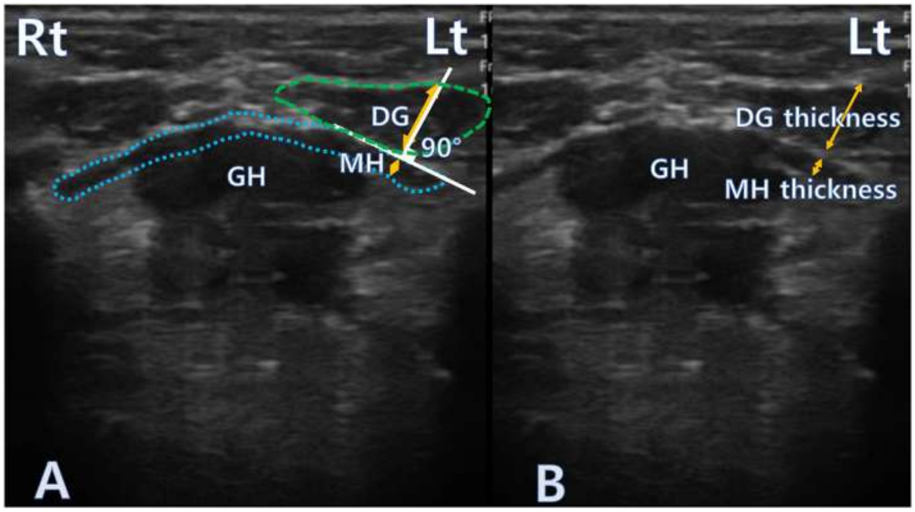

Fig. 2. Thickness measurements of the suprahyoid muscles.
A: measurement procedure; B: thickness measurement.
DG: anterior belly of digastric muscle, MH: mylohyoid muscle, GH: geniohyoid muscle, Rt: right, Lt: left.

therapy and sEMG and ultrasonographic evaluation of swallowing. For blinding of the analyzer during analysis of the outcome measurements, data from every assessment session was represented by a digit-code.

2.3. Training protocol

The 8-week training protocol was conducted twice a week at the same time in the same location and each session lasted 20 min. During training, the participants sat on an upright chair. Every 20 s, the electronic timer rang a bell. At the sound of the bell, all participants extended their head maximally back, and while looking at the ceiling, swallowed their saliva comfortably. If a participant was unable to swallow because of inadequate saliva production, the participant was permitted to take a sip of water to aid swallowing in the assigned position. Each time after ringing the bell, the author and research assistants checked whether all the participants had performed the exercise appropriately. The participants continued to exercise for 10 min continuously, and to avoid fatigue, took a 2-min rest before continuing to exercise for another 10 min (Oh, 2016). Therefore, the total exercise time was 22 min and the total number of HESE was 60 times. All training sessions were completed as in-person sessions and not performed independently at home.

2.4. Statistical analysis

All data were analyzed with SPSS (version 23.0) for Windows (SPSS Inc., Chicago, IL, USA). sEMG, ultrasonographic, and tongue endurance data were logarithmically transformed to normalize the data distribution. For tongue pressure measurements (tongue tip pressure, tongue base pressure, normal swallowing pressure, and effortful swallowing pressure), raw data were used in the analysis. Data are reported as means ± standard deviation. Descriptive statistics and tests for normality (Shapiro-Wilks test) were performed for all outcome variables. All variables were found to be normally distributed, and paired *t*-test was performed for the comparison between baseline and post-exercise measurements at 8 weeks. The significance level was set at $p < 0.05$.

3. Results

3.1. Submental muscle activation

Table 2 presents the changes in sEMG peak amplitudes (logarithmically transformed %RVC) during normal swallowing, and effortful swallowing and the effortful-normal ratio ([suprahyoid muscle activation in effortful swallow / suprahyoid muscle activation in normal swallow] × 100) during 8 weeks. Suprahyoid muscle activation during effortful swallowing and the effortful-normal ratio were significantly increased at 8 weeks compared with baseline ($p = 0.002$ and 0.033, respectively).

Table 2
Training effects of HESE on suprahyoid muscle activation (logarithmically transformed % RVC) during swallowing.

	Baseline	8 week	t	*p*-Value	Cohen's d
	Mean ± SD	Mean ± SD			
Normal swallow	5.18 ± 0.49	5.21 ± 0.52	0.571	0.574	0.05
Effortful swallow	5.76 ± 0.50	5.91 ± 0.52	3.552	0.002**	0.29
Effortful-normal ratio	5.18 ± 0.30	5.31 ± 0.37	2.276	0.033*	0.39

HESE: head extension swallowing exercise, RVC: reference isometric voluntary contraction, SD: standard deviation.
* $p < 0.05$.
** $p < 0.01$.

3.2. Lingual strength

Table 3 presents the changes in isometric tongue pressure at the tongue tip and base, normal swallowing pressure, effortful swallowing pressure, and tongue tip endurance. Tongue tip pressure, tongue base pressure, normal swallowing pressure, effortful swallowing pressure, and tongue tip endurance were significantly increased at 8 weeks compared with baseline ($p = 0.014$, 0.004, 0.046, 0.009, and 0.004, respectively).

3.3. Suprahyoid muscle thickness

Table 4 presents the changes in muscle thickness of suprahyoid muscles. The thickness of the digastric and mylohyoid muscles were significantly increased at 8 weeks compared with baseline ($p = 0.000$ and 0.004, respectively).

4. Discussion

In this study, we applied HESE for 8 weeks in healthy elderly

Table 3
Training effects of HESE on tongue pressures.

	Baseline	8 week	t	*p*-Value	Cohen's d
	Mean ± SD	Mean ± SD			
Tongue tip pressure (kPa)	39.91 ± 12.24	45.43 ± 13.03	2.660	0.014*	0.44
Tongue base pressure (kPa)	39.17 ± 11.65	43.78 ± 12.39	3.237	0.004**	0.38
Normal swallowing pressure (kPa)	20.00 ± 7.89	25.83 ± 12.97	2.120	0.046*	0.54
Effortful swallowing pressure (kPa)	37.04 ± 10.88	41.52 ± 13.28	2.856	0.009**	0.37
Tongue tip endurance (s)[a]	2.30 ± 1.05	3.02 ± 1.12	3.244	0.004**	0.66

HESE: head extension swallowing exercise, SD: standard deviation.
[a] Log transformed variable.
* $p < 0.05$.
** $p < 0.01$.

Table 4
Training effects of HESE on suprahyoid muscle thickness.

	Baseline	8 week	t	*p*-Value	Cohen's d
	Mean ± SD	Mean ± SD			
Digastric muscle thickness (mm)	5.69 ± 0.94	6.37 ± 1.15	4.42	0.000**	0.65
Mylohyoid muscle thickness (mm)[a]	0.63 ± 0.23	0.86 ± 0.36	3.25	0.004**	0.76

HESE: head extension swallowing exercise, SD: standard deviation.
[a] Log transformed variable.
** $p < 0.01$.

individuals. We modified some previous protocols for healthy adults (head extension and swallowing once every 10 s) (Oh, 2016); therefore, the participants performed the HESE every 20 s considering the physical strength and endurance of the elderly population. As a result of the exercise, the suprahyoid muscle activation, tongue pressure, and suprahyoid muscle thickness of the participants were significantly improved compared with the pre-exercise values.

The increase in suprahyoid muscle activation identified in this study reflects increased motor unit activation in the peripheral nervous system. This indicates that the discharge rate of the motor units was increased or the number of the recruited motor units was increased (Wheeler et al., 2007). In the head extension posture, attempts to swallow increase the gravitational effects on the structures involved in swallowing, and the movement distance of these structures also increases, thus providing resistance (Oh, 2016). Because of this resistance, the elderly subjects who participated in this study were able to obtain muscle strengthening effects associated with swallowing. Generally, a greater amount of resistance must be applied than is used in routine activities to cause an improvement in muscle strength (Burkhead et al., 2007). Therefore, the HESE performed in this study seems to have been able to provide enough resistance throughout the exercise period to induce muscle strength without additional tools or resistance. In this study, the effortful-normal ratio was calculated as the concept of functional reserve (Burkhead et al., 2007). This was calculated using the suprahyoid muscle activation during normal and effortful swallowing and was used to show that 8 weeks of exercise can improve the functional reserve, which is known to gradually decrease as a result of aging (Yeates et al., 2010). Increased functional reserve through this exercise may help elderly individuals maintain safe swallowing for a longer time. In the case of increased tongue pressure, the suprahyoid muscles are known to partially contribute to the tongue pressure generation (Huckabee and Steele, 2006; Yoshida et al., 2007). In addition, when the head is extended, effortful swallowing will naturally try to overcome the resistance. The pressure of the tongue is known to increase significantly during effortful swallowing (Fukuoka et al., 2013), and the tongue muscle strength seems to have improved naturally during the exercise for 8 weeks in this study.

In addition to the improvements of the suprahyoid muscle activation and tongue strength as in a previous study on healthy adults (Oh, 2016), hypertrophy of the suprahyoid muscle was identified in this study. Muscle hypertrophy through strengthening exercise usually occurs when the exercise is continued for > 6–7 weeks (Kraemer et al., 2002). The increase in the suprahyoid muscle thickness of the elderly participants confirmed with ultrasonography in this study indicated that the HESE provided sufficient resistance to cause hypertrophy of the suprahyoid muscles of the participants.

In this study, the change in the tongue endurance before and after exercise was confirmed by the endurance at the absolute force level according to Clark's recommendation (Clark, 2012). In general, the effect of strength training on swallowing-related muscles tends not to directly improve endurance. This is because, in general tongue endurance measurements, the endurance measurement is based on the new muscle strength, which is increased by the effect of the exercise, resulting in a higher target value than the baseline (Clark, 2012). In this study, the target value applied at baseline was also applied after 8 weeks. Therefore, the tongue endurance at the absolute force level as well as the isometric/swallowing pressure of the tongue were significantly increased as a result of the 8-week strengthening exercise of the suprahyoid muscle. This suggests that endurance can be improved together with strength after applying prolonged muscle strengthening exercises to swallowing-related muscles.

This study showed that the HESE can be a good option for strengthening the suprahyoid muscle and tongue strength of the elderly population. Additionally, it has the advantage of not needing additional equipment, allowing this exercise to be performed anytime and anywhere. A variety of exercise options tailored according to individual characteristics may be helpful in choosing the proper exercise.

Several aspects should be considered when performing this exercise. Although it is a compensatory swallowing method applied in patients with head and neck cancer who have difficulty in oral transfer, this posture is recommended for those with complete pharyngeal and laryngeal functions because of the safety problem related to the possibility of airway aspiration during swallowing (Calvo et al., 2017). During this study, some elderly participants were coughing while a large amount of water was present in their mouths in order to facilitate swallowing while their head was extended. If the airway protection mechanism (e.g., cough reflex) is not intact, this situation can increase the risk of airway aspiration. Therefore, this exercise should be attempted in individuals with sufficient airway protection, and as with the participants in this study, when performing this exercise, the participants should try to swallow a small amount of saliva or a small amount of water if it is not feasible.

4.1. Limitations

Several limitations of this study need to be acknowledged. First, in this study, sEMG, tongue pressure measurements and ultrasonography were used to confirm the strengthening effect of the HESE. Although these devices can be used to identify the effect of muscle strength gain, they cannot directly identify the change in the movement of the anatomical structures involved in swallowing. Therefore, in future studies, it is necessary to follow the process of confirming the movement change of these structures by using a videofluoroscopic swallowing study. Second, this study was conducted on a healthy elderly population with no problems with swallowing. Therefore, this exercise would be difficult to apply to patients with dysphagia. Future studies should be conducted to validate the effect of this exercise in patients with dysphagia who present with decreased hyolaryngeal elevation. Finally, the sample size of this preliminary study was limited to 23 motivated healthy elderly subjects; therefore, the results should be interpreted with some caution.

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