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ACOUSTICAL LETTER

Difference in vocal tract shape between upright and supine postures: Observations by an open-type MRI scanner

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1. Introduction

The magnetic resonance imaging (MRI) technique has been used for visualizing the geometry and dynamic behavior of the speech organs owing to its excellent imaging capability with no known harmful effects [1,2]. With most existing MRI scanners, subjects need to phonate in a supine posture, whereas normally they speak with the upper body held upright. The vocal tract shape during speaking may differ between supine and upright postures because the direction of gravity is different in the two conditions. This study aims to reveal possible effects of body posture on vowel articulation using an open-type MRI scanner that permits imaging with subjects sitting both upright and lying supine.

Gravitational effects on muscle activity during speech production have been measured using electromyography (EMG). Niimi *et al.* [3] reported that EMG activity for the posterior portion of the genioglossus muscle was higher in supine posture than in an upright one, which suggests a gravitational effect in motor control of the tongue. Moon *et al.* [4] compared EMG activity of the velopharyngeal muscle during bilabial closure for a plosive between upright and supine postures.

Other measurement systems have also been used for the same purpose as this study. Tiede *et al.* [5,6] described differences in articulator shape and position between upright and supine postures using electromagnetic and X-ray microbeam systems. Stone *et al.* [7] also studied gravitational effects on shape and motion of the tongue using an ultrasound imaging system.

The above studies suggested that body posture affects articulatory configuration and consequently alters the vocal tract shape. Because of technical limitations, however, these studies did not provide any geometrical contrasts of the entire speech organs or the whole vocal tract. In this study, we compare midsagittal images during vowel gestures in upright and supine postures using an open-type MRI scanner for examining possible effects of body postures.

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2. MRI acquisition

2.1. Open-type MRI scanner

Magnetic resonance images were obtained with an open-type MRI scanner, GE 0.5T MRI SIGNA SP/i, at the Institute of Biomedical Research and Innovation. This scanner was designed especially for monitoring MR images during medical procedures. As shown in Fig. 1, two torus-shaped super-conductive magnets are positioned with a space for operators. In this study, subjects were positioned in the space in supine and upright postures during imaging, as shown in Fig. 1(b).

2.2. Subjects

Three Japanese male subjects A, B, and C (35, 48, and 54 years of age, respectively) participated in the measurements.

2.3. Conditions for data acquisition

Midsagittal MR images were obtained from the subjects producing five Japanese vowels (/a/, /e/, /i/, /o/, and /u/) in supine and upright postures. The imaging sequence was a Spoiled Gradient Recalled Echo (SPGR) method with 10-mm slice thickness, no averaging, a 250×250-mm field of view (FOV), a 256×256 pixel image size, 30° flip angle (FA), 6.9-ms echo time (TE), and 35-ms repetition time (TR). The acquisition time was approximately 4 s.

A flexible radio frequency (RF) coil was used to surround the subject's face so that the vocal tract was centered in the FOV. Figure 2 shows a subject with the flexible coil. Although the external nose of the subjects was deformed by the coil, they reported that attachment of the coil did not affect vowel articulation.

Each subject was briefed on the experimental procedures prior to scanning, and each was positioned to sit upright and to lie supine in the space between the two magnets. The subject's head was fastened to the platform of the MRI unit. The subjects were instructed to maintain steady phonation of vowels during scanning.

3. Morphological analysis

Effects of body postures on vowel articulation were analyzed with reference to the rigid structures. Since the subjects' head position in the MR images were different

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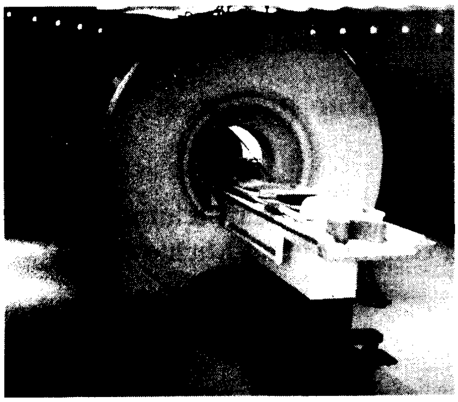
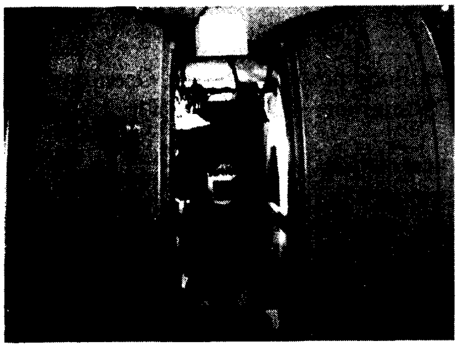


(a) front view



(b) lateral view

Fig. 1 The open-type MRI scanner used for MR image acquisition.

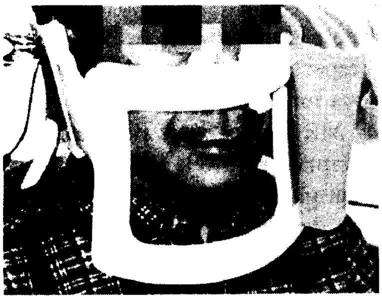


Fig. 2 A subject having on the flexible RF coil.

between the two postures, the MR images were aligned with reference to a line connecting the anterior nasal spine and the posterior margin of the foramen magnum using an affine transformation. Following the alignment, outlines of the vocal tract, upper and lower lips, hard and soft palates, mandible, hyoid bone, thyroid cartilage and the cervical spine were traced manually on the two sets of images to be superimposed together for each vowel. The outlines of the soft palate of subject C in the supine posture could not be traced because measured planes of the MR images in this posture were off-center.

4. Results and discussion

All the tracings are shown in Fig. 3, indicating possible effects of body posture. The differences in the position of the tongue tip between the conditions are shown in Table 1. These figures and the table illustrate that body posture during vowel articulation affects vocal tract shape and that the effect varies among individuals.

Comparison of tongue position between the two conditions revealed that the tongue tended to be retracted by gravitational force in the supine posture. This observation is consistent with Tiede *et al.* [5,6]. The maximum distance for the tongue tip between the postures was 3 mm for subject A, 20 mm for subject B, and 2 mm for subject C as shown in Table 1. In the case of subject B, tongue retraction in the supine posture creates a cavity between the lower front teeth and the tongue tip, as shown in the superimposed outlines.

Vowel-to-vowel comparison indicates that in the supine posture the tongue is more retracted in back vowels than in front vowels. This is possibly because the subjects stabilize the tongue position by pressing the sides of the tongue against the hard palate during front vowels, whereas a similar stabilizing force could not be applied for back vowels.

Gravitational effects were also observed on the thickness of the upper and lower lips and the direction of the lower end of the uvula of the soft palate. The lips in the supine posture were thinner than those in the upright posture, and the lower end of the uvula turned to the same downward direction with gravity.

The height of the larynx shows a difference between the two conditions, with the arytenoid part higher in the supine posture. The maximum vertical displacement of the apex of the arytenoid part between the postures was 3 mm for subject A, 5 mm for subject B, and 9 mm for subject C. This fact implies that vocal tract length changes according to body posture. A possible account for the higher larynx position in the supine posture may be found in the structure of the respiratory system. In the upright posture, gravity acts on the abdominal organs to lower the diaphragm and lung tissue, which keeps the larynx in a low position. In the supine posture, however, the gravity no longer applies such vertical force, thus the larynx is set back in a higher position.

The cervical spine and posterior pharyngeal wall of subjects B and C differ in orientation and curvature, and they appear to be retracted backward in the supine body posture. This is possibly due to the change in head orientation rather than to gravity. The head translates front and back relative to the body axis between the two conditions, which results in changes to the orientation of the cervical spine and to the shape of the pharynx. In fact, the displacement of the posterior pharyngeal wall is maximally 6 mm for subjects B and C when measured at the level of the intervertebral disc between the third and forth cervical vertebrae.

The difference in head orientation also affects the position of the lower jaw and the lower lip. In the supine posture, the head orientation limits the degree of jaw opening because of a decrease in the post-mandibular space.

The displacements of the speech organs mentioned above between the postures exert influence on vocal tract shape. In the supine body posture, the shape of the front oral cavity, pharyngeal and laryngeal cavities were changed by the backward retraction of the tongue and posterior pharyngeal wall.

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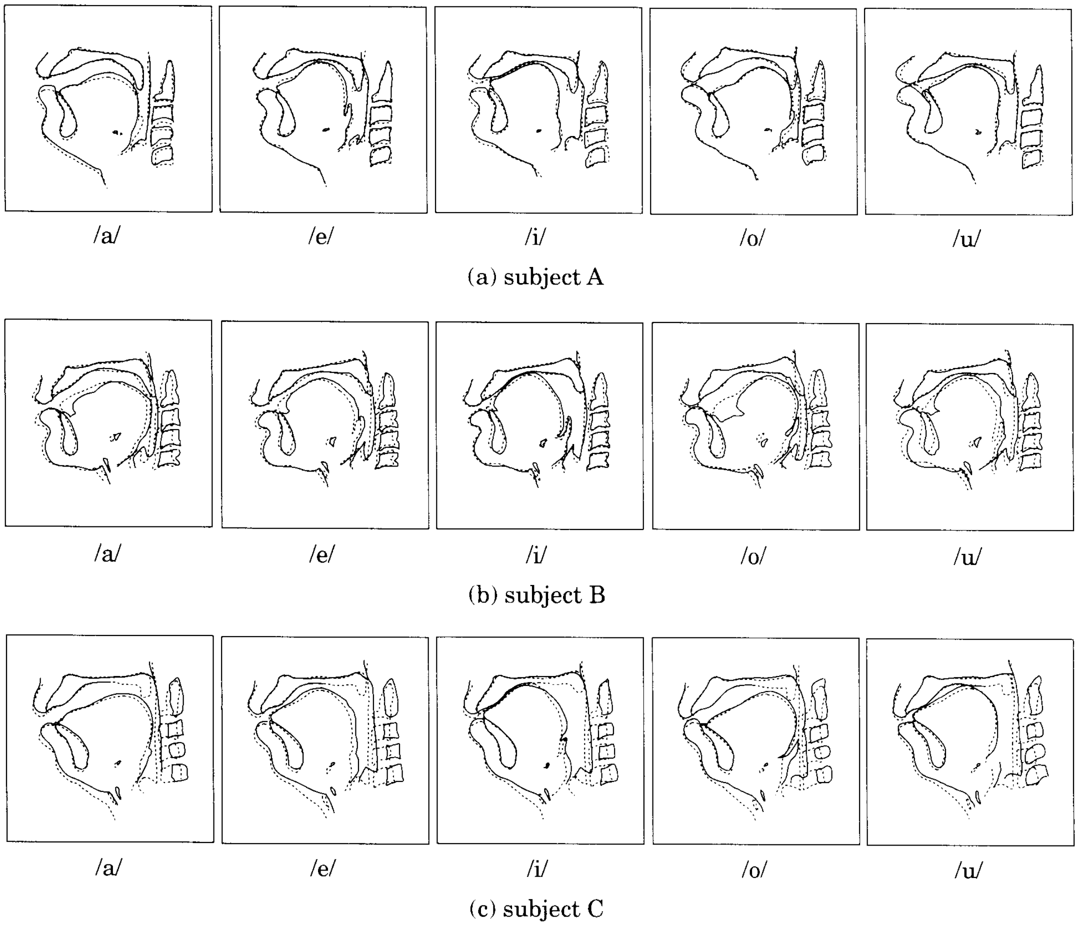

Fig. 3 Superimposed mid-sagittal outlines of speech organs for five Japanese vowels. The solid lines show outlines in the supine posture and the dashed lines show outlines in the upright posture. The outlines of the thyroid cartilage of subject A were excluded because the MR images for this structure were indistinct.

Table 1 Distances of the tongue tip between the upright and supine postures [mm].

	/a/	/e/	/i/	/o/	/u/
subject A	2	3	3	2	3
subject B	10	8	5	20	7
subject C	2	1	2	2	1

5. Conclusions

To investigate possible effects of body postures in vowel articulation, we obtained midsagittal images in upright and supine postures using the open-type MRI scanner. Comparisons of the shapes of the vocal tract and the articulators between the two postures relative to the rigid structures were carried out on three male subjects. The results show influences both on the soft tissue and rigid structures: the tongue, soft palate, and lips tend to deform according to gravity, while the positions of the jaw and larynx vary due to gravity as well as body posture. The tongue tends to be more retracted in the supine posture for back vowels than for front vowels. In the upright posture, the cervical spine and posterior pharyngeal wall were found to be more anterior, which suggests effects of head posture rather than of gravity.

Our results also indicated a strong individual difference in the effects of gravity on the tongue body, as in the case of subject B in Fig. 3(b). Therefore, it is necessary to provide appropriate instructions to the subject or to exclude the data from analysis when unnatural tongue retraction is observed.

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