Effect of visual biofeedback of posterior tongue movement on articulation rehabilitation in dysarthria patients

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Article category: Oral rehabilitation

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Abstract

Articulation is driven by various combinations of movements of the lip, tongue, soft palate, pharynx and larynx, where the tongue plays an especially important role. In patients with cerebrovascular disorder, lingual motor function is often affected, causing dysarthria. We aimed to evaluate the effect of visual biofeedback of posterior tongue movement on articulation rehabilitation in dysarthria patients with cerebrovascular disorder. Fifteen dysarthria patients (10 men and 5 women; mean age, 70.7 ± 10.3 years) agreed to participate in this study. A device for measuring the movement of the posterior part of the tongue was used for the visual biofeedback. Subjects were instructed to produce repetitive articulation of [*ka*] as fast and steadily as possible between a lungful with/without visual biofeedback. For both the unaffected and affected sides, the range of ascending and descending movement of the posterior tongue with visual biofeedback was significantly larger than that without visual biofeedback. The coefficient of variation for these movements with visual biofeedback was significantly smaller than that without visual biofeedback. With visual biofeedback, the range of ascent exhibited a significant and strong correlation with that of descent for both the unaffected and affected sides. The results of this study revealed that use of visual biofeedback leads to prompt and preferable

change in the movement of the posterior part of the tongue. From the standpoint of pursuing necessary rehabilitation for patients with attention and memory disorders, visualization of tongue movement would be of marked clinical benefit.

Key words: visual biofeedback, tongue movement, articulation, rehabilitation, dysarthria

Introduction

Articulation is driven by various combinations of movements of the lip, tongue, soft palate, pharynx and larynx (1), where the tongue plays an especially important role. In patients with cerebrovascular disorder, lingual motor function is sometimes affected, thus causing dysarthria (2-4). A speech language pathologist (SLP) uses various methods to rehabilitate dysarthria patients. Traditional approaches include 1) integral stimulation (watch and listen imitation tasks); 2) phonetic placement (e.g., hands-on assistance in attaining targets and movements, pictured illustrations of articulatory targets) (1). However, most of these approaches are mainly based on the subjective impression of the therapist, and the therapist's instructions are sometimes difficult for the patient to understand correctly (5-7). As the tongue moves within the enclosed field, i.e., the mouth, only limited information can be gained by visual observation. Therefore, it has been difficult to present a specific exercise target, and also measure the training effect.

Objective evaluation of tongue movement during articulatory training is important, and several methodologies have been reported so far. Electropalatography (EPG) is one of the most precise modalities to evaluate the physical contact between the tongue and palate during articulation (8-11). EPG

is a potential tool for providing feedback on tongue movements during speech. Some reports illustrated its application to therapy for motor speech disorders, with evidence of positive effects on intelligibility (8, 10-13). Although EPG could record the location of tongue contact for more than 50 measurement points on the palate in time series, EPG needs to be constructed for each subject, and thus might not be appropriate for daily speech rehabilitation. Tongue pressure measurement during articulation has also been reported (14). The equipment for measuring the pressure enables real-time observation of tongue pressure at five points on the palate during speech. However, for rehabilitation, movement of the tongue before it touches the palate should be monitored. Magnetic resonance imaging and X-ray micro-beam computed tomography have been used for tongue movement analysis (15, 16). However, because of the posture during examination and the impractical accessibility, these modalities would not be appropriate for daily use during rehabilitation. Ultrasonography would be a good modality for the evaluation of tongue movement during rehabilitation; it is noninvasive and can assess tongue movement during articulation in detail (16, 17). However, as the location of the probe cannot be stabilized during mandibular movement while speaking, it would only be suitable for qualitative evaluation. The use of ultrasonography for speech therapy of the hearing

impaired has been reported (18). Electromyographic biofeedback was used to help an individual with spastic dysarthria to reduce tension and facilitate restoration of voluntary mandibular control, with subsequent reduction of drooling and improved speech intelligibility (19). However, even though some of these reported methods are noninvasive, a quantitative and practical method to assess and treat the posterior part of the tongue elevation during articulation has not been established yet.

In our previous study, new equipment to evaluate the tongue-lifting movement, especially in the posterior part of the tongue during velar plosive articulation in healthy adults, was developed (20). This equipment is capable of producing visual biofeedback and also recording the tongue movement quantitatively in time series, which would be suitable for clinical use during speech rehabilitation. In the present study, we aimed to reveal the effect of visual biofeedback of the posterior tongue movement on articulation rehabilitation using this equipment in dysarthria patients with cerebrovascular disorder.

Materials and Methods

Subjects

Subjects were selected from among inpatients at Kawasaki Medical School

Hospital, who were referred to the Department of Rehabilitation. The inclusion criteria were as follows: 1) dysarthria patient with cerebrovascular disorder in origin, and 2) referred to SLP for speech therapy by a rehabilitation doctor. The exclusion criteria were: 1) aphasia, 2) unable to obtain informed consent because of cognitive impairment, 3) unable to position the measuring equipment because of missing maxillary teeth, 4) history of major surgery to the head or neck, and 5) progressive neurological disorder. Fifteen dysarthria patients (10 men and 5 women; age range, 51–87 years; mean age, 70.7 ± 10.3 years) agreed to participate in this study. Their primary diseases were cerebral infarction (9 subjects), cerebral hemorrhage (5 subjects), and combination of cerebral infarction and cerebral hemorrhage (1 subject). The types of dysarthria were unilateral upper motor neuron (UUMN) dysarthria (11 subjects), ataxic dysarthria (2 subjects) and spastic dysarthria (2 subjects). All subjects presented with posterior tongue movement disorder. The protocol of this study was approved by the ethics committee of Okayama University (No. 1172) and Kawasaki Medical School (No. 1119). Informed consent was obtained from all subjects prior to participation in this study.

Instrument

A device for measuring the movement of the posterior part of the tongue (OE-TMMD-TP1; Oisaka Electronic Device Ltd., Fukuyama, Japan) (20) was used in this study (Fig. 1a). The device consists of a posterior bite fork (PB), upper anterior bite fork (UAB), lower anterior bite fork (LAB), right measuring rod (RMR) and left measuring rod (LMR). This device can evaluate the up–down movement of the posterior part of the tongue noninvasively using the RMR and LMR. The RMR and LMR are metallic rods covered with a silicon tube 1.95 mm in diameter. Both the LMR and RMR were adjusted to fit the palate of the subject before measurement. The LMR and RMR were 10 mm lateral from the sagittal midline, and the posterior ends of the LMR and RMR were adjusted to be at the Ah-line. The device was placed in the mouth by positioning the upper central incisors on the UAB and upper bilateral molars on the PB to standardize the reference plane parallel to the occlusal plane of the upper dental arch. The PB was fit to the upper dental arch using Hydrophilic Vinyl Polysiloxabe impression material (Putty type GC, Tokyo, Japan). Subjects were instructed to close their mouths until their lower central incisors contacted the LAB, resulting in a mouth opening of 20 mm between the upper and lower incisors (Fig. 1b). The LMR and RMR were designed to generate an average downward force of 31 mN to maintain contact with the tongue throughout the tongue movement. The distal

end of the LMR and RMR contacted the dorsal surface of the posterior part of the tongue and detected the up–down movement (Fig. 1c). This movement was converted to rotary motion in the device and was output as a change in voltage. The output voltage was recorded with a personal computer via an analog-to-digital converter and bench-calibrated with prescribed vertical dimensions (Fig. 1d). Calibration in the mouth was also performed for each subject to determine the relative position of the upper most point of the hard palate to the measuring device by manually placing the distal end of the LMR and RMR in contact with the palate. The position was regarded as the origin of the vertical deviation, which was expressed as the distance from the origin. The LMR and RMR were visually confirmed not to be in contact with the anterior part of the tongue.

Procedure

At first, the SLP assessed the tongue motor function of the subjects to confirm the unaffected/affected side of the tongue. Subjects were asked to sit in an upright position on a chair without a headrest. After the installation of the equipment, subjects were instructed to produce repetitive articulation of [*ka*] as fast and steadily as possible between a lungful without visual biofeedback to

record the baseline condition. The baseline condition was recorded by three times. The display of the computer was subsequently made visible to provide visual biofeedback. Using the biofeedback, subjects were allowed to practice making a correct waveform for [*ka*] with the largest possible strokes. After having practiced several times, not more than 3 times, they produced repetitive articulation of [*ka*] as fast and steadily as possible. The subjects repeated as many articulations as possible between each lungful at an easily producible volume. The pronounced voice was recorded with a data recorder (ICD-SX850; Sony, Tokyo, Japan). The subjects were instructed to relax their lips throughout these tasks.

Data analysis

The wave analysis targets were five peaks except for the first peak of the repetitive up–down movements (Fig. 2), because the first peak includes the initial movement of the tongue from the rest position to the repetitive articulation position. From the waveform, the range of the ascent, which was from the nadir to the peak, and the range of the descent, which was from the peak to the nadir, were analyzed. The mean and coefficient of variation (mean/standard deviation) for five ranges of the ascent and descent were calculated for each condition.

Each peak interval were analyzed and mean utterance rates was calculated.

Auditory impression

The auditory impression of the recorded voice was evaluated. Five SLPs who were blind to the experimental condition evaluated each recorded [*ka*] sound for audible distortion. The mean prevalence of distorted sound was calculated.

Statistical analysis

The range of tongue movement, coefficient of variation and utterance rate were statistically compared between with and without visual biofeedback using the Wilcoxon signed-rank test. The relationship between the range of tongue ascent and descent was analyzed using Pearson's correlation coefficient. The difference of the mean prevalence of the distorted [*ka*] sound was evaluated using the paired Student's t-test. Statistical analysis was performed using IBM SPSS Statistics Version 19 (IBM Japan, Tokyo, Japan). Statistical significance was set at $p < 0.05$.

Results

Figure 3 shows an example of typical wave patterns for one subject. Marked

improvement of the posterior tongue movement could be observed not only on the unaffected side but also on the affected side in this subject.

Range of tongue movement (Fig. 4a)

Regarding the range of posterior tongue movement during repetitive articulation of [*ka*] without visual biofeedback, the ascent was 1.56 ± 1.22 mm and the descent was −0.94 ± 0.87 mm for the unaffected side, while the ascent was 1.50 ± 1.10 mm and the descent was −0.94 ± 0.62 mm for the affected side. Regarding the range of posterior tongue movement during repetitive articulation of [*ka*] with visual biofeedback, the ascent was 3.72 ± 2.10 mm and the descent was −3.23 ± 2.07 mm for the unaffected side, while the ascent was 3.43 ± 1.39 mm and the descent was −3.06 ± 1.39 mm for the affected side. The ranges of ascent and descent for both the unaffected and affected sides during repetitive articulation of [*ka*] with the visual biofeedback were significantly larger than those during articulation without visual biofeedback ($p < 0.01$).

Coefficient of variation (Fig. 4b)

For the unaffected side without visual biofeedback, the coefficient of variation during repetitive articulation of [*ka*] for the ascent was 0.88 ± 0.32, and that for the descent was −0.92 ± 0.42. For the affected side without visual biofeedback,

the coefficient of variation during repetitive articulation of [*ka*] for the ascent was

0.94 ± 0.42, and that for the descent was –0.78 ± 0.45. For the unaffected side

with visual biofeedback, the coefficient of variation during repetitive articulation

of [*ka*] for the ascent was 0.42 ± 0.23, and that for the descent was –0.29 ± 0.26.

For the affected side with visual biofeedback, the coefficient of variation during

repetitive articulation of [*ka*] for the ascent was 0.35 ± 0.20, and that for the

descent was –0.22 ± 0.13. For both the unaffected and affected sides, the

coefficient of variation during repetitive articulation of [*ka*] with visual

biofeedback was significantly smaller than that without visual biofeedback (p <

0.01).

Relationships between the range of ascent and descent

The ranges of the ascent and descent for all subjects (five peaks for each

subject) are shown in Figs. 5 and 6. Figure 5 shows the relationship without

visual biofeedback, and Figure 6 shows the relationship with visual biofeedback.

Without visual biofeedback, the range of ascent exhibited a significant

correlation with that of descent on the unaffected side (r = –0.39, P < 0.01).

However, no significant correlation was observed on the affected side (r = –0.12,

P = 0.32). For the relationships without visual biofeedback, the R^2 values were

small. With visual biofeedback, as shown in Fig. 6, the range of ascent exhibited

a significant and strong correlation with that of descent for both the unaffected

and affected sides (r = −0.80, P < 0.01; r = −0.67, P < 0.01). The range of the

ascent and descent increased with use of visual biofeedback.

Auditory impression

Table 1 shows the mean prevalence of the distorted [*ka*] sound with/without

visual biofeedback. With visual biofeedback, the prevalence of the distorted [*ka*]

sound decreased significantly from 50.9% to 19.5% (p < 0.01).

Utterance rate

The utterance rate during repetitive articulation of [ka] without visual biofeedback

for the unaffected side was 206.32 ± 42.48 msec, and that for the affected side

was 203.58 ± 42.73 msec. The utterance rate during repetitive articulation of [ka]

with visual biofeedback for the unaffected side was 264.52 ± 72.80 msec, and

that for the affected side was 266.90 ± 74.93 msec. The utterance rate for both

the unaffected and affected sides during repetitive articulation of [ka] with the

visual biofeedback were significantly slower than those during articulation

without visual biofeedback (p < 0.01).

DISCUSSION

Influence of visual biofeedback

This study revealed that the range of movement of the posterior part of the tongue and coefficient of variation for the repetitive articulation of [*ka*] promptly improved on both the affected and unaffected sides with the use of visual biofeedback using a device for measuring posterior tongue movement. Direct visual observation of the posterior part of the oral cavity during articulation of [*ka*] is not possible externally. The equipment used in this study successfully enabled real-time observation during phonation, thus allowing patients and medical staff to deal with the movement directly.

Patients with cerebrovascular disorder often suffer from higher brain dysfunction, i.e., attention and memory disorders. Therefore, it would be more difficult for these patients not only to comprehend the traits of their tongue's disordered movement but also to pay attention to the movement itself. In this study, these problems could easily be overcome by visual biofeedback of the movement of the posterior part of the tongue. Therefore, it would be suggested that visual biofeedback of this movement would support effective speech

rehabilitation even for dysarthria patients with higher brain function disorder.

Using EPG, Michi et al. (11) indicated the following advantages of visual biofeedback for tongue placement in the treatment process: 1) Visual biofeedback for tongue placement provides accurate real-time information regarding the effectiveness of articulatory placement, 2) Articulatory placement can be recorded and played back, and the behavioral changes during (and following) treatment can be objectively documented, 3) Visual biofeedback treatment provides both qualitative and quantitative measurements so progress can be assessed objectively, 4) Visual information presented by the clinician can be used as a target pattern, and patients can then manipulate and adjust their articulatory movements by repeated observation of the display model, 5) Visual biofeedback for tongue placement provides reward for the patient's progress and increases the patient's motivation, 6) Visual biofeedback for tongue placement is an effective aid for less highly trained clinicians, because it can help them to objectively demonstrate and explain articulatory activity, and 7) Most important is the speed and effectiveness with which the inconvenience and embarrassment of the patients can be alleviated. Although targeted function of the visual biofeedback system used in the present study is different from their EPG system, similar advantages as a biofeedback system seemed to have been achieved

with the patients in the present study. Different from other instruments, the present system could evaluate the tongue movement even when the tongue is unable to touch the palate. Therefore, it was considered that this system would be effective for the rehabilitation of patients with severer tongue movement disorder.

Movement of the posterior part of the tongue

Visual biofeedback using a device for measuring posterior tongue movement increased the range of movement of the posterior tongue and lowered the coefficient of variation during repetitive articulation of [*ka*].

Cerebrovascular disorder sometimes causes tongue movement dysfunction (2-4). Tongue pressure has been reported to decrease in cases of tongue movement dysfunction (21). Consequently, the plosive sound is distorted from insufficient closure between the tongue and palate during exhalation. By improving the range and strength of the movement of the posterior tongue during articulation, improvement of the distortion of plosive sound would be expected. Actually, significant improvement of the [*ka*] sound could be observed by employing visual biofeedback in the present study. With visual biofeedback, some subjects actually slowed the speed of the tongue movement to achieve the

expected movement of the tongue. It is suggested that the utterance rate became slow because subjects were careful to move larger and correctly of the movement of the posterior tongue by visual biofeedback. Rate control would be one of the most powerful, behaviorally modifiable variables for improving intelligibility. It was reported that incorrect articulation could be improved by reducing the utterance rate (22). The visual biofeedback system used in the present study effectively controlled the utterance rate.

Significant correlation of the ascent and descent range of the posterior tongue during articulation could be achieved using visual biofeedback in this study. Without visual biofeedback, it was often observed that the ascending movement was not followed by the appropriate descending movement, and the descending movement was not followed by the appropriate ascending movement. This is because the sound of [*ka*], which tends to be an all-or-none phenomenon, is the only feedback to the subject. These movements could be markedly improved by use of visual biofeedback, showing the effectiveness of the system for rehabilitation.

Test sound

As the background disease of most of the study participants was UUMN dysarthria, their dysarthria conditions were relatively mild. There was little articulatory skewness for the monosyllable. They tended to show substantial skewness at the sentence level. Because it is one of the most skewed syllables in the subject group and also because it is a syllable produced using the posterior part of the tongue, [*ka*] was adopted as the test sound. The function of the posterior part of the tongue is closely related to the production of velar consonants, /k/ and /g/, and swallowing (23, 24). The sound was repeated, as it could be the most effective way to detect the skewness of the sound. Repetitive articulation was commonly used as an articulatory evaluation in oral diadochokinisis (oral DDK). This oral DDK is reported to be useful for judging the speed and regularity of tongue movements (1). Although only one task, i.e., the repetition of [*ka*], was used in this study, it was assumed that this task would be one of the most appropriate tasks for the training of the regularity and speed of posterior tongue movement with visual biofeedback using a device for measuring posterior tongue movement.

Limitations

Because the measuring system used in the present study needs to be inserted into the mouth, UAB and LAB were used to maintain the interincisal distance of

20 mm. This worked as a mandibular positioner to eliminate the possible positional change of the mandible during articulation. However, because of this mandibular positional limitation, the posterior tongue movement observed in this study might be slightly different from that under normal physiological articulation. However, Shirahige et al. (20) reported that the auditory impression of the /k/ articulation could not reveal any perceivable skewness in healthy subjects using a system identical to the one used in the present study. Therefore, a mouth opening of 20-mm interincisal distance would not negatively influence the posterior tongue movement of the [*ka*] articulation. Moreover, from the standpoint of rehabilitation, this mouth opening could function as a loading test of additional distance to evaluate the kinetic reserve capacity of the posterior tongue.

The results of this study revealed that use of visual biofeedback leads to prompt and preferable change in the movement of the posterior part of tongue. This would be of marked benefit for the patient with attention and memory disorders to achieve necessary rehabilitation (25). Further investigations are needed to clarify the long-term efficacy of the rehabilitation procedure using this system. Considering the functional importance of the posterior tongue for swallowing, a

preferable effect on the rehabilitation for swallowing function is also expected using this system.

Acknowledgement

Disclosure

The authors declare that there is no conflict of interest.

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Table 1. Prevalence of distorted [*ka*] sound

Subject	Mean prevalence of distorted [*ka*] sound (%)	
	Baseline	With visual Biofeedback
1	8.0	0
2	28.0	0
3	84.0	4.0
4	28.0	0
5	88.0	48.0
6	8.0	0
7	36.0	0
8	80.0	44.0
9	16.0	4.0
10	36.0	28.0
11	84.0	28.0
12	84.0	20.0
13	56.0	20.0
14	44.0	28.0
15	84.0	68.0
Total mean (S.D.)	50.9(29.5)	19.5(20.6)

Figure legends

Figure 1.

Measuring device. (a) oblique perspective view; (b) the device in position; (c) schematic diagram of the movement of the measuring rod during tongue function and a detection data example; (d) measuring system. UAB, upper anterior bite fork; LAB, lower anterior bite fork; PB, posterior bite fork; RMR, right measuring rod; LMR, left measuring rod.

Figure 2.

Schematic diagram of the wave analysis. Wave analysis was achieved for the five peaks except for the first peak of the repetitive up–down movements, because the range of tongue movement for the first peak includes the ascending movement of the tongue from the initial rest position.

Figure 3.

Typical wave pattern of the posterior tongue movement for repetitive articulation in a subject. a) without visual biofeedback, b) with visual biofeedback. Note the markedly improved movement of the posterior tongue with visual biofeedback.

Figure 4.

Tongue movement analysis on unaffected side and affected side.

(a) Range of tongue movement; (b) coefficient of variation. Note the significant

difference in each parameter with the use of visual biofeedback for both the

unaffected and affected sides.

Figure 5.

Relationships between the range of ascent and descent without visual

biofeedback.

Figure 6.

Relationships between the range of ascent and descent with visual biofeedback.