Oral motion classification of the elderly for prevention and rehabilitation of dysphagia

Makoto SASAKI*, Shumpei ITO*, Katsuhiro KAMATA*, Masahiro YOSHIKAWA**,
Isamu SHIBAMOTO*** and Atsushi NAKAYAMA****

*Graduate School of Engineering, Iwate University
4-3-5 Ueda, Morioka, Iwate 020-8551, Japan
E-mail: makotosa@iwate-u.ac.jp

**Graduate School and Faculty of Robotics and Design, Osaka Institute of Technology
1-45 Chayamachi, Kita-ku, Osaka 530-8568, Japan

***Department of Speech Language and Hearing Sciences, Seirei Christopher University
3453 Mikatahara-cho, Kita-ku, Hamamatsu, Shizuoka 433-8558, Japan

****Department of Engineering for Future Innovation, National Institute of Technology, Ichinoseki College
Takanashi, Hagisho, Ichinoseki, Iwate 021-8511, Japan

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Abstract

Several people, particularly the elderly population, have difficulties in swallowing; therefore, to address this issue, we built an oral motion classification system based on the muscle activity pattern of the suprahyoid muscles and tested it on 12 elderly people (seven males and five females) without a history of dysphagia and five healthy young men. Surface electromyography (sEMG) signals of the suprahyoid muscles were measured using a 22-channel electrode that was designed as a thin flexible boomerang-shaped patch attached to the underside of the jaw. Six oral motions involving various tongue, jaw opening, and swallowing exercises were classified from the root mean square (RMS) features and cepstrum coefficients (CC) features of sEMG signals using a support vector machine (SVM) classifier. Results showed that the six oral motions for elderly patients were classified with an accuracy of 95.2% and 95.4% for young patients. There was no statistically significant difference in the mean classification accuracy between the two groups. We also found that the six oral motions can be classified with an accuracy of 95.2% regardless of sex, subcutaneous fat thickness on the underside of the jaw, or the level of oral function. Therefore, it appears that the system proposed here can be an effective tool for accurately measuring oral motions and it can be employed to develop an effective game-based training protocol for the elderly whose swallowing capabilities require maintenance and improvement.

Keywords : Electromyography, Oral movement, Motion classification, Dysphagia rehabilitation

1. Introduction

In 2011, pneumonia became the third leading cause of death in Japan (Ministry of Health, Labor and Welfare's (MHLW) summary of vital statistics). Of the 124,452 fatalities from this disease, 96.5% were elderly patients aged ≥ 65 years. About half of these deaths were attributed to aspiration pneumonitis caused by a swallowing disorder (dysphagia). At the time, approximately 30% of elderly people in Japan aged >75 years had dysphagia, and the number of such cases is now estimated to be at least 5 million. In 2006, the leading cause of death due to accidents was suffocation (MHLW's specified report of vital statistics). Approximately half of these deaths were due to the aspiration of food, and in Japan, approximately 5,000 people die from aspiration each year. The "eating" function has a significant role in daily life; however, dysphagia significantly degrades this capability in the elderly people, substantially lowering their quality of life. This issue is becoming more serious in Japan, which is faced with a rapidly aging population. Therefore, it is important to determine if the swallowing function can be accurately measured, maintained, and improved through daily training.

The training method of swallowing function is divided into two approaches: the direct approach using food and the indirect approach without using food (Japan Society of Dysphagia Rehabilitation (JSDR) medical treatment exploratory committee, 2014). The former involves the risk of death from food aspiration or suffocation, whereas the indirect approach can more safely train individuals to improve the neuromuscular controls necessary for the swallow and to strengthen swallowing muscles. As part of the established approach to the indirect approach, there are various exercises such as tongue, jaw opening, swallowing, and head raising exercises. However, this approach involves a monotonous process, and maintaining a patient's motivation to such training has often proven difficult.

In recent years, several training systems using computer games that can operate with oral motion have been studied as a solution to this challenge (Kothari et al., 2014; Pan et al., 2015; Liu et al., 2016). In an earlier preliminary study, the authors proposed a training system that can involve tongue motion in an indirect training (Sasaki et al., 2013, 2014b). The key technology necessary to effectively develop these games is a method for detecting the state of oral motion involving the tongue and jaw. Previous studies have examined tongue interfaces comprising a small permanent magnet attached to the tip of the tongue and a magnetic field sensor to detect its position (Kothari et al., 2014; Huo et al., 2008). In another interface approach, few pairs of light emitting diodes and photodiodes were mounted on an artificial palate to detect the tongue position (Saponas et al., 2009). An interface containing an artificial palate with a force sensor was also proposed to detect the tongue contact force (Ichinose et al., 2003). However, such an intra-oral interface might require several layers of effort for maintaining oral hygiene and may also produce various difficulties related to talking and eating. In contrast, the authors have developed a new interface based on the classification of tongue motions from surface electromyography (sEMG) signals of the suprahyoid muscles detected at the underside of the jaw (Sasaki et al., 2016). This interface has the substantial advantage of not requiring the insertion of a measuring device into the oral cavity. There also happens to be current research on this issue of oral motion detection that involves using the Kinect game device (Pan et al., 2015; Liu et al., 2016). Although the Kinect approach has the advantage of not having to wear a measuring device, it is not possible to detect tongue motions, such as tongue lift movement, that are performed when the mouth is closed. In addition, information on the force necessary for biofeedback training, such as the mechanical load on the tongue during tongue-strengthening exercises, and the muscle activity level of the suprahyoid muscles during tongue, jaw opening, and swallowing exercises cannot be detected. Our interface can detect tongue motion with an accuracy of 95% even with the mouth closed, which the Kinect approach cannot presently accomplish. In addition, because the interface is based on muscle activity of the suprahyoid muscles, it cannot only detect the level of muscle activity but it also has the advantage of predicting the magnitude of tongue contact force (Sasaki et al., 2014a). In contrast, the effectiveness of the oral motion classification method proposed by the authors has, to date, only been investigated and shown to be accurate in connection with young people having healthy oral functions. It has not yet been verified whether oral motion can be classified with the same degree of accuracy for elderly people who may have weakened oral function and are at a risk of developing a swallowing disorder. Furthermore, it has also not yet been clarified how the classification accuracy of oral motion might be influenced by any difference in the oral function of elderly people. Therefore, if oral motions in such elderly people can be classified with high accuracy, the proposed method will be an effective tool for realizing a novel game-based training system for the elderly whose swallowing capabilities require maintenance and improvement.

The purpose of this study was to verify the classification performance of the oral motion classification method for detecting six oral motions (right, left, up, and down tongue motion, jaw motion, and saliva swallowing) in elderly individuals in tongue, jaw opening, and swallowing exercises and to clarify the effect of differences in age, sex, and oral function on the classification accuracy.

2. Methods

2.1 Subjects

Subjects were 12 elderly individuals (aged 62–80 years, average 69.4 years) without any history of dysphagia. Of these, seven were male (66–77 years, average 71.1 years), and five were female (62–80 years, 67.0 years). As comparison subjects, five healthy young men (21–24 years, average 22.2 years) were also examined in this investigation. Approval for tests was obtained in advance by the Ethical Review Board of Iwate University. Before the start of tests, the study objectives, experimental protocol, and risks were explained to each subject, and written consent was received from all participants.

2.2 Measurement of sEMG signals

Our chief focus here was on the suprahyoid muscles involved in various oral motions, such as tongue and jaw motion as well as swallowing. Because these muscles comprise several components, such as the digastric, stylohyoid, mylohyoid, and geniohyoid muscles, it is difficult to observe only the activity of a specific one of these at a time. Therefore, using a 22-channel sEMG measurement system developed by the authors (Sasaki et al., 2016), the muscle activity of the entire suprahyoid muscle group was observed. This electronic system was designed as a thin flexible boomerang-shaped patch to be attached to the underside of the jaw. However, because this electrode was initially designed to fit the lower jaw of the adult male, it was very large for female subjects. Therefore, a new 22-channel electrode was designed to better fit the lower jaw of female subjects (Fig. 1). To help ensure uniformity across all experimental conditions, this redesigned electrode was used for all subjects.

Fig. 1 The 22-channel electrode.

For each experiment, the 22-channel electrode was adhered to the region above the hyoid bone in the anterior triangle of the neck using film dressing (CATHEREEPLUS; Nichiban Co. Ltd.). The anterior triangle of the neck is the region bounded by the anterior median line of the neck, the inferior border of the mandible, and anterior border of the sternocleidomastoid muscle. Further, a ground electrode and an indifferent electrode were connected to the left and right earlobes, respectively, via ear clips. The electric potential between each electrode of the 22-channel device and the indifferent electrode was amplified using a separate differential amplifier with reference to the potential of the ground electrode. The gain of the differential amplifier was set to 2052. A band-pass filter with a passband from 16 to 440 Hz bandwidth was used to remove the noise superimposed on sEMG signals. sEMG signals of all 22 sEMG channels were digitized using a 16-bit analog-to-digital converter (USB-6218; National Instruments Corp.). The sampling rate was set to 2,000 Hz.

The oral motion set included four tongue motions in tongue exercise (right, left, up, and down tongue motion performed with opened mouth), a jaw motion in jaw opening exercise and a saliva swallowing in swallowing exercise (Fig. 2). These six oral motions were selected to be consistent with advice given in the publication "Summary of the training method" recommended by the Japan Society of Dysphagia Rehabilitation (JSDR medical treatment exploratory committee, 2014; Ooka et al., 2008). In the experiment, each oral motion was executed for 2 s at a speed comfortable for the subject (i.e., arbitrary effort). A resting period of 2 s was allowed before the start of the next motion. Consequently, all six oral motions in the set were completed for a total of 26 s. Each subject was asked to perform the motion set 14 times. The sEMG signals during each test were recorded as shown in Fig. 3. As a result, 14 datasets were produced for each subject.

Fig.2 Illustration of the six oral motions in the set.

Fig. 3 22-channel sEMG signals for six oral motions.

After the sEMG measurements, we used a skinfold caliper to measure the subcutaneous fat thickness on the underside of the jaw, where the electrode system was placed, to help investigate the relationship between the amount of this tissue and the classification accuracy of the oral motions (Adipometer; Medical Science Publications Inc.) (Fig. 4). This measurement was performed only for the elderly group.

Fig. 4 Measurement of the subcutaneous fat thickness of the underside of the jaw.

2.3 Classification of oral motions

Figure 5 outlines the oral motion classification method developed by the authors in a previous study (Sasaki et al., 2016). In the current effort, this method was applied to the classification of six oral motions of the elderly for tongue movement, jaw opening, and swallowing exercises. The first four repetitions of the 14 total sEMG measurement sets were used as training data for the support vector machine (SVM) and the remaining 10 datasets were used as test data for the evaluation of classification accuracy. The SVM training and oral motion classification were performed for each subject.

Fig. 5 Flowchart of oral motion classification (Sasaki et al., 2016).

First, in the experimental procedure, sEMG signals measured from all 22 channels were segmented for feature extraction into data windows comprising 256 samples (128 ms). The next sampling segment was slid over the current one after a time increment of 16 ms (Englehart et al., 2001). For composition of the feature vector, the root mean square (RMS) and cepstrum coefficients (CC) of sEMG signals were calculated for each window and channel. The RMS features are characteristics of a time domain and provide amplitude information of sEMG signals. The CC features are characteristics of the frequency domain, and low-order CC include information about the spectral envelope of the power spectrum of sEMG signals. In this study, low-order (1–5) CC were adopted as CC features. The dimension of the feature vector as described above is 132 ((1-dimensional RMS features + 5-dimensional CC features) $\times$ 22 channels).

Next, to prepare training and test data, feature vectors were labeled as correct class labels obtained by threshold triggering of sEMG signals. Then, using training data comprising pairs of feature vectors and correct class labels, the decision function for classifying each motion was created using an SVM classifier with a radial basis function (RBF) kernel. The RBF kernel non-linearly maps samples into a higher dimensional space and allows linear classification in this space. The hyperparameters (kernel parameter γ and penalty parameter C) of the SVM were optimized using a grid search process within training data. The searches included combinations of γ and C for $\gamma = \{2^{-10}, 2^{-9}, \dots, 2^1\}$ and $C = \{2^1, 2^2, \dots, 2^8\}$. The optimal combination with the highest classification rate was defined using fivefold cross validation.

After training the SVM with optimized hyperparameters for γ and C , oral motion classification was performed using unknown sEMG signals from test data. The LIBSVM library was used for SVM training and oral motion classification (Chang et al., 2016). Predicted class labels were replaced with a “neutral” tongue position when all sEMG signals were under the threshold level (i.e., relaxed state). Then, to reduce the effect of possible misclassification, a majority voting technique was applied to a moving window comprising 20 frames, and the final predicted class label with the largest number of wins was obtained.

Finally, the classification accuracy of six oral motions was calculated using the following equation:

$$\text{Classification accuracy (\%)} = \frac{\text{number of correctly predicted class labels}}{\text{total number of predicted class labels}} \times 100. \quad (1)$$

2.4 Evaluation of oral function

To investigate the relationship between the classification accuracy of oral motions and the oral function itself, oral function tests were conducted as mentioned below, but only for the elderly group.

2.4.1 Tongue pressure test

The maximum tongue pressure generated between the tongue and the palate decreases due to aging or dysphagia (Utano-hara et al., 2008). Maximum tongue pressure was measured using the JMS tongue pressure measuring instrument (TPM-01; JMS Co. Ltd.) with a disposable oral balloon probe. The measurement was performed twice, and the largest value was taken as the maximum tongue pressure. Based on the official position paper regarding oral hypofunction in the elderly population by the Japanese Society of Gerontology, a diagnosis of decreased tongue pressure was made when the maximum tongue pressure obtained by this test was <30 kPa (Minakuchi et al., 2018). Oral hypofunction is the stage at which recovery can be expected by performing appropriate treatment before oral dysfunction occurs.

2.4.2 Oral diadochokinesis

Oral diadochokinesis is an oral functionality index to evaluate articulatory oral motor skill, including the function of lips and tongue (Yamada et al., 2015). Subjects were asked to sequentially repeat the /pa/, /ta/, /ka/ syllables as fast as possible for 5 s. The number of repetitions per second was calculated using a digital counter (T.K.K.3350 digital counter; Takei Scientific Instruments Co. Ltd.). This measurement was performed twice, and the larger value was taken as the maximum number. A diagnosis of decreased tongue-lip motor function was made when the number of any of the /pa/, /ta/ or /ka/ sounds produced per second was <6 (Minakuchi et al., 2018).

2.4.3 Repetitive Saliva-Swallowing Test

The repetitive saliva swallowing test (RSST) is an oral functionality index used to evaluate the ability to voluntarily swallow repeatedly and is regarded as a screening test for functional dysphagia (Oguchi et al., 2000). In this test, subjects were asked to repeatedly swallow their saliva as many times as possible within 30 s. An RSST count of <3 in 30 s suggested dysphagia.

2.4.4 Water swallow test

The water swallow test is also widely used as a screening test of functional dysphagia (Horiguchi et al., 2011). In this exercise, subjects were asked to drink 30 ml of water, and the swallowing condition was scored. Score 1 indicated that the subject had the ability to swallow 30 ml of water at once without coughing and was judged to be healthy. Score 2 indicated that the subject had the ability to swallow 30 ml of water more than twice without coughing and was judged to be suspicious of dysphagia (i.e., deterioration of swallowing function). Scores 3–5 indicated that the subject had an ability to swallow 30 ml of water with coughing or had an inability to swallow water at all. Subjects with a score of ≥ 3 were judged to have abnormal swallowing function.

2.5 Statistics

Independent t-test and correlation analysis were performed using Matlab R2016b (Statistics and Machine Learning Toolbox; The Mathworks Inc.). The level of significance was set at $p < 0.05$.

3. Results

3.1 Physical characteristics

Table 1 shows physical characteristics of all subjects. As determined by t-test, there were significant differences in terms of age, height, and body mass index (BMI) between the elderly and young subjects. There was also a significant difference in height and BMI values between male and female elderly subjects. In particular, female elderly subjects E9 through E12 exceeded the target range of BMI recommended by the Japanese MHLW's dietary reference intakes for Japanese), and a slight obesity tendency was observed. The mean subcutaneous fat thickness on the underside of the jaw,

Table 1 Physical characteristics of all subjects.

Table 1. Anthropometric characteristics of study subjects							
Subjects	Sex	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m ²)	Subcutaneous fat thickness (cm)	
Elderly subjects	E1	Male	73	170	68	23.5	14
	E2	Male	77	162	62	23.6	6
	E3	Male	72	160	58	22.7	6
	E4	Male	74	163	62	23.3	10
	E5	Male	66	160	56	21.9	6
	E6	Male	69	156	59	24.2	8
	E7	Male	67	162	57	21.7	6
	Mean±SD		71.1±4.0	161.9±4.3	60.3±4.1	23.0±0.9	8.0±3.1
	E8	Female	62	148	51	23.3	8
	E9	Female	65	154	62	26.1	14
	E10	Female	80	148	57	26.0	12
	E11	Female	65	154	65	27.4	16
	E12	Female	63	151	57	25.0	16
	Mean±SD		67.0±7.4	151.0±3.0	58.4±5.4	25.6±1.5	13.2±3.3
Mean±SD		69.4±5.7	157.3±6.7	59.5±4.5	24.1±1.8	10.2±4.0	
Young subjects	Y1	Male	21	165.	51	18.7	-
	Y2	Male	22	182	80	24.2	-
	Y3	Male	23	171	60	20.5	-
	Y4	Male	24	164	60	22.3	-
	Y5	Male	21	167	54	19.4	-
	Mean±SD		22.2±1.3	169.8±7.3	61.0±11.3	21.0±2.2	-

where the 22-channel electrode was placed, was 8 mm for elderly male and 13.2 mm for elderly female subjects, indicating a significant difference between both groups.

3.2 Classification capability

Table 2 shows the classification accuracy of six oral motions for all subjects. In elderly subjects, the highest classification accuracy was a remarkable 99.0%, the lowest was 92.3%, and the mean was 95.2%. In contrast, the highest classification accuracy in young subjects was 98.4%, with the lowest value at 92.9% and the mean at 95.4%. As evaluated by t-test, there was no statistically significant difference in the mean classification accuracy between the elderly and young subjects, indicating no difference in classification accuracy regarding oral motions depending on age. In addition, the mean classification accuracy in male elderly subjects was 94.9% and that in female elderly subjects was 95.6 %. As shown by t-test, there was again no statistically significant difference in the mean classification accuracy between male and female elderly subjects, indicating no difference in the classification accuracy of oral motions depending on sex.

Table 3 shows the confusion matrix. The reason that neutral tongue position is included in the predicted class is that the majority voting technique was used to reduce the effect of misclassification. None of the male and female elderly subjects or young subjects had an average misclassification rate exceeding 5% for any motion, and the misclassification rate of many motions were within 3%. The only motions with a misclassification rate exceeding 3% were swallowing in male elderly subjects and left tongue motion and jaw opening in female elderly subjects.

3.3 Oral function

Table 4 shows the measurement results of the oral function of the elderly subjects. The mean value of maximum tongue pressure was 31.4 kPa for male elderly subjects and 37.8 kPa for female elderly subjects, although there was no significant difference between the two groups. Three out of 12 elderly subjects (male subjects E1, E4 and female subject E11) had a maximum tongue pressure of less than 30 kPa and were therefore suspected of having oral frailty.

Table 2 Classification accuracy of six oral motions of all subjects.

Subjects		Right	Left	Up	Down	Jaw Opening	Swallowing	Mean	
Elderly subjects	Male	E1	87.7	96.0	100	93.8	97.9	100	95.9
		E2	97.4	86.5	97.1	94.3	81.2	97.0	92.3
		E3	99.1	100	100	99.1	96.6	83.8	96.4
		E4	98.6	100	97.6	96.3	99.7	95.1	97.9
		E5	95.1	99.5	96.7	94.5	95.0	97.0	96.3
		E6	94.0	98.6	93.0	83.1	96.8	88.6	92.4
		E7	96.6	81.8	92.8	92.8	98.8	94.7	92.9
	Mean±SD	95.5±3.9	94.6±7.4	96.7±2.9	93.4±5.0	95.1±6.3	93.7±5.6	94.9±2.3	
	Female	E8	94.0	76.2	98.4	95.9	97.5	98.6	93.4
		E9	97.2	100	99.3	100	79.8	90.7	94.5
		E10	99.1	100	98.7	96.1	99.5	100	98.9
		E11	99.0	99.6	98.8	99.7	99.4	97.3	99.0
		E12	94.2	82.6	92.8	94.7	92.4	97.8	92.4
		Mean±SD	96.7±2.5	91.7±11.4	97.6±2.7	97.3±2.4	93.7±8.3	96.9±3.6	95.6±3.1
		Mean±SD	96.0±3.3	93.4±8.9	97.1±2.7	95.0±4.4	94.6±6.9	95.1±4.9	95.2±2.6
Young subjects	Y1	99.3	94.3	98.5	95.2	93.3	96.0	96.1	
	Y2	89.2	89.0	100	84.7	94.4	100	92.9	
	Y3	96.3	88.4	96.7	94.3	87.7	99.5	93.8	
	Y4	98.6	98.7	96.3	87.3	93.5	99.5	95.7	
	Y5	99.7	99.6	97.9	99.4	94.1	100	98.4	
	Mean±SD	96.6±4.4	94.0±5.3	97.9±1.5	92.2±6.1	92.6±2.8	99.0±1.7	95.4±2.2	

Table 3 Confusion matrix for six oral motions.

Actual class		Predicted class							
		Right	Left	Up	Down	Jaw Opening	Swallowing	Neutral	
Elderly subjects	Male	Right	95.5	0.6	0.8	0.8	1.0	0	1.3
	Male	Left	1.8	94.6	0.4	0.9	1.2	0	1.1
	Male	Up	0.6	0.6	96.7	0.8	0.2	0.3	0.8
	Male	Down	2.0	1.2	1.8	93.4	0.7	0.2	0.7
	Male	Jaw Opening	0.8	0	0	0.3	95.1	2.6	1.2
	Male	Swallowing	0.7	0	0	0	1.4	93.7	4.2
	Female	Right	96.7	0.8	0.9	0.2	0	0	1.4
	Female	Left	4.7	91.7	0.8	2.3	0	0	0.5
	Female	Up	0.2	0	97.6	0	0	1.3	0.9
	Female	Down	0.1	0.6	0.2	97.3	0.4	0	1.4
	Female	Jaw Opening	0.6	0.6	3.3	0	93.7	0.2	1.6
	Female	Swallowing	0.2	0	1	0.4	0	96.9	1.5
Young subjects	Right	96.6	1.4	0.2	0.6	0.6	0	0.6	
	Left	1.0	94.0	2.5	1.1	0.2	0	1.2	
	Up	1.2	0.2	97.9	0	0	0	0.7	
	Down	2.9	2.3	0	92.2	0.2	0.3	2.1	
	Jaw Opening	1.3	2.2	0.8	0.9	92.6	0.1	2.1	
	Swallowing	0	0	0.8	0	0	99.0	0.2	

Table 4 Oral functions of all subjects.

Subjects		MTP (kPa)	OD (times / sec)			RSST (times / 30 sec)	WST (Score)	CA (%)	
			/pa/	/ta/	/ka/				
Elderly subjects	Male	E1	25.0	6.6	6.6	6.4	7	1	95.9
		E2	32.6	6.2	6.4	6.4	6	2	92.3
		E3	33.3	7.4	7.2	7.0	6	2	96.4
		E4	23.0	6.2	6.4	6.4	4	1	97.9
		E5	36.5	7.6	7.4	7.4	6	1	96.3
		E6	36.5	7.2	7.4	6.8	2	1	92.4
		E7	32.9	7.2	7.0	5.8	9	1	92.9
	Mean±SD	31.4±5.3	6.9±0.6	6.9±0.4	6.6±0.5	5.7±2.2	1.3±0.5	94.9±2.3	
	Female	E8	34.1	6.6	6.4	6.6	4	2	93.4
		E9	48.4	6.0	7.0	6.8	5	2	94.5
		E10	43.2	5.0	5.4	5.0	4	1	98.9
		E11	22.8	6.8	6.6	5.6	7	2	99.0
		E12	40.4	8.0	7.2	7.2	7	1	92.4
		Mean±SD	37.8±9.8	6.5±1.1	6.5±0.7	6.2±0.9	5.4±1.5	1.6±0.5	95.6±3.1
Mean±SD		34.1±7.8	6.7±0.8	6.8±0.6	6.5±0.7	5.6±1.9	1.4±0.5	95.2±2.6	

MTP: Maximum tongue pressure, OD: Oral diadochokinesis, RSST: Repetitive saliva swallowing test, WST: Water swallow test, CA: Classification accuracy of oral motions

The mean numbers of repetitions per second of syllables /pa/, /ta/, /ka/ was respectively 6.9, 6.9, 6.6 times for male elderly subjects and 6.5, 6.5, 6.2 times for female elderly subjects. There was no statistically significant difference in the results of oral diadochokinesis between these two groups. Three out of 12 elderly subjects (male E7 and females E10, E11) had a syllable in which the number of repetitions per second was less than 6.0 and these were judged to have decreased tongue-lip motor function.

The mean value of RSST was 5.7 times for elderly male and 5.4 times for elderly female subjects, respectively. There was no statistically significant difference in the results of RSST between the genders.

In the water swallow test, no cough was observed in either elderly male or subjects, and no significant difference in the scores was observed between the genders. However, five out of 12 elderly subjects (males E2, E7 and females E8, E9, E11) generated a score 2, which suggests the possibility of a deteriorated swallowing function.

3.4 Accuracy of classification

Table 5 shows the correlation between the classification accuracy of oral motions for the elderly subjects and each parameter. As is evident, no significant correlation was found between any of the parameters and the classification accuracy. Based on this result, it became clear that the six oral motions addressed here can be classified with high precision even for subjects suspected of having a deteriorating oral function.

Table 5 Correlation between classification accuracy and oral motions.

	Age	Height	Weight	BMI	SFT	MTP	OD			RSST	WST
							/pa/	/ta/	/ka/		
<i>r</i>	0.34	-0.01	0.30	0.34	0.30	-0.32	-0.41	-0.47	-0.46	-0.04	-0.02
<i>p</i>	0.28	0.10	0.34	0.28	0.34	0.31	0.18	0.12	0.13	0.89	0.94

r: correlation coefficient, *p*: *p*-value (Statistical significance), SEF: Subcutaneous fat thickness, MTP: Maximum tongue pressure, OD: Oral diadochokinesis, RSST: Repetitive saliva-swallowing test, WST: Water swallow test

4. Discussion

4.1 Relation between age and classification accuracy

The age of elderly subjects participating in this study was wide from 62 to 80 years old, and the age difference between young subjects was about 40 to 60 years. In general, it is known that the positions of the hyoid bone and larynx at rest in many elderly people are lowered as due to atrophy of the muscle fibers of the suprahyoid muscles, a decrease in the muscle tone, loose ligament, etc (Yaniguchi et al., 2013; Logemann, 1998). In addition, sagging of the underside of the jaw, which is a place of attachment of 22-channel electrode, is likely to occur due to aging. Therefore, in our method focusing on the muscle activity pattern of the suprahyoid muscles in which anatomical aging change occurs, it was concerned that the classification accuracy of the oral motions of the elderly subjects would be lower than that of the young subjects. However, as a result of the analysis, the average classification accuracy of oral motions was 95.2 % for elderly subjects and 95.4 % for young subjects respectively, and no statistically significant difference was observed. In addition, there was no difference in classification accuracy between male and female elderly subjects. This means that the our method using SVM could consider not only the difference in muscle activity pattern depending on the type of oral motion but also the difference in muscle activity pattern depending on age and agenda, as individual characteristics for oral motion classification. In other words, this is a benefit of the superior performance of machine learning (artificial intelligence) in pattern classification. Due to such advantages, it is thought that high classification accuracy of oral motions could be achieved to the subjects of a wide age in this study.

4.2 Relation between subcutaneous fat thickness and classification accuracy

The subcutaneous fat thickness of underside of the jaw for the elderly subjects was distributed in the range of 6 to 16 mm, and the mean thickness of female subjects were significantly thicker than that of male subjects. In general, it is known that as the subcutaneous fat thickness increases, the amplitude of the integrated sEMG signals decreases (Farina et al., 1999; Minetto et al., 2013). Therefore, in our method, in which the RMS reflecting the amplitude information of

the sEMG is one of the features for oral motion classification, there was concern that the classification accuracy would decrease as the subcutaneous fat thickness increased. However, no correlation was found between subcutaneous fat thickness of underside of the jaw and classification accuracy of oral motions and it was shown that six oral motions could be classified with high accuracy regardless of differences in subcutaneous fat thickness. The reason for this may be that differences in muscle activity patterns dependent on subcutaneous fat thickness could also be considered as individual features for oral motion classification.

4.3 Relation between oral function and classification accuracy

In the training game development for maintaining and improving the swallowing function, the most fundamental thing is to detect the various oral motions in indirect training of the elderly, especially persons who need training due to functional deterioration. In this study, in order to clarify the relationship between oral function and classification accuracy of oral motions, 4 oral function tests (Tongue pressure test, Oral diadochokinesis, Repetitive Saliva-Swallowing Test, Water swallow test) were performed for elderly subjects. However, no correlation was found between each evaluation result of oral function and the classification accuracy. In particular, female elderly subject E11 who was judged to be functionally impaired by three oral function tests was considered to have the lowest classification accuracy, but contrary to this expectation, the subject E11 showed the highest 99% among the all elderly subjects. This suggests that our method may be effective as a method for detecting oral motions in elderly people with high accuracy regardless of oral function.

4.4 Findings and study limitations

In this study, it was clarified that not only the oral motions of young subjects but also the oral motions of elderly subjects with different age and agenda and oral function can be classified safely and noninvasively without inserting a measuring device into the oral cavity. In addition, although 22-channel electrode of the same shape and size was used for sEMG measurement for young subjects, male elderly subjects and female elderly subjects, no significant difference in classification accuracy of oral motion was observed among them. From this result, it was suggested that it is possible to classify oral motions with sufficient precision without necessarily using electrodes matching the shape of the individual's underside of jaw. The oral motion classification method using SVM, which is a machine learning method, is a technique for predicting oral motions from the sEMG signals pattern of the suprahyoid muscles. The subjects who participated in this experiment differed not only in age, sex, subcutaneous fat thickness, oral function, and the shape of the underside of their jaw but also in the speed, intensity, and range of motion of the oral motion. Due to these factors, the measured sEMG signals were absolutely different from subject to subject. Nevertheless, it was possible to classify six oral motions with a high accuracy of 95% from each individual's sEMG signals. This is because of the benefits of the superior performance of machine learning in pattern classification and because the features extracted from sEMG signals measured using a 22-channel electrode were also suitable for oral motion classification in the elderly. From this fact, it can be considered that the proposed method is effective detecting means of oral motions for realizing a training game for elderly people who have deteriorated swallowing function. In future, it is necessary to advance training game realization and clarification of its training effect. In addition, in the training game, it is necessary to actively consider not only oral motion but also force information such as the muscle activity level of the suprahyoid muscles and the mechanical load on the tongue. As a result, more effective training suitable for the oral function of individuals, which cannot be realized with image-based methods, will be possible. If a biofeedback training system using oral motion and force information is realized and the error between the target value and the game operation can be quantified, it will be possible to evaluate the oral function and the training effect through this training game. On the contrary, muscle fatigue may reduce the classification accuracy of oral motions and may affect game operations, and thus in the future, it will be necessary to verify in detail how much the classification accuracy will decrease depending on the training content and training time. The training game that we want to realize in this research assumes the following usage: (i) Maintenance and improvement of swallowing function in elderly individuals who have reduced swallowing function or are in a state of frailty (dysphagia potential), (ii) Rehabilitation of swallowing function for people with dysphagia. In this study, we focused on the former, evaluated the classification accuracy of oral motions in the elderly, and investigated the effect of differences in age, sex, and oral function on the accuracy of the oral motion classification method. Since the effectiveness of the oral motion classification method for an individual with dysphagia has not been verified, in a future study, it will be important to clarify the relationship between the disability level of the swallowing disorder and the classification accuracy of oral motions.

5. Conclusions

In this study, we aimed to verify the classification accuracy of oral motions in the indirect training of swallowing function for the elderly subjects by using oral motion classification method based on the muscle activity pattern of the suprahyoid muscles. The sEMG signals of the suprahyoid muscles were measured via 22-channel electrode developed in consideration of the size of the lower jaw of female subjects. Six oral motions (right, left, up, and down tongue motion, jaw motion and saliva swallowing) in tongue exercise, jaw opening exercise, swallowing exercise were classified from RMS features and CC features of the sEMG signals using an SVM classifier. Results showed that the six oral motions for elderly subjects were classified with high accuracy of 95.2 %. The mean classification accuracy for young subjects was 95.4 %. There was no statistically significant difference in the mean classification accuracy between the elderly and the young subjects. In addition, results was also showed that six oral motions can be classified with 95.2 % accuracy regardless of gender, subcutaneous fat thickness of underside of the jaw, level of the oral function. Therefore, it can be considered that the proposed method can be an effective and highly accurate tool for classifying oral motions in elderly individuals who require maintenance and improvement of swallowing function. From now on, we will develop a serious game to train and improve the swallowing function using the method, and will verify the effect on elderly people who have deteriorated oral function and those with dysphagia.

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