FUNDAMENTAL TONGUE MOTIONS FOR TRUMPET PLAYING

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ABSTRACT

OBJECTIVE: Though the motions of the outside of the mouth in trumpet performance have been reported, the dynamics of intraoral structures remain unelucidated. This study explored tongue's movement in trumpet playing using cine magnetic resonance imaging (cine MRI) and demonstrated the effects of intraoral anatomical structures on changes in pitch and dynamics.

METHODS: Cine MRI was applied to 18 trumpet players, who were divided into two groups according to level (beginner n = 7 and advanced n = 11) based on their ability to play a certain high note. They were instructed to play a custom-made MRI-compatible simulated trumpet. Pitch-change tasks and dynamics-change tasks were assigned. The positions of the anatomical points and intraoral areas were identified on the outlined images and the changes associated with each task were evaluated.

RESULTS: A forward and upward projection of the tongue was observed in the production of higher pitches, and there were no significant differences in the areas. In louder dynamics, a backward and downward bending occurred, the tongue area became smaller, and the cavity area became larger ($p < 0.001$ and $p < 0.001$, respectively). No significant differences between beginner and advanced were seen in the changes in pitch and dynamics.

CONCLUSION: It was demonstrated using cine MRI that certain tongue movements were associated with each task. Tongue protrusion in the production of higher pitch and bending in louder dynamics can be rationalized using acoustics theory and the movements of anatomical structures. These findings seem to be consistent regardless of proficiency.

TEXT

The playing of brass instruments requires appropriate breath control. The oral cavity is the air's main pathway from the lungs and plays an important role in controlling breathing.[1] For example, the controlling the space between upper and lower teeth is crucial for transferring air pressure to lip vibration, and larynx affects air modulation.[2] Although changes in the orofacial area have been partially visualized using various techniques, such as endoscopy[2] and stroboscopy,[3] it has been challenging to observe tongue movements in the oral area's main part. With the recent development of cine magnetic resonance imaging (cine MRI) technology, we can now observe the brass players' oropharyngeal area. Previous studies have used similar technology for professional players of the trumpet (1 player, Kaburagi;[4] 12 players, Schumacher[5]) and French horn (more than 20 players, Iltis[6–8]). Furthermore, Iltis examined amateur-level trumpet, French horn, trombone, and tuba players.[9] In these studies, several promising findings about the intraoral region in brass instrument performance were reported: 1) in the production of higher pitches, the tongue is positioned more anteriorly[4] and increases in the total free space of the oral and the pharyngeal cavity were observed;[5,9] 2) as an increase in the total free space was also observed in louder dynamics.[5] However, few researchers have examined unskilled trumpet players, so the fundamental motor strategy of the oral area in trumpet playing remains poorly understood. This study explored the tongue's movement in trumpet playing using cine MRI and demonstrates the effects of intraoral anatomical structures on changes in pitch and dynamics. Additionally, we elucidate the distinctions in the proficiency level from cine MR images.

METHODS

Subjects

In all, 18 healthy trumpet players served as voluntary participants in the current study. All the participants had no signs or symptoms, past history, and interventions in the head and neck regions. The mean age of participants was 32.4 yrs (range 21-66), and 39% were woman. They were classified into groups at two levels (beginner and advanced) based on whether or not they were able to play a certain high note (F5, concert pitch). According to the criteria, 1 professional player and 10 amateur players were included in the advanced group.

-- College's ethics committee and institutional review board approved the research protocol. Written informed consent was obtained from all participants before the experiment.

Simulated trumpet

All exercises were played using a custom-made MRI-compatible simulated trumpet. This was the same instrument as was used in Kaburagi's study.[4] Polyvinyl chloride tubes were used to mimic the bore of an actual B-flat trumpet (Yamaha YTR-2320E) with an acrylic mouthpiece. Prior to performance, subjects were allowed to practice with the simulated trumpet until they felt comfortable performing the exercises. A level check was conducted and set pitch values were prerecorded before the examination.

Task

The subjects were instructed to play two exercises, using a sustained tone, along with the metronome (Fig. 1). The first exercise included sustained low and high notes at the dynamic level mezzo forte (*mf*). The second exercise involved sustained middle notes at different dynamics, pianissimo (*pp*) and fortissimo (*ff*). B-flat3, B-flat4, and F5 were used if possible, but the pitch values were adjusted based on the player's skill. The dynamics level was perceptually graded by each subject in accordance with following criteria: *mf* was the most comfortable dynamics to produce an intended note; *pp* was the minimum voluntary dynamics; *ff* was the maximum voluntary dynamics. Every task period was 30 seconds in duration and each tone was performed four times after the task's computer demonstration.

Cine MRI

The examination was performed using a 1.5-T MR scanner (Philips Healthcare, Best, The Netherlands) with a 16-channel Neurovascular coil. Sagittal 2D real-time image sequences using a T1-Fast Field Echo technique with Cartesian k-space sampling were applied. A frame rate of 4.55 fps was used, with the following parameters: TR = 3.54 ms, TE = 1.14

ms, flip angle = 5°, SENSE reduction factor = 3.5, acquisition matrix size = 144 × 144, reconstruction matrix = 0.5 × 0.5 mm, field of view (FOV) = 216 × 216 mm, slice thickness = 15 mm, number of dynamic scans = 140, and total scan duration = 30.5 s per sequence.

Within 1 cine MRI (30.5 s) session, after the computer demonstration played (3 s) and a rest period (3 s), the participants repeated sustained tone playing (3 s), with resting (3 s) four times. All exercises were played along with an electronic metronome sound from a speaker. MR scans were manually started in concert with the rhythm.

The subjects were placed in the supine position and their heads were positioned with the Frankfort plane perpendicular to the floor. Cine MR images were obtained in a mid-sagittal plane set with reference to the anterior nasal spine and the spinous process of the third cervical vertebra.

Image preparation

To enable the quantification of image data, image preparation using a Fiji image processing program (http://fiji.sc/) was used for MR images.[10] First, MRI data in the Digital Imaging and Communications in Medicine (DICOM) format were imported into Fiji (Fig. 2A) and note durations were visually determined for each task. A note’s start time was defined when both velopharyngeal closure and stable tongue were achieved and the end time was determined when either was lost. Second, each tone’s middle five images were selected and averaged. The averaged images were then binarized and converted to outlined images. Four outlined images per task were used for further analysis.

Data analysis

Seven positions of anatomical points, eight distances between pairs of points, and three intraoral areas were measured in each outlined image. The coordinate origin was set as the image's lower left corner. We used the following coordinate system: x-axis in the anterior–posterior direction (positive posteriorly), y-axis in the caudocranial direction (positive superiorly).

First, three points of the hard tissue, mandibular bone (Me), hyoid bone (Hy), and sella turcica (S), were manually noted, and four tongue points, centroid (Cent), the highest point (High), tongue tip (Tip), and the most posterior point (Back), were calculated from the coordinates of the tongue area outline (Fig. 2B). Details of how we set the tongue points are as follows: Cent was the tongue area's centroid; High was the point with the highest y-coordinate within the tongue area; Tip was the point with the leftmost x-coordinate within the tongue area; and Back was the point with the rightmost x-coordinate within the tongue area except for the epiglottis.

Second, eight distances between two anatomical points that reflect the muscles' directions were measured. The muscles of interest in the images are the three extrinsic tongue muscles, the genioglossus (GG) muscles, the hyoglossus (HG) muscles, and the geniohyoid (GH) muscles, as well as one set of intrinsic tongue muscles, the superficial longitudinal (SL) muscles. In basic terms, the extrinsic muscles adjust tongue position and the intrinsic muscles make the tongue shape.[11] The measured muscles' details and corresponding distances are as follows: the GG muscles are the fan-shaped paired muscles originating from the mental spine of the mandible that are inserted throughout the tongue, corresponding to

Me-Tip, Me-High, and Me-Back; the HG muscles originate from the hyoid bone, are inserted along the tongue's length, and correspond to Hy-Tip, Hy-High, and Hy-Back; the GH muscles connect the mental spine of the mandible and the hyoid bone corresponding to Me-Hy; and the SL muscles originate from the tongue's back part and are inserted into the tongue tip, corresponding to the Tip-Back. These 8 distances were calculated from the coordinates of each point given above (Fig. 2C). Other tongue muscles, such as the styloglossus muscles, were excluded from the analysis because we could not observe these muscles directly in the midsagittal plane.

Third, tongue area and total area were directly traced and oral cavity area was obtained by subtraction of the tongue area from the total area (Fig. 2D). Tongue area was the region surrounded by the tongue dorsum outline, the line between the tongue tip and the mandibular bone, and the line between the mandibular bone and the hyoid bone. The first line was extracted using binarization, and the latter two lines were linearly connected between two anatomical points. Total area was the region enclosed by the line between the tongue tip and the mandibular bone, the line between the tongue tip and the upper central incisor's alveolar crest, the palatal line, the posterior pharyngeal wall line, and the line between the mandibular bone and the hyoid bone.

Statistical analyses

All statistical analyses were performed using EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria).[12] Paired data (low and high notes, soft and loud notes) were compared using a two-tailed Wilcoxon signed-rank test, and the value of the changes between the two levels was analyzed using a Mann–Whitney U test. Spearman's rank correlation coefficient was used to ascertain correlations between instrument-playing history and proficiency level. Statistical significance was set at $p < 0.05$.

RESULTS

Intraoral structures were well delineated and all anatomical landmarks were identified clearly.

Pitch

All anatomical points moved forward significantly in producing high notes (Table 1A). Cent, Tip, Hy, and Me also moved upward. Me-Tip and Tip-Back became significantly longer (Table 1B). Therefore, higher notes result in a forward and upward projection of the tongue. There were no significant differences between low and high notes in the tongue and oral cavity area.

Dynamics

Cent moved both backward and downward significantly in louder dynamics (Table 2A). Tip moved backward and High moved downward significantly. There were no significant differences in the hard tissue's position. Me-High and Tip-Back became significantly shorter in loud dynamics (Table 2B). Therefore, a backward and downward bending of the tongue was observed in moving from soft to loud dynamic levels. The total and oral cavity areas were significantly increased with increases in loudness, while the tongue area was decreased ($p = 0.02$, $p < 0.001$, and $p < 0.001$, respectively) (Fig. 3).

Proficiency level

Brass instrument- and trumpet-playing history showed significant correlations with level (brass instrument, $p < 0.01$, Spearman's rho = 0.628; trumpet, $p = 0.02$, Spearman's rho = 0.54). Further, significant correlation was also observed between these two histories ($p < 0.01$, Spearman's rho = 0.601). After the level check, the subjects were classified as 7 beginner and 11 advanced players (Table 3). In the transition from low tone to high tone, significant differences between beginner and advanced were not observed in points or areas and were only seen for one distance, Hy-Back. This distance became shorter in the advanced group, while it became longer in the beginner group ($p = 0.03$) (Fig. 4). With respect to the change in dynamics, no significant differences were observed in points, areas, or distances.

DISCUSSION

Pitch

The tongue protruded forward and upward with increases in pitch, while no significant tendency was found in the areas. These movements can be rationalized by the change in acoustic impedance. In higher pitches, the vocal tract's acoustic impedance has a considerable influence on tone production.[13–15] Increasing the oral cavity's impedance by protruding the tongue can lead to easier production of treble tones.

On closer examination of the movement of anatomical points, the average displacements of tongue points and the hyoid bone seemed greater than those of other hard tissues (Me and S) (Table 2A), suggesting that the tongue's deformation and the hyoid bone's movement mainly cause oropharyngeal changes. Kumada et al. selected High, Tip, and Back as parameters representing tongue shape and reported that these parameters can describe the functions of each tongue muscle in detail.[16] From an anatomical perspective, the changes in these parameters suggest that the GG muscles are the movement's predominant source. The GG muscles have a role in the tongue's protrusion and depression, which correspond with the movement in pitch changes.[11]

Kaburagi et al. investigated one trumpet player and reported that when the pitch was high, the tongue was positioned more anteriorly.[4] Our findings on tongue movement entirely follow this result.

Our results for area change are inconsistent with previous studies. Schumacher et al. reported an increase in the total free space of both the oral and the pharyngeal cavity with increasing tone pitch.[5] In addition, Iltis et al. reported a change of the oropharyngeal area with increases in pitch for various amateur brass players.[9] Both studies noted that a great difference in characteristic patterns, or so-called individual variations, can be observed even in professional players. Our observations affirm this, and we consider that no remarkable tendency was found between different pitches in the areas, owing to large individual variations.

Dynamics

Backward and downward tongue bending occurred in the production of loud dynamics. The tongue area became smaller and the oral cavity area became larger with increases in dynamics. From a musical acoustics perspective, these movements can be explained in terms of intraoral pressure. The vocal tract in brass performance can be regarded as a closed space, and thus intraoral pressure is considered to be nearly equal to lung pressure. According to previous studies, making loud tones requires greater lung pressure.[17,18] Taken together, the tongue's morphological changes in playing loud tones can be explained by the following two factors: the first is the primary change for tolerating high intraoral pressure and the second is secondary changes due to the high pressure itself.

In more detail, from an anatomical perspective, the HG muscles and the SL muscles seem to support the function of the GG muscles. The HG muscles' action produces a retrusion and depression of the tongue's lateral margin, and the SL muscles shorten it,[11] which corresponds with the movement from soft to loud dynamics. Furthermore, the styloglossus muscles are also likely to support the GG muscles' movements. Although we cannot observe these muscles directly in the midsagittal plane, their action mainly involves the tongue's retrusion,[11] which also corresponds with the movement in changes in dynamics.

To the best of our knowledge, no study has investigated the role of tongue shapes or movements in producing different dynamics during trumpet playing. Schumacher et al. reported that there were increases in total free space in both the oral and the pharyngeal cavity with increases in tone loudness.[5] Our results entirely support this. Additionally, Iltis et al. reported the oropharyngeal area's expansion in the coronal section in loud dynamics for elite horn players, although that study had a small sample size.[8] Taken together, the space of the oral cavity seems to be entirely enlarged in louder dynamics levels. Consequently, the features observed in our study can be applied to both beginner and advanced players, though individual variations are not negligible.

Proficiency level

No significant difference was seen between the beginner and advanced levels in the positions of anatomical points and areas in changes in both pitch and dynamics. Considering change of distance, a significant difference was observed only in pitch change. Hy-Back became shorter in advanced players and extended in beginners in the higher register. This result shows that advanced players are likely to use a different strategy when adjusting pitch compared to beginners, and the hyoid bone's movement appears to affect trumpet playing. Little attention has been paid to the hyoid bone so far, and thus its impact on the performance of wind instruments is still unknown. Further studies will be needed to explore the effect of intraoral structures, including the hyoid bone.

Limitations

We have demonstrated basic tongue motions for playing trumpet. Further studies will obviously be required to determine if this basis applies to other brass instruments. We examined only the midsagittal plane, meaning other anatomical structures, such as the styloglossus muscles, were out of our range. These structures should be investigated in future studies. In addition, the body posture would affect the movements of intraoral structures. Kitamura et al. have reported the shape of the front oral cavity, pharyngeal and laryngeal cavities were changed by the backward retraction of the tongue and posterior pharyngeal wall in supine position.[19] We should adjust for the effect in further detailed analyses.

Although we were unable to synchronize scans and playing sounds in our scanner, our study sufficed to determine the basis of trumpet performance in the stationary phase. The verification of dynamics was subjectively determined in this study because our apparatus was not equipped with any objective measuring devices such as microphone systems or sound level meters. Though perceptual grading suffices for our study, it would be more comparable using these devices as Echternach et al. have explored an effect of dynamics on articulation during singing.[20] The frame rate of 4.55 fps that we used was slower than that of previous studies,[5–9] but it also suffices for this study. A high-specification scanner is dispensable for our method, and thus it allows more and more researchers to conduct this kind of study to elucidate the motor strategy of playing wind instruments. A better understanding of how to play wind instruments may aid in developing new pedagogical methods as well as preventive methods for the medical problems of the performing arts.

CONCLUSION

Cine MRI clearly demonstrated a fundamental motor control strategy within the oropharyngeal area during trumpet performance. Tongue protrusion in the production of higher pitches and its bending in the production of louder dynamics were observed in both beginner and advanced players. This movement can be rationalized by acoustics theory and the movements of anatomical structures. We suggest that the shape and position of the tongue tunes air properties in the oral cavity to achieve accurate tone production for an intended pitch and dynamic level regardless of proficiency.

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FIGURE LEGENDS

FIGURE 1. Performance exercises. Each exercise includes four sustained notes after computer demonstration (diamond noteheads).

FIGURE 2. Example of acquired MR image (A) and measurement parameters (B, C, D).

A, Anatomical landmarks were delineated sharply.

B, Measurement of seven locations of tongue and hard tissue: centroid (Cent), the highest point (High), tongue tip (Tip), the most posterior point (Back), mandibular bone (Me), hyoid bone (Hy), and sella turcica (S).

C, Measurement of eight distances along the length of the tongue muscles: Me-Tip, Me-High, and Me-Back (solid lines, genioglossus), Hy-Tip, Hy-High, and Hy-Back (dashed lines, hyoglossus), Me-Hy (dotted line, geniohyoid), and Tip-Back (bold line, superficial longitudinal).

D, Measurement of three areas of the tongue: Tongue (dotted area), oral cavity (hatched area), and total area.

FIGURE 3. Percent change in area from *pp* to *ff* tones. Data are aligned in numerical order for each proficiency group. The total and oral cavity areas were significantly increased with dynamics, while tongue area was decreased ($p = 0.02$, $p < 0.001$, and $p < 0.001$, respectively).

Black bars, tongue area; gray bars, oral cavity area.

FIGURE 4. Percent change in Hy-Back distance. A significant difference between beginner and advanced groups was only seen in Hy-Back (p = 0.03).

TABLE 1A. Displacements of anatomical landmarks from low to high notes

		X (mm)				Y (mm)			
		Median	25%	75%	*p*-Value	Median	25%	75%	*p*-Value
Tongue	Cent	-4.26	-5.91	-2.48	<0.001 ***	1.60	0.44	2.93	0.010 *
	High	-7.17	-10.43	-1.27	0.005 **	1.20	-1.59	2.82	0.246
	Tip	-4.19	-7.94	-2.66	<0.001 ***	4.19	2.50	5.12	<0.001 ***
	Back	-8.20	-10.80	-3.27	0.016 *	1.68	-3.22	4.74	0.551
Hard tissue	Me	-2.69	-5.06	-0.91	<0.001 ***	1.06	0.31	2.22	0.015 *
	Hy	-3.12	-4.38	-1.22	<0.001 ***	2.25	0.09	5.12	0.033 *
	S	-0.75	-1.38	-0.22	0.003 **	0.56	-0.09	1.25	0.055

Cent, centroid; High, the highest point; Tip, tongue tip; Back, the most posterior point; Me, mandibular bone; Hy, hyoid bone; S, sella turcica.
$*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

TABLE 1B. Changes in distance from low to high notes

		ΔChange (mm)			
		Median	25%	75%	*p*-Value
GG	Me-Tip	1.88	0.50	5.96	0.004 **
	Me-High	-1.00	-1.81	1.44	0.393
	Me-Back	-0.13	-1.66	3.21	0.671
HG	Hy-Tip	0.60	-1.96	5.96	0.304
	Hy-High	-1.05	-3.07	0.08	0.108
	Hy-Back	-0.01	-3.58	1.74	0.734
GH	Me-Hy	-0.01	-1.90	1.66	0.865
SL	Tip-Back	3.22	1.41	5.95	0.004 **

GG, genioglossus muscles; HG, hyoglossus muscles; GH, geniohyoid muscles; SL, superficial longitudinal muscles.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

TABLE 2A. Displacements of anatomical landmarks from soft to loud dynamics

		X (mm)				Y (mm)			
		Median	25%	75%	*p*-Value	Median	25%	75%	*p*-Value
Tongue	Cent	1.86	-0.50	3.53	0.027 *	-1.91	-4.25	-0.39	0.004 **
	High	0.92	-3.15	4.20	0.799	-2.76	-4.77	0.84	0.012 *
	Tip	3.19	-0.62	6.03	0.010 *	-0.75	-2.91	1.09	0.191
	Back	-1.51	-5.19	0.89	0.966	-1.54	-4.20	0.38	0.119
Hard tissue	Me	0.06	-1.34	1.06	0.632	-0.44	-1.59	0.53	0.130
	Hy	0.31	-0.47	1.19	0.394	-2.50	-5.56	1.12	0.170
	S	0.00	-0.56	0.22	0.305	0.00	-0.44	0.47	0.979

Cent, centroid; High, the highest point; Tip, tongue tip; Back, the most posterior point; Me, mandibular bone; Hy, hyoid bone; S, sella turcica.
$*p < 0.05$; $**p < 0.01$; $***p < 0.001$.

TABLE 2B. Changes in distance from soft to loud dynamics

		ΔChange (mm)			
		Median	25%	75%	*p*-Value
GG	Me-Tip	-1.11	-3.18	0.29	0.067
	Me-High	-2.22	-3.11	0.91	0.043 *
	Me-Back	-1.10	-3.10	0.77	0.284
HG	Hy-Tip	-1.12	-4.45	0.64	0.108
	Hy-High	-0.38	-1.59	1.53	0.609
	Hy-Back	0.04	-2.92	3.01	0.865
GH	Me-Hy	0.25	-2.72	1.54	0.865
SL	Tip-Back	-0.88	-4.97	-0.35	<0.001 ***

GG, genioglossus muscles; HG, hyoglossus muscles; GH, geniohyoid muscles; SL, superficial longitudinal muscles.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

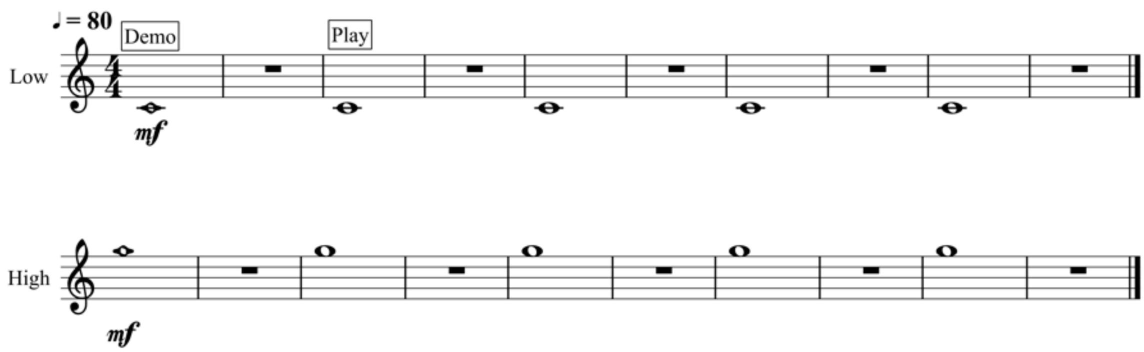
TABLE 3. Subject characteristics

Level	Trumpet Playing History (yrs)	Brass Instrument Playing History (yrs)	Gender	Age (yrs)
B	0	1	F	26
B	0	12	M	42
B	0	8	F	28
B	0	8	F	27
B	0	0	F	21
B	1	6	F	28
B	2	2	M	29
A	0	14	M	26
A	0	6	M	22
A	0	7	M	43
A	1	25	M	38
A	8	8	M	28
A	10	10	M	25
A	12	12	F	26
A	13	19	M	31
A	16	16	M	50
A*	17	17	F	27
A	20	20	M	66

The rows are sorted in ascending order by level and trumpet playing history.
B, beginner; A, advanced; *, professional player.
F, female; M, male.

FIGURE 1.

1. Pitch



2. Dynamics

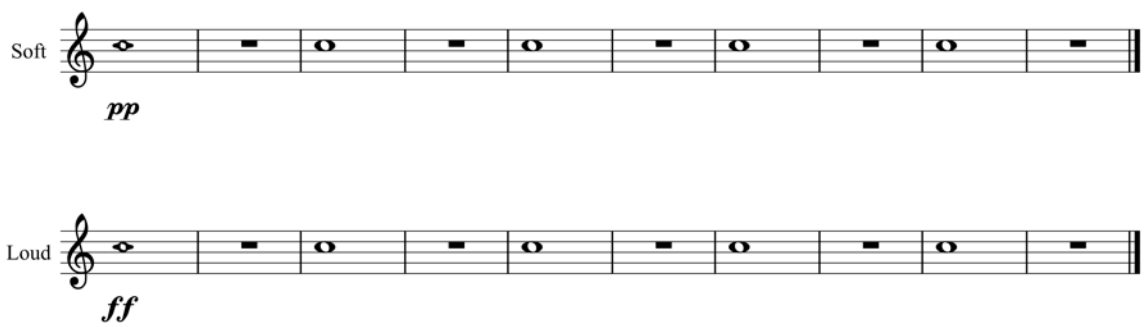


FIGURE 2.

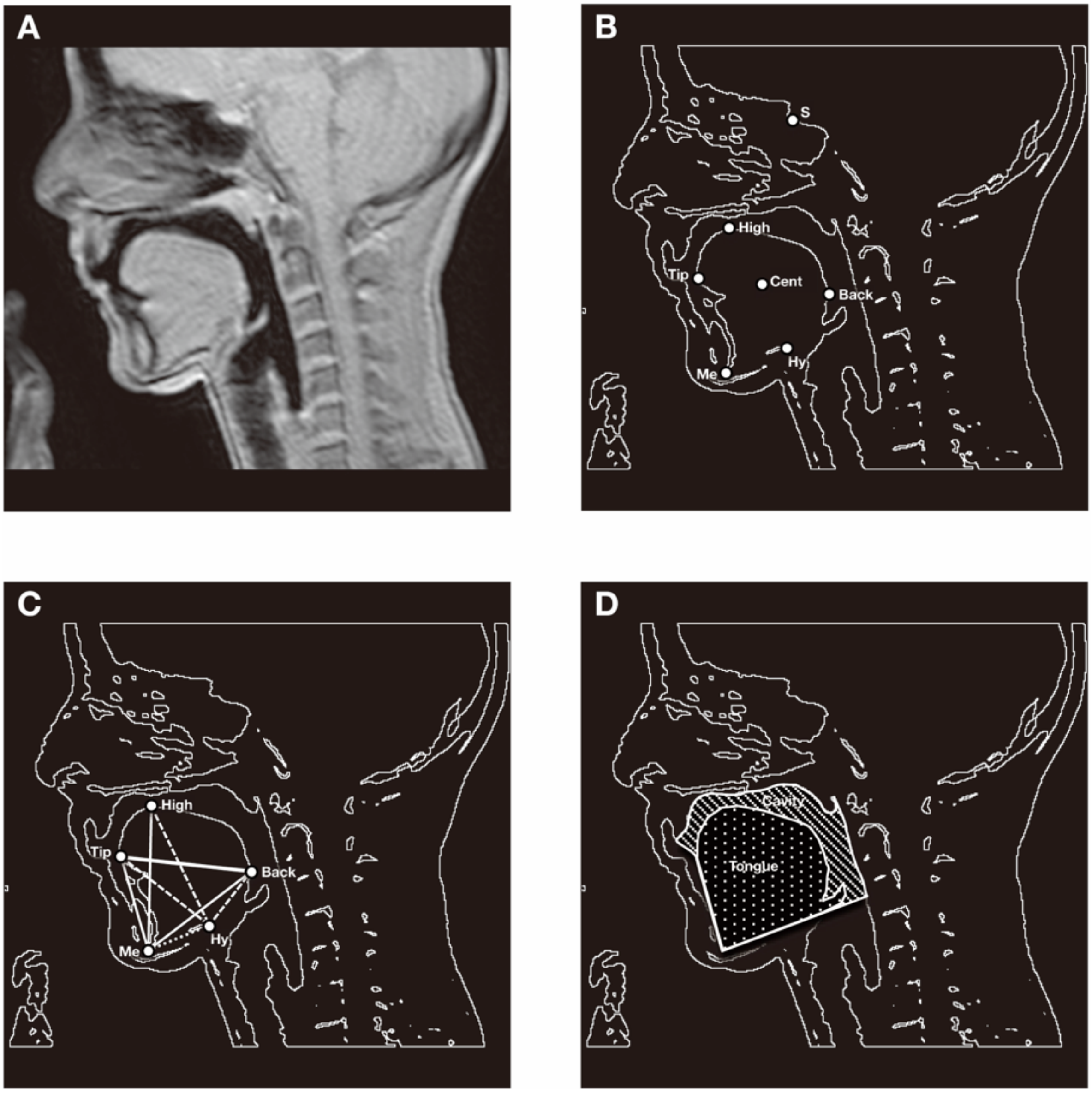

A
B
S
High
Tip
Cent
Back
Hy
Me
C
High
Tip
Back
Me
Hy
D
Cavity
Tongue

FIGURE 3.

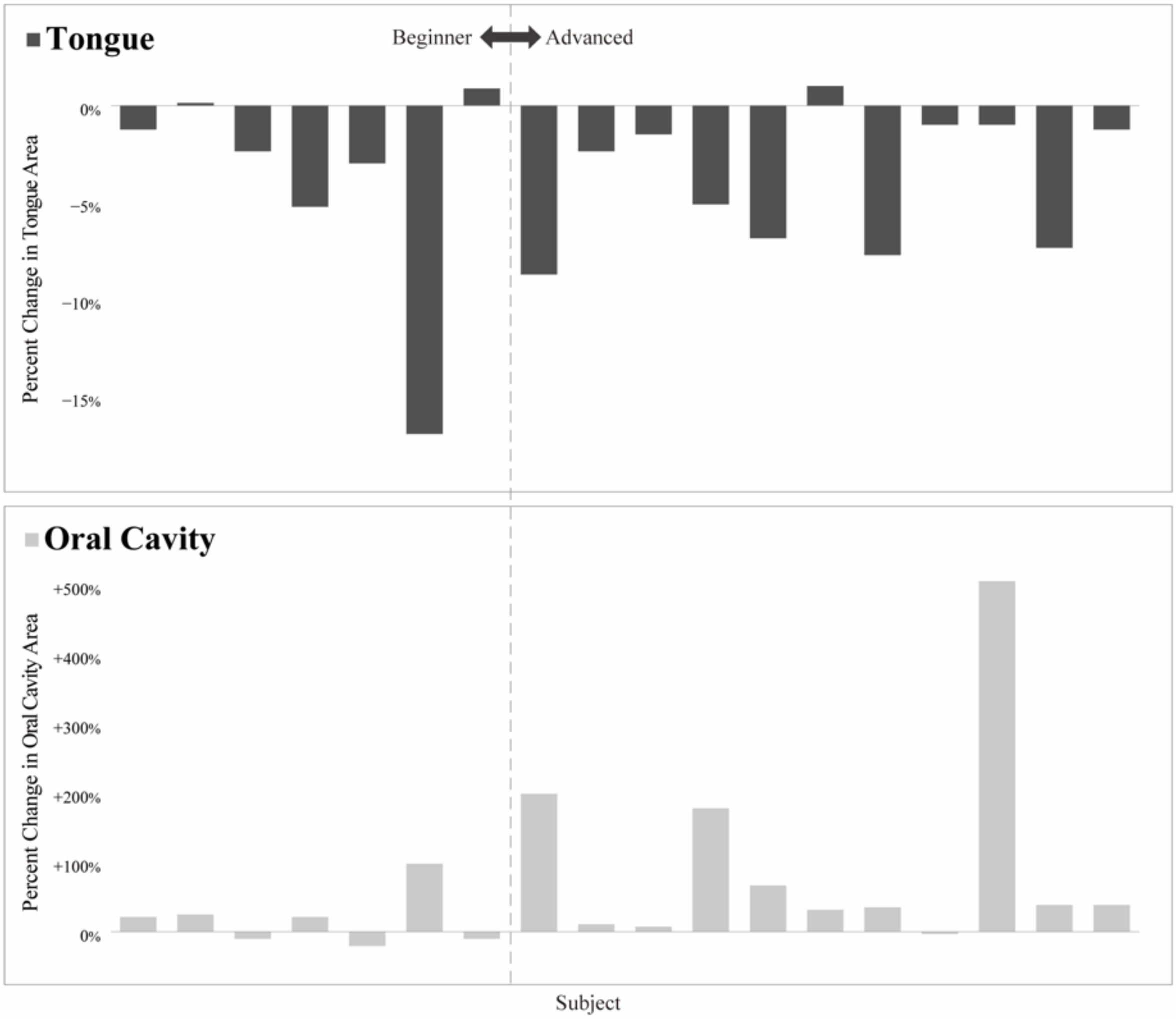
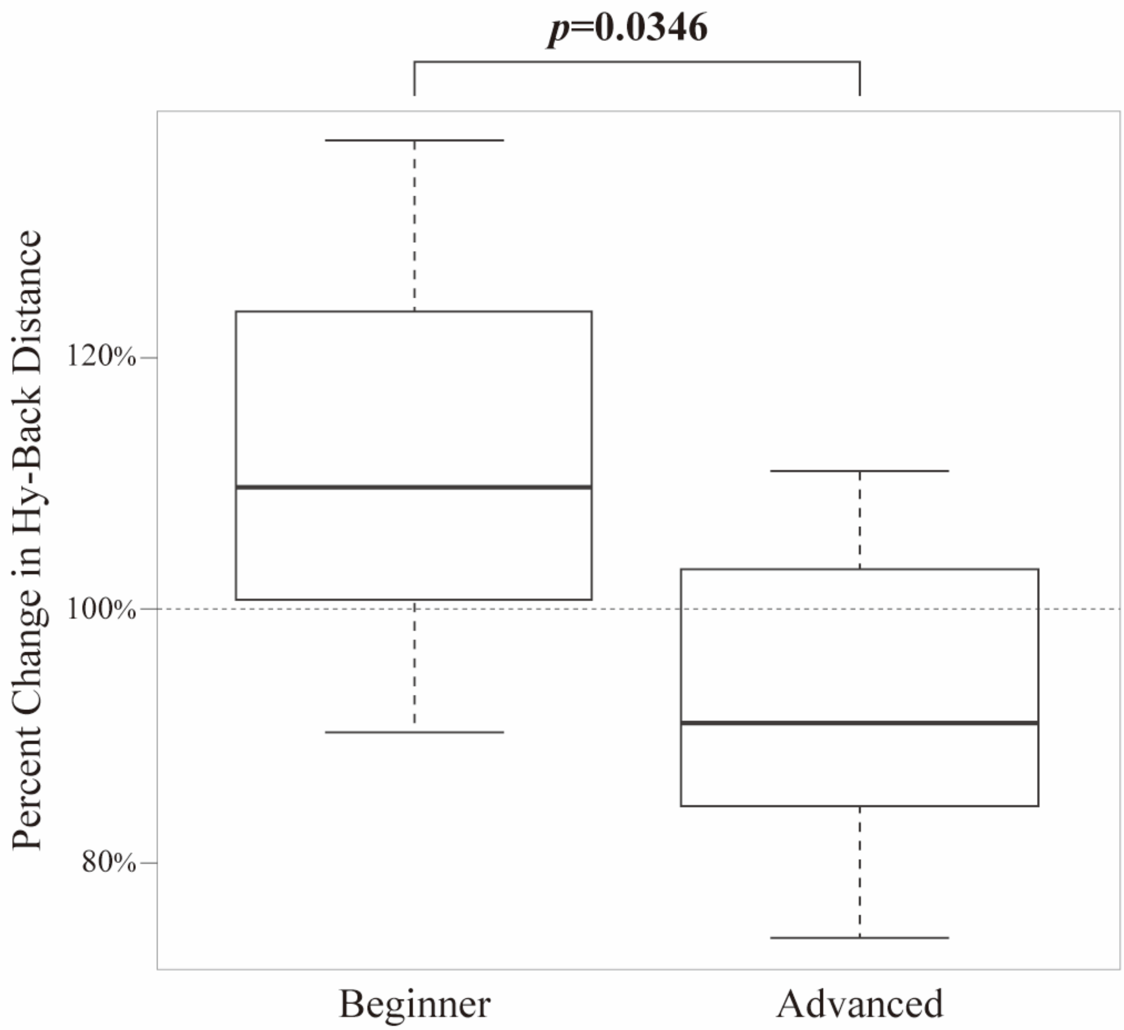

Tongue
Beginner
Advanced
0%
−5%
−10%
−15%
Percent Change in Tongue Area
Oral Cavity
+500%
+400%
+300%
+200%
+100%
0%
Percent Change in Oral Cavity Area
Subject

FIGURE 4.


p=0.0346
Percent Change in Hy-Back Distance
120%
100%
80%
Beginner
Advanced