—**Original**—

Physiological Studies of the Palatopharyngeal Muscle as a Speech Muscle in the Adjustment of Velar Position during Speech Production

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Background: We aimed to investigate the contribution of the palatopharyngeal muscle (PP) as a speech muscle in adjusting the velar position.
Methods: X-ray kinematic analysis of the position of the palatopharyngeal arch and an electromyographic study of the PP during speech were performed in two healthy volunteers.
Results: X-ray kinematic analysis revealed that the palatopharyngeal arch was positioned lower during the production of the low-back vowel /a/. However, no significant differences were observed between the vowels included in the nasal sounds during nasal sound productions. The electromyographic study showed higher PP activity during nasal sound productions. However, no significant differences were observed in muscle activity during the productions of five vowels or the same vowels included in the nasal sounds. During the production of two consecutive phonemes involving voiceless bilabial plosive consonants and nasal sounds, the PP activity demonstrated synchronous coordination with the levator veli palatini muscle activity. This activity was higher during the production of the low-back vowel /a/ included in the voiceless bilabial plosive consonant. It was also higher during the production of voiceless bilabial plosive sounds than during the production of voiced bilabial plosive sounds.
Conclusions: When the distance between the origin and arrest of the PP is achieved through the velar elevation, the tonic condition and muscle strength of the PP are enhanced. When the scaffold below the PP is stabilized by the contractions of the glossopharyngeal part of the superior pharyngeal constrictor muscle during the production of the low-back vowel, the PP likely contributes to regulation of the velar position. (J Nippon Med Sch 2024; 91: 446–456)

Key words: palatopharyngeal muscle, levator veli palatini muscle, glossopharyngeal part of the superior pharyngeal constrictor muscle, velum, speech

Introduction

The velum plays an important role in the upward and downward movements during swallowing, respiration, and speech production. The upward movement of the velum can be accomplished by contracting the levator veli palatini muscle (LVP), which facilitates velopharyngeal closure with the contraction of the superior pharyngeal constrictor muscle[1,2]. The downward movement of the velum is primarily mediated by the relaxation of the LVP and the elastic restoring force exerted by the soft tissue around the velum[1–3]. However, the degree of velar elevation during the production of the low-back vowel /a/ is less than that during the production of the high-front vowels /i/ and /e/. Consequently, incomplete velopharyngeal closure occurs during the production of the low-back vowel /a/ in some cases[4–6]. In addition, the

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position of the velum was higher during the production of fricative and plosive consonants than during the production of vowels[6]. During consecutive speech production, the position of the velum depends on the vowel context, differing from that in the case of monosyllabic vocalization[7]. The velar movement might not be solely mediated by the contraction of the LVP. Therefore, factors other than the contraction of the LVP and the elastic restoring force of the soft tissue may be involved in regulation of velar position. Considering the anatomical conditions, the palatoglossus muscle (PG) and palatopharyngeal muscle (PP) may affect the velar movement. However, it was reported that PG moves concomitantly with the lingual rather than the velar movement[2]. The PP acts synchronously with the LVP at velar position and velopharyngeal closure[2]. Thus, the PP could play an important role in adjusting the position of the velum. However, muscle fibers of the PP run downward from the velum in the direction opposite to that of velar elevation induced by the contraction of the LVP. The precise role of the PP in the adjustment of velar position and velopharyngeal closure remains unclear.

Using a physiological approach that included X-ray kinematics and electromyographic analysis, we investigated the potential role of the PP in the adjustment of velar position during speech production. The results indicated that the PP contributes to the position of the velum during the production of the low-back vowel and voiceless consonants. These findings were then used to assess the physiological significance of the PP.

Materials and Methods

Ethical Considerations

All procedures in the present study were approved by and conducted in accordance with the institutional ethics committee guidelines of the Nippon Medical School Hospital (approval number: 20020701). Each subject provided written informed consent prior to participating in the study. The subjects were afforded the liberty to withdraw or discontinue their participation in the study at any time, without the need to provide an explanation or receive sanctions for participating in future studies.

Subjects

Two healthy adult volunteers without articulatory disorders (Subject 1: a 42-year-old man and, Subject 2: a 34-year-old man) were examined. Both subjects were native Japanese who spoke the Tokyo dialect.

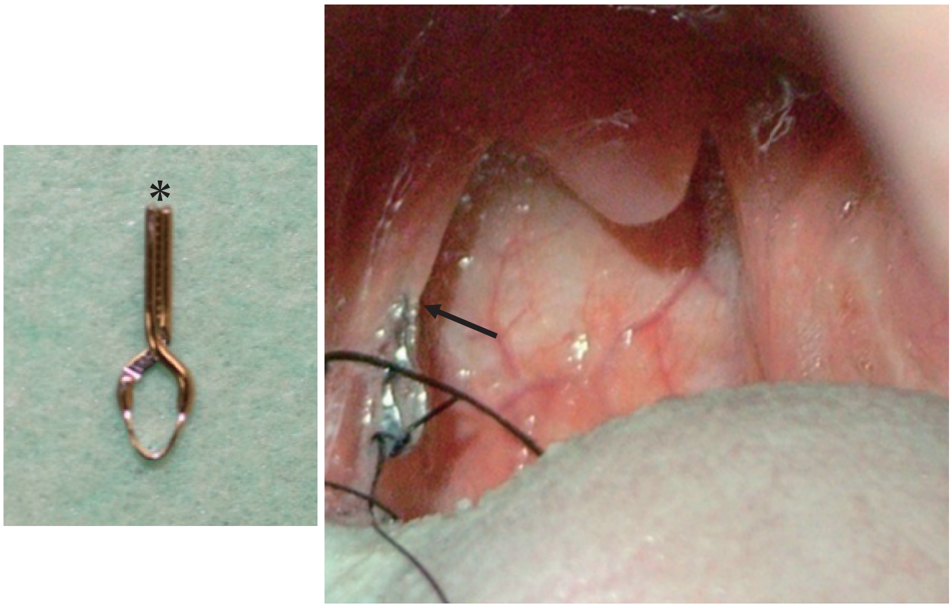
Experiment I

Kinematic analysis of the PP during speech production

The PP is covered by the mucosa and attached to the posterior area of the velum as the palatopharyngeal arch. Therefore, the palatopharyngeal arch moves concomitantly with the upward and downward movements of the velum during the production of various speech sounds. Further contraction of the PP may affect the degree of the adjustment in the position of the palatopharyngeal arch. Therefore, we investigated the changes in the position of the palatopharyngeal arch during the production of vowels or nasal sounds in two healthy volunteers.

Speech tasks: Five vowels (/i/, /e/, /a/, /o/, and /u/), palatal nasal sounds (/ni/, /ne/, /na/, /no/, and /nu/), and bilabial nasal sounds (/mi/, /me/, /ma/, /mo/, and /mu/) followed by the same vowels, were examined.

Methods: Lateral X-ray fluorography of the mid-pharyngeal cavity was performed. Imaging results were recorded on s-VHS videotapes. Then, an extremely small cobalt chromium alloy vascular clip for neurosurgery (Mizuho, Sugita AVM Microclip) was attached to the upper and lower middle portions of the palatopharyngeal arch on the right side (**Fig. 1a and b**). An extra-fine nylon thread was connected to the end of the clip to prevent the detached clip from dropping into the pharyngeal cavity. The other end of the nylon thread was placed outside the mouth. The subjects were requested to keep a consistent positional relationship between the head and body axis. Using lateral X-ray fluorography imaging, we investigated the position of the tip of the clip attached to the palatopharyngeal arch during the production of speech tasks (**Fig. 2**). For image analysis, an imaginary line parallel to the anterior surface of the second cervical vertebra was established as the axis. Subsequently, a line vertical to the imaginary line was projected through the tip of the clip, and the height of the tip of the clip on the imaginary line during speech production was measured. To compare the height of the tip of the clip across speech tasks, its height during the production of the bilabial nasal sound /mi/ was assumed to be 0 (0%), while that during the production of the high-front vowel /i/ was assumed to be the standard value of 100%. Subsequently, each measured value was divided by the width between the upper and lower ends of the anterior surface of the second cervical vertebra, to standardize the data[6,8,9]. Each speech task was performed three times, and the average of the kinematic measurements was obtained. The rela-



(a) (b)

Fig. 1 The neurosurgical clip to be attached to the palatopharyngeal arch and the site of attachment
(a) A vascular clip for neurosurgery measuring 3 mm in length. The tissue is held by opening the tip of the clip (*).
(b) The attachment (black arrow) to the upper and lower middle portions of the palatopharyngeal arch on the right side with nylon thread was appended to the other end of the clip to prevent it from falling into the pharyngeal cavity.

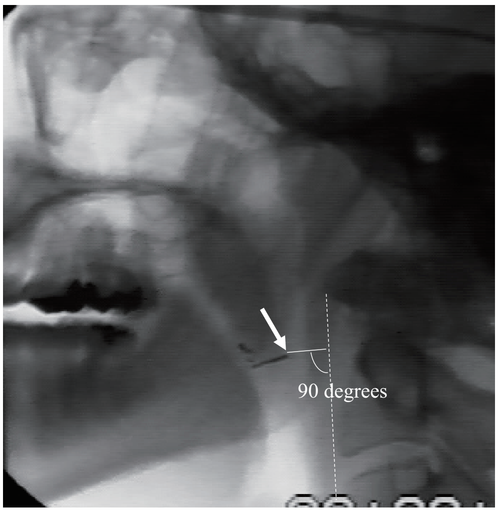


Fig. 2 X-ray image of the side of the tip of the clip attached to the palatopharyngeal arch.
With regard to the position of the tip of the clip (white arrow) attached to the palatopharyngeal arch, an imaginary line (dotted line) parallel to the anterior surface of the second cervical vertebra was established as an axis. Then, a line (solid line) vertical to the imaginary line was projected through the tip of the clip. The height of the tip of the clip on the imaginary line during the speech production were measured.

tive heights of the tip of the clip during each speech task were compared. The paired t-test was used for statistical analysis ($p < 0.05$).

Experiment II

Electromyographic studies of the PP and LVP

The electromyographic activities of the PP and LVP were recorded. Bipolar hooked-wired electrodes were used for the electromyographic recordings during speech production. The electrodes for monitoring the PP and LVP were inserted per-orally, as detailed below.

Insertion of the electrode for the PP: The electrode for the PP was inserted per-orally into the upper and lower middle portions of the palatopharyngeal arch. Proper placement of the electrode for the PP was verified by determining whether the muscle activity increased upon sniffing[2,3].

Insertion of the electrode for the LVP: The electrode for the LVP was inserted per-orally into a lateral area adjacent to the palatal dimple that formed during the contraction of the LVP, which was observed when the velum was elevated during the production of the vowel /a/. Proper placement of the electrode for the LVP was verified by determining whether muscle activity increased during the production of non-nasal sounds and was suppressed during sniffing[2,3].

The subjects were requested to keep a consistent positional relationship between the head and body axis. Subsequently, we investigated the amplitudes of the electromyographic signals of the PP and LVP during speech production in these two healthy volunteers.

(1) Electromyographic activities of the PP and LVP during the production of five vowels and the same vowels included in the nasal sounds

Speech tasks: The vowels (/i/, /e/, /a/, /o/, and /u/), palatal nasal sounds (/ni/, /ne/, /na/, /no/, and /nu/), and bilabial nasal sounds (/mi/, /me/, /ma/, /mo/, and /mu/) were examined. The speech tasks were performed out five times.

Methods: The electromyographic signals generated during the production of five vowels and the same vowels included in the nasal sounds from the middle portion of each voice signals were recorded for 0.2 seconds[3,8]. These signals were integrated using a wave analyzer system on a personal computer. Subsequently, the amplitudes of the five integrated electromyographic signals were averaged. The average activity of the PP during the production of /a/ was assumed to be the standard value (100%) of the activity of the PP, while the average activity of the LVP during the production of /a/ was assumed to be the standard value (100%) of the activity of LVP[8]. The average activities of these muscles during the production of vowels and the same vowels included in the nasal sounds were compared. A paired t-test was used for performing statistical analyses ($p < 0.05$).

(2) Electromyographic activities of the PP and LVP during the production of vowels included in the two consecutive phonemes consisting of voiceless bilabial plosive consonants and nasal sounds

Speech tasks: The speech tasks consisted of two phonemes: voiceless bilabial plosive sounds as the first phoneme, and nasal sounds as the second phoneme. As the bilabial plosive sound /p/ did not affect tongue movement, bilabial plosive sounds were considered useful for comparing the electromyographic activities of the PP and LVP during the productions of vowels included in other speech tasks. For the first phoneme, the vowels that followed the voiceless bilabial plosive sound /p/, the low-back vowel /a/, or the high-front vowel /e/ were adopted. For the second phoneme, the low-back vowel /a/ and the high-front vowel /e/ were adopted as vowels that followed the nasal sound /n/. The following speech tasks were performed:

a) A speech task comprising the voiceless bilabial plosive sound /p/ and the low-back vowel /a/ as the 1st phoneme: /pan/, /pana/, and /pane/

b) A speech task comprising the voiceless bilabial plosive sound /p/ and the high-front vowel /e/ as the 1st phoneme: /pen/, /pena/, and /pene/

All the speech tasks were carried out five times.

Methods: The electromyographic signals generated during the production of vowels included in both voiceless bilabial plosive sounds and nasal sounds in the middle portion of each voice signal for 0.2 seconds[3,8]. The signals were integrated using a wave analyzer system on a personal computer. The amplitudes of the five integrated electromyographic signals were then averaged. The average activity of the PP during the production of /a/ included in /pan/ was assumed to be the standard value (100%) of the activity of the PP, and the average activity of the LVP during the production of /a/ included in /pan/ was assumed to be the standard value (100%) of the activity of the LVP[8]. The average activities of these muscles during the production of vowels included in bilateral labial plosives and nasal sounds were compared. A paired t-test was performing for statistical analyses ($p < 0.05$).

(3) Electromyographic activities of the PP and LVP during the production of vowels included in the two consecutive phonemes consisting of voiced bilabial plosive consonants and nasal sounds

Speech tasks: The speech tasks consisted of two phonemes: voiced bilabial plosive sounds as the first phoneme, and nasal sounds as the second phoneme. As the voiced bilabial plosive sound /b/ did not affect tongue movement, bilabial plosive sounds were considered useful for comparing the electromyographic activities of the PP and LVP during the productions of vowels included in other speech tasks. For the first phoneme, the vowels that followed the voiced bilabial plosive sound /b/, the low-back vowel /a/, or the high-front vowel /e/ were adopted. For the second phoneme, the back-low vowel /a/ and the high-front vowel /e/ were adopted as the vowels that followed the nasal sound /n/. The following speech tasks were performed:

c) A speech task comprising the voiced bilabial plosive sound /b/ and low-back vowel /a/ as the 1st phoneme: /ban/, /bana/, and /bane/

d) A speech task comprising the voiced bilabial plosive sound /b/ and high-front vowel /e/ as the 1st phoneme: /ben/, /bena/, and /bene/

All speech tasks were carried out five times.

Methods: The electromyographic signals generated

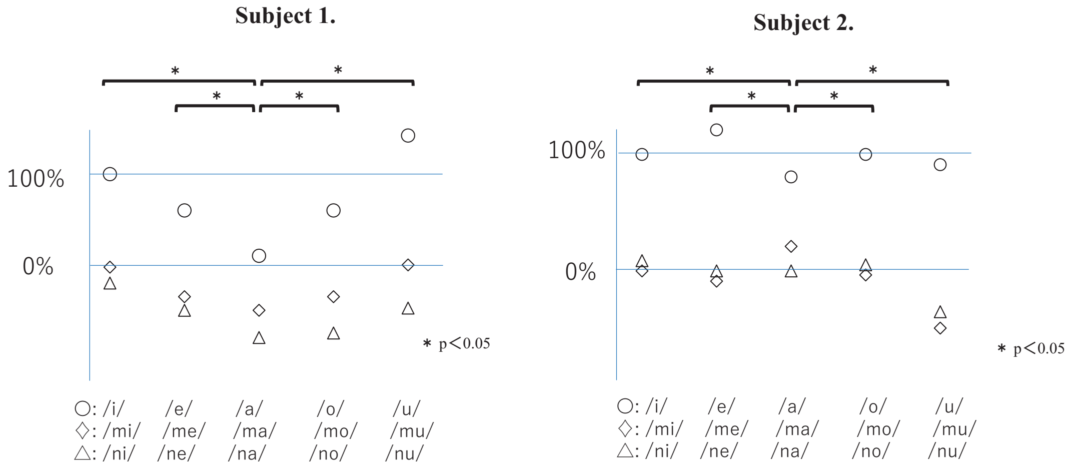


Fig. 3 Position of the tip of the clip attached to the palatopharyngeal arch during the production of vowels and the same vowels included in the nasal sounds. The position on the virtual line along the anterior surface of the 2nd cervical vertebra was compared by dividing it by the length between the upper and lower ends on the anterior surface of the 2nd cervical vertebra to standardize the data. The position of the clip of the tip during the production of the sound /i/ was set as 100%, while that during the production of the sound /mi/ was set as 0%.

during the production of vowels included in the voiced bilabial plosive sounds and nasal sounds in the middle portion of each voice signals were recorded for 0.2 seconds[3,8]. The signals were integrated using a wave analyzer system on a personal computer. The amplitudes of the five integrated electromyographic signals were then averaged. To compare the average activities of these two muscles, the average activity of the PP during the production of /a/ included in /pan/ was assumed to be the standard value (100%) of the activity of the PP, while the average activity of the LVP during the production of /a/ included in /pan/ was assumed to be the standard value (100%) of the activity of the LVP, as calculated in Experiment II-(2)[8]. The average activities of these muscles during the production of vowels in both voiced bilabial plosive sounds and subsequent nasal sounds were compared. In addition, the results were compared with those obtained during the production of the voiceless bilabial plosive sound /p/ as the 1st phoneme (Experiment II-(2)). The paired t-test was used for statistical analysis ($p < 0.05$).

Results

Kinematic Analysis of the Palatopharyngeal Arch

The two subjects exhibited similar results (**Fig. 3**). The height of the tip of the clip attached to the palatopharyngeal arch was significantly lower during the production of palatal and bilabial nasal sounds than during the production of the five vowels. The height of the tip of the clip was significantly lower during the production of the low back vowel /a/ than during the production of the other vowels. However, no significant differences were observed in the height of the tip of the clip during the production of vowels included in the nasal sound.

Electromyographic Activities of the PP and LVP during the Production of Vowels and the Same Vowels Included in the Nasal Sounds

The two subjects exhibited similar results (**Fig. 4**). The activities of the PP during the production of the five vowels were smaller than those during the production of the same vowels included in the nasal sounds. The activity of the LVP during the production of the five vowels was greater than that during the production of the same vowels included in the nasal sounds. However, no significant differences were observed in the muscle activities of the PP and LVP between the five vowels or the same vowels included in the nasal sounds.

Electromyographic Activities of the PP and LVP during the Production of Vowels Included in the Two Consecutive Phonemes Consisting of Voiceless Bilabial Plosive Consonants and Nasal Sounds

The two subjects exhibited similar results (**Fig. 5**). The activities of the PP and LVP during the production of voiceless bilabial plosive consonants as the 1st phoneme were significantly greater than those during the production of nasal sounds as the 2nd consonant. The activity of the PP during the production of the low back vowel /a/ included in the voiceless bilabial consonants as the 1st phoneme was significantly greater than during the production of the front-high vowel /e/ included in voiceless

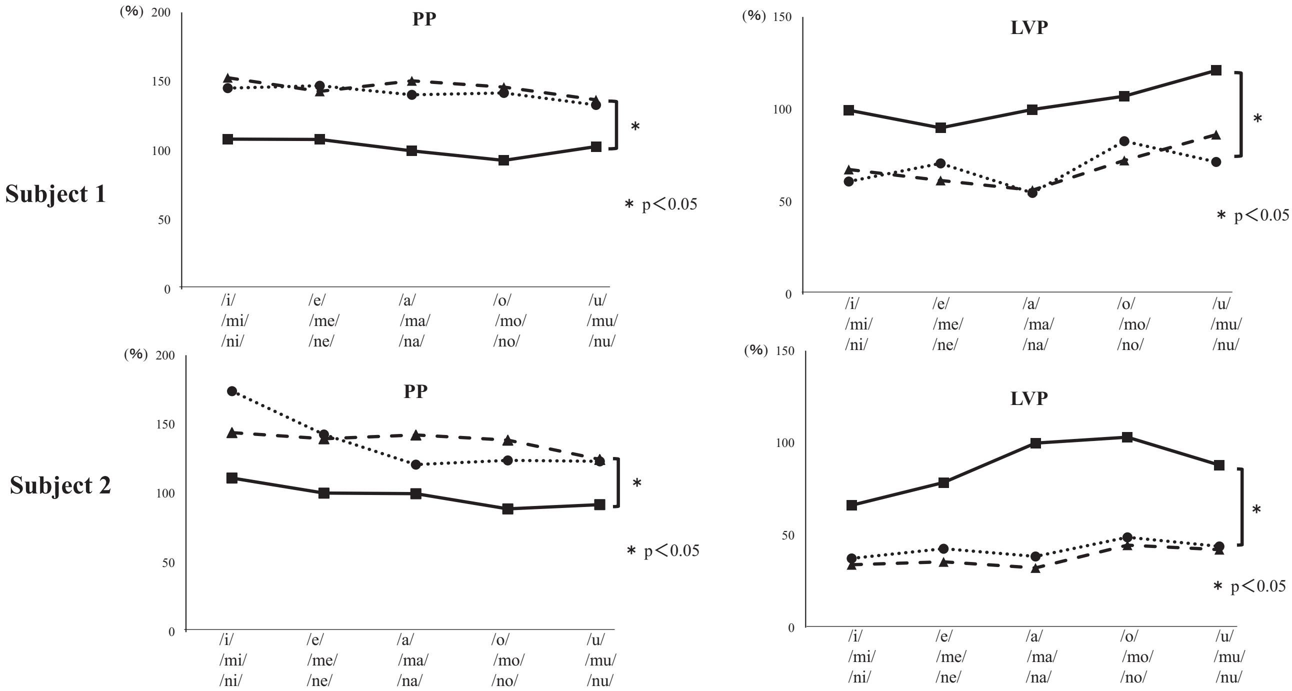


Fig. 4 Averaged integrated electromyographic activities of the PP and the LVP during the production of five vowel sounds and the same vowels included in the labial and palatal nasal sounds. The integrated electromyographic value during the production of the continuous vowel /a/ was set as 100%; relative values are presented.
■ Vowel, ● Labial nasal sound /m/, ▲ Palatal nasal sound /n/

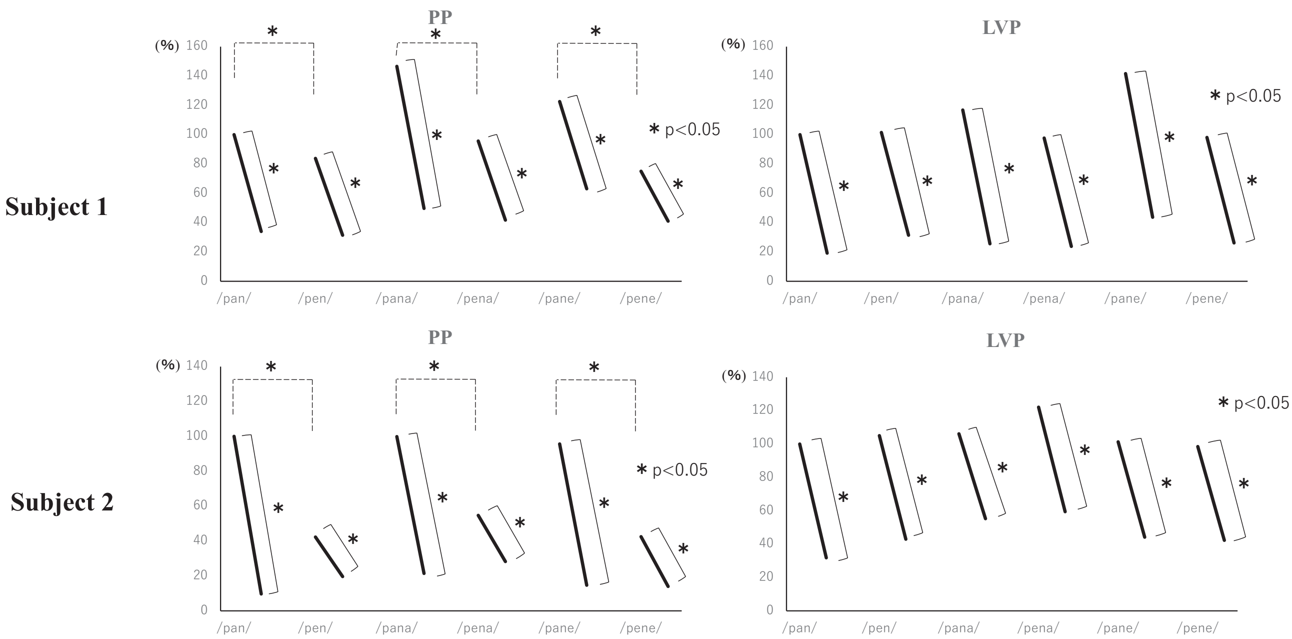


Fig. 5 Averaged integrated electromyographic activities of the PP and the LVP during the production of two phonemes composed of voiceless bilabial plosive and nasal sounds. The averaged integrated electromyographic activities of the PP and the LVP during the production of the sound /a/ included in /pa/ were assumed to be the standard value (100%) of each muscle. Then, the average activities of the muscles during the production of consecutive two phonemes were compared. PP; palatopharyngeal muscle, LVP; levator veli palatine muscle

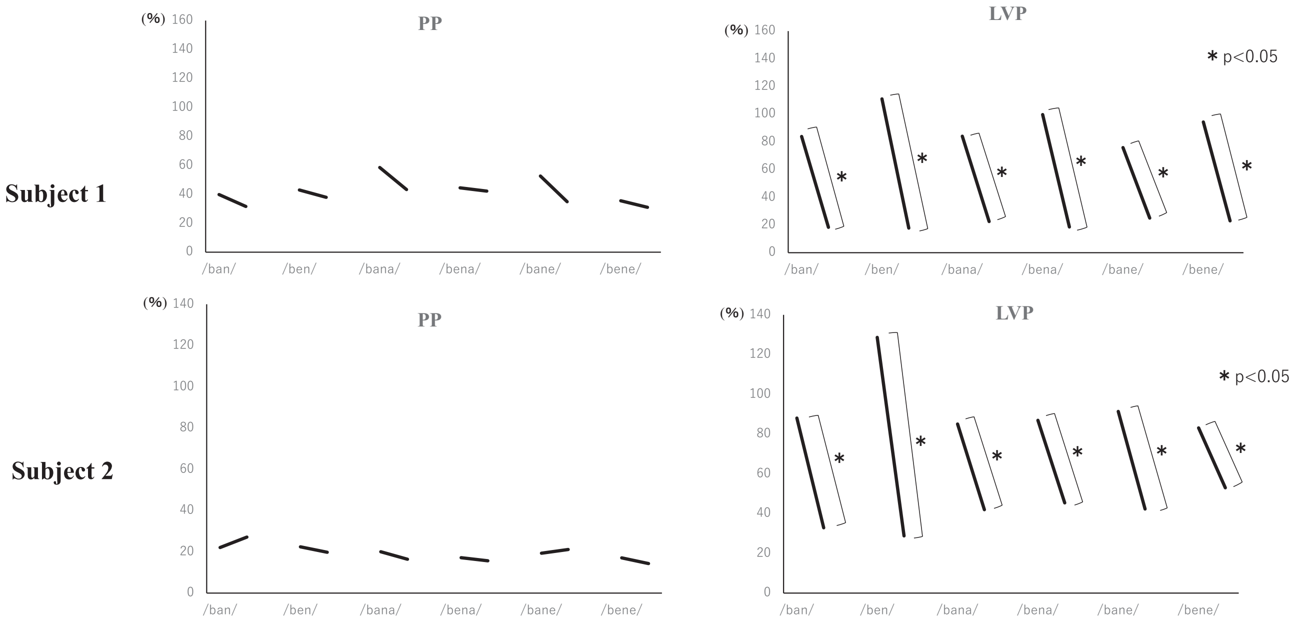


Fig. 6 Averaged integrated electromyographic activities of the PP and the LVP during the production of two phonemes composed of voiced bilabial plosive and nasal sounds. The averaged integrated electromyographic activities of the PP and the LVP during the production of the sound /a/ included in /pa/ were assumed to be the standard value (100%) of each muscle. Then, the average activities of the muscles during the production of consecutive two phonemes were compared. PP; palatopharyngeal muscle, LVP; levator veli palatine muscle

bilabial consonants. However, no significant differences were seen in the activities of the LVP during the production of /a/ and /e/ included in the voiceless bilabial consonants. Moreover, no significant differences were seen in the activities of the PP and LVP during the production of nasal sounds alone, the low-back vowel, or the high-front vowel included in nasal sounds as the 2nd consonant.

Electromyographic Activities of the PP and LVP during the Production of Vowels Included in the Two Consecutive Phonemes Consisting of Voiced Bilabial Plosive Consonants and Nasal Sounds

The two subjects exhibited similar results (**Fig. 6**). No significant differences were seen between the activity of the PP during the production of voiceless bilabial plosive consonants as the 1st phoneme and that during the production of nasal sounds as the 2nd consonant. In contrast, the activities of the LVP were significantly greater during the production of voiced bilabial plosive consonants as the 1st phoneme than during the production of nasal sounds as the 2nd consonant. Moreover, no significant differences were noted in activity of the PP between the back-low /a/ and the high-front vowel /e/. The activities of the PP during the production of vowels included in the voiced bilabial plosive consonants as the 1st consonant were significantly smaller than those included in the voiceless bilabial consonants (**Fig. 7**). No differences were seen in the activity of the LVP during the production of vowels between voiceless and voiced plosive consonants (**Fig. 8**). Furthermore, no significant differences were seen in the activities of the PP and LVP during the production of nasal sounds alone, the low-back vowel, or the high-front vowel included in the nasal sounds as the 2nd consonant (**Fig. 6**).

Discussion

The PP acts synchronously with the LVP during velar elevation and velopharyngeal closure. The activities of the PP during the production of the low-back vowels /a/ and /o/ are greater than those during the production of the high-front /i/ and /e/[2,5]. Hirose[3] reported that the PP might support velar elevation of the velum and velopharyngeal closure during the contraction of the LVP. However, muscle fibers of the PP run down from the velum in a direction opposite to that of velar elevation induced by the contraction of the LVP. The anatomical conditions of the PP make it a unique muscle. It does not attach to hard structures, such as bony or cartilaginous structures, which function as scaffolds. This surrounding condition of the PP suggests that even when the PP contracts independently, it may not generate sufficient muscle strength, but leaves the position of the velum unaffected. The PP is attached to the velum through the LVP, which is divided into the superficial and deep fas-

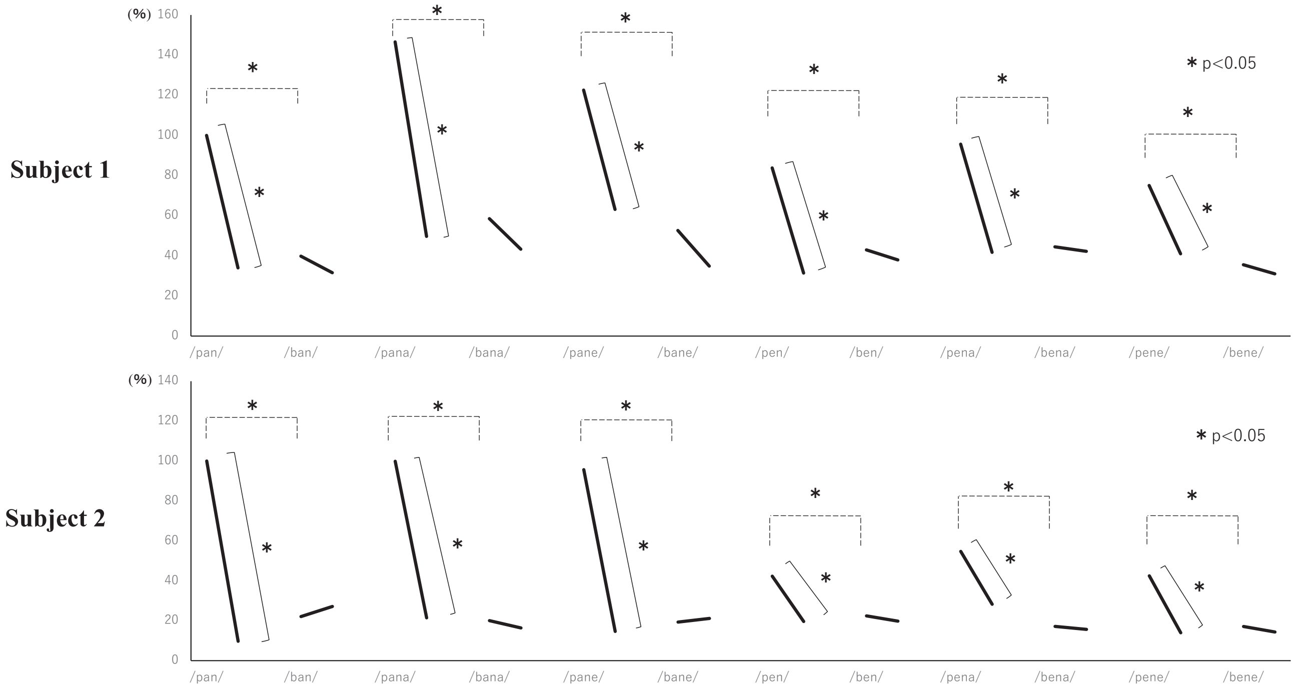


Fig. 7 Averaged integrated electromyographic activities of the PP during the production of voiceless bilabial plosive-nasal sounds and voiced bilabial plosive-nasal sounds. PP; palatopharyngeal muscle

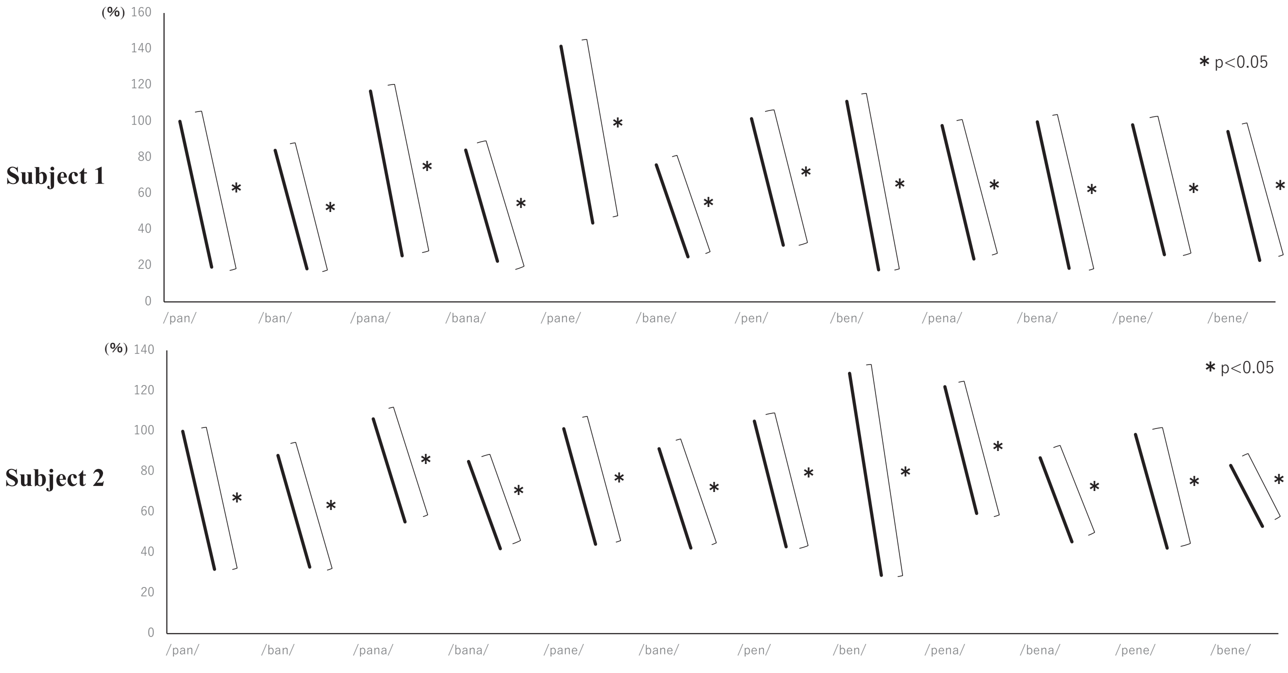


Fig. 8 Averaged integrated electromyographic activities of the LVP during the production of voiceless bilabial plosive-nasal sounds and voiced bilabial plosive-nasal sounds. LVP; levator velli palatine muscle

ciculi[10,11]. The superficial fascicle of the PP is thick and originates from the median of the velum and the posterior margin of the palatine aponeurosis on the oral side of the velum. The deep fascicle is thin and originates from the submucosal area on the side of the velopharyngeal port and the submucosal area of the uvula. The superficial and deep fasciculi converge to form the palatopharyngeal arch, then joining with the fibers of the salpingopharyngeal muscle. Subsequently, the superficial fascicle passes as if being caught through the area between the glossopharyngeal part of the superior pharyngeal constrictor muscle (GSPC) and the middle pharyngeal constrictor muscle, eventually converging with the stylopharyngeal muscle that passes through the same area. On the other side, the deep fascicle of the PP converges at the median raphe via the posterior lateral area of the mid-pharynx. Therefore, the deep fascicle does not affect the position of the velum. The GSPC is connected to the transverse lingual muscle as an intrinsic muscle at the base of the tongue, comprising a ring-like structure. It simultaneously induces retrusive tongue movement and contraction of the mid-pharynx during the production of the low-back vowel /a/[8,12]. Thus, the superficial fascicle of the PP is affected by the degree of the contraction of the GSPC stabilizing a scaffold below the PP and contributes to the adjustment of velar position during the contraction of the GSPC. Velar elevation induced by the contraction of the LVP could also affect the tonic condition of the PP and enhance its muscle strength.

In this study, X-ray kinematic analysis revealed that the position of the palatopharyngeal arch was lower during the production of nasal sounds than during the production of the five vowels, as Niimi[4] described. Among the vowels, the position of the mid-portion of the palatopharyngeal arch was significantly lower during the production of the low-back vowel /a/ than during the production of the other vowels. However, during the production of nasal sounds, no significant differences were observed in the position of the mid-portion of the palatopharyngeal arch among the five vowels included in the nasal sounds. Electromyographic studies showed that the activities of the PP during the production of the five vowels were smaller than those during the production of the same vowels included in the nasal sounds. The activity of the LVP during the production of vowels was greater than that during the production of the same vowels included in nasal sounds. However, no significant differences were observed in the activities of the PP and LVP during the production of the five vowels or the same vowels included in the nasal sounds, as previously reported[2,3,13]. The likely reasons for these findings are as follows. Because the scaffold below the PP can be stabilized by the contraction of the GSPC during the production of the low-back vowel /a/, the upward movement of the velum in this state induces a tonic condition of the PP and enhances the muscle strength of the PP. The position of the mid-portion of the palatopharyngeal arch was significantly lower during the production of the low-back vowel /a/. Although the distance between the origin of the PP and the scaffold below is shortened by the descent of the velum, the muscle strength related to the contraction of the PP did not affect the velar position during the production of the low-back vowel /a/.

Electromyographic studies of the PP and LVP during the production of two consecutive phonemes consisting of voiceless bilabial plosive consonants and nasal sounds showed that the activity of the PP synchronized with that of the LVP. The activity of the PP during the production of the low-back vowel /a/ included in the voiceless bilabial consonants as the 1st phoneme was significantly greater than that during the production of the high-front vowel /e/ included in the voiceless bilabial consonants. However, no significant differences were found in the activities of the LVP during the production of /a/ and /e/ included in the voiceless bilabial consonants. No significant differences were seen in the activities of the PP and LVP during the production of the nasal sound alone, the low-back vowel /a/, or the high-front vowel /e/ included in the nasal sounds as the 2nd consonant. These results suggest that the tonic condition of the PP might have been achieved by the elevation of the velum induced by the contraction of the LVP and the enhancement of the muscle strength of the PP. With the reduction in the activities of the LVP, the velum may have descended[2,3,5,13], thereby reducing the tension and activity of the PP. In addition, during the production of the low-back vowel /a/ induced by the contraction of the GSPC upon the elevation of the velum, the tonic condition and muscle strength of the PP were enhanced by the stabilization of the scaffold below the PP.

Regarding the relationship between voiced and voiceless consonants, the timing of glottal closure or narrowing is more advanced during the production of voiced consonants than during the production of voiceless consonants, which increases intra-oral pressure. Moreover, the volume of the vocal tract is larger during the production of voiced consonants than during the production of voiceless consonants[6,14]. The position of the velum and the activity of the LVP during the production of voiced consonants were higher than during the production of voiceless consonants[2,3,6]. However, speaking languages with fluency or naturalness, especially those involving voiceless/voiced consonants, may be compromised if the volume of the vocal tract is altered phoneme by phoneme because of other conditions affecting the speech muscles. In this study, the activity of the PP was smaller during the production of voiced bilabial plosive sounds than during the production of voiceless bilabial plosive sounds. Rosenberg[9] estimated that the enlargement of the pharyngeal wall during the production of voiced conso-

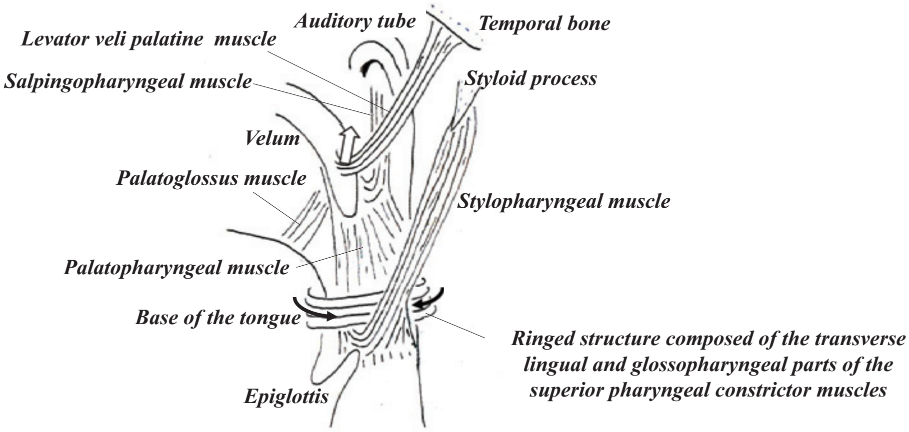


Fig. 9 A diagram showing anatomical and functional relationships between the palatopharyngeal muscle, levator veli palatine muscle, and the ringed structure composed of the glossopharyngeal part of the superior pharyngeal constrictor and transverse lingual muscles at the base of the tongue. The contraction of the levator veli palatine muscle contributes to the upward tension in the upper part of the palatopharyngeal muscle (white arrow), and the ringed structure composed of both the glossopharyngeal part of the superior pharyngeal constrictor muscle and the transverse lingual muscle at the base of the tongue serves as the scaffold for the lower part of the palatopharyngeal muscle (black arrows).

nants is likely attributable to the contraction of the stylopharyngeal muscle as a pharyngeal elevator muscle. The present results suggest that the upward and outward displacement of the pharyngeal wall caused by the contraction of the stylopharyngeal muscle during the production of voiced consonants decreases the tonic condition of the PP by stabilizing the scaffold below the PP. Procter[6] reported that during the production of voiced fricative consonants the pharyngeal cavity expanded into the upper pharyngeal region above the epiglottis and below the uvula. The present results suggest that the reduced tonic condition of the PP might not contribute to the narrowing of the fauces, which could be useful for enlarging the volume of the vocal tract during the production of voiced consonants. Enlargement of the volume of the vocal tract during the production of voiced consonants could also be useful for sustaining vocal folds vibrations during the glottal closure interval of voiced consonants[6,14]. By contrast, the tonic condition of the PP during the production of voiceless consonants could be useful in maintaining the position of the velum against increasing intraoral pressure before vocal fold vibrations.

In general, muscle strength and tonus are influenced by the degree of contraction of muscles with scaffolds of hard structures, including bone or cartilage. However, muscles lacking such a scaffold, such as intrinsic lingual muscle, are affected by the condition and position of the beginning and end of the muscle. Thus, the degree of muscle tonus and the distance of the movement of the organ to which the muscle is attached could be adjusted based on the flexible patterns of the surrounding conditions. Therefore, the PP, LVP, and GSPC could contribute to the changes in human speech production and communication under various conditions, including the production of nasal/non-nasal sounds, front/back vowels, and voiceless/voiced sounds with flexible positioning of the velum (**Fig. 9**). Among the pharyngeal muscles, extremely few muscle spindles, Golgi tendon organs, or free nerve endings are responsible for muscle-inherent perception[15]. However, a small number of muscle spindles were detected in the LVP and PG[16]. Muscle spindles have not been detected in the PP. However, the muscle spindles are responsible for the length-control system by which the muscle length is maintained through inputs to antagonize muscles. Some inputs might occur from muscle spindles in the LVP to the PP. Conversely, a small number of muscle spindles may facilitate regulation of free movement independently of muscle spindle control. This mechanism contributes to the fluent production of nasal/non-nasal sounds, voiceless/voiced sounds, and front/back vowels.

Further investigations of the motor control of the human velum and velopharyngeal port are therefore warranted.

Conclusions

When the distance between the origin and arrest of the PP is achieved through the velar elevation, the tonic condition and muscle strength of the PP are enhanced. When the scaffold below the PP is stabilized by the contractions of the glossopharyngeal part of the superior pharyngeal constrictor muscle during the production of the low-back vowel, the PP likely helps to regulate the velar position.

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