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Trombone players seem to use different tongue positions while playing sustained notes, depending on their native languages

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ABSTRACT

We used ultrasound imaging of the tongue to record midsagittal tongue contours of eight trombone players with different native languages while producing sustained notes on an identical 'pBone' plastic trombone and during speech production in their First Language. While speakers of New Zealand English seem to have the option of using a tongue shape close the central unstressed schwa vowel /ə/ or in the vicinity of the cardinal vowel /o/, players whose native languages do not include centralized vowel positions seem to be constrained to using the higher and more retracted position close to /o/. Furthermore, while both highly proficient and less experienced players seem to change the height of the back of their tongue when rising throughout the trombone's register, the directions of these changes are the opposite. This paper discusses possible reasons for these differences and relates them to earlier empirical research on the function of the tongue in brass instrument playing.

I. BACKGROUND

To the best of our knowledge, no other researchers have carried out systematic empirical research on First Language (L1) influence on playing brass instruments. However, several anecdotal accounts of this hypothesized influence have been exchanged within the brass community, for example, speculation about why players of some nationalities are 'better' than others at certain facets of brass playing or why learners may have specific problems related to their language background. An old, but classic, example of the former is Fitzgerald's (1946) report of the great Herbert Clarke's thoughts about 'Latin' brass players: "their language may help them to be more decisive, besides guiding them with greater certainty as to the attack for the different varieties of tongueing." Fitzgerald himself tried to add credibility to this by stating that "this opinion is well founded since the Latin language and those closely related to it employ a much greater variety of vowel sounds than the average American uses in his speech and requires both extreme flexibility and velocity in lingual movement, particularly in the use of the tip of the tongue" (p. 5-6); though note that linguists agree that Latin languages (understood here to be Spanish and other closely related languages) have *fewer* vowel phonemes than American English.

Focusing on the problems of certain populations of players, one can find some more recent and linguistically grounded accounts such as Joseph Bowman sharing his experience of teaching trumpet to Thai students in the International Trumpet Guild Journal (2011): "Looking at the Thai language specifically, the wonderful tonal language contains very few hard consonants. A hard "taa", "kaa," or "gaa" sound doesn't exist, so introducing those takes time and persistence" (p. 90). As any brass player would know, these are the kinds of syllables that most teachers and methods advocate to use when articulating on a brass instrument.

Only a few brass players have looked at the issue through a more scientific lens, however. Two recent DMA dissertations (Cox, 2014; Mounger, 2012) attempted to find evidence for language influence by examining the vowel inventories as a measure of timbre of different languages and varieties thereof, and employing quantitative and qualitative methods. Additionally, empirical research starting with studies using x-ray imaging conducted from 1954 to 1975 has documented the function of the articulators during brass playing; more recent research has made use of magnetic resonance imaging (MRI) and ultrasound imaging of the tongue (UTI).

A. Prior Research on First Language Influence on Brass Instrument Playing

The most comprehensive study on the topic that we are aware of is Cox's D.M.A. dissertation (2014), in which the author calculated average formants of the vowels used in speech (F1 & F2) and the timbre produced during trombone playing (the 2nd and 3rd harmonics, corresponding to F1 & F2 in speech) for 18 British (BE) versus 12 American English (AE)-speaking amateur trombonists. The author found differences at the large group (BE vs. AE), dialect subgroup (different dialects of BE) and individual levels, although no statistical tests were performed to determine whether these differences were significant (visual inspection of the graphs included in the dissertation suggests they are). Interestingly, participants in this study were not able to correctly identify the nationality of professional players on different recordings of the same piece of music but some participants performed better than chance when asked which rendition they preferred, more often than not selecting recordings of players from their own language background.

Another study that used a combination of qualitative and quantitative data is Mounger's D.M.A. dissertation (2012), in which the author aimed to analyze "the orchestral trombone sound of France, Germany, and the United States … through the lens of language" (p. ii). The dissertation includes an analysis of "representative audio recordings of trombonists from France, Germany, and the United States" and tries to explain its impressionistic account of differences in sound by looking at the frequency of each vowel in the 500 most common words in these languages. While the author tried to describe the trombone playing on selected recordings (including both solo and orchestra settings) "as succinctly and in the most objective terms possible" (p. 82), several problems exist with the qualitative part of her research, not least that a native speaker of Italian was included as an exponent of American playing based on the fact that he is the principal trombonist of a renowned American Orchestra. Underlying the quantitative part of this and Cox's study seems to be the widely-held, but empirically non-tenable belief that brass players use the full range of vowel tongue positions during playing (we will discuss some of the relevant studies disproving this notion in the following section). Both authors certainly are not alone in making this assumption as a survey of the brass pedagogical literature will attest (Larson, n. d.; Reinhardt, 1973; but see Irvine, 2003; Loubriel, 2011; and Steenstrup, 2004 for critiques). Even if brass players used a wider range of tongue positions than empirical research attests, simply looking at the relative frequency of the tongue positions correlated with these sounds across different languages could provide only a weak chain of evidence. Thus, while Cox seems to have been able to uncover some evidence for the hypothesis of language influence (although lacking statistical validation), Mounger writes in her conclusion that "the quantitative data for this research does not fully support the concept that language can affect one's natural sound production on the instrument." We contend that both studies leave considerable room for improvement in terms of statistical validation, and participant classification and linguistic analysis, respectively.

Another study that explicitly mentions the possibility of L1 influence on brass playing is Budde's Ph.D. thesis (2011) on "Methods for Teaching Middle School Band Students to Articulate." The author provides a comprehensive survey of the syllables that have traditionally been used to teach articulation on wind instruments and subsequently provides a careful account of the possible phonetic realizations of the consonants and vowels contained in these syllables within different languages. This leads him to state that "these differences manifest themselves in various ways as performers articulate on wind instruments" and to formulate the requirement that these "be taken into account when devising a method for teaching articulation to young musicians" (p. 5). No evaluation of language background is included in the comparison of students assigned to certain treatment groups, however, other than creating an 'articulation guide group' which received and regularly reviewed an 'articulation guide sheet' developed by the author "based on the study of phonetics, native language, and music pedagogy" (p. 238). Students in this group scored significantly lower in the final evaluation of their ability to "articulate[d] clearly with accurate execution across various tempos" (p. 219) than students in the other test conditions, including a "practice group" and an "audio model group."

B. The Role of the Articulators in Brass Playing

While there seems to be a long-standing consensus among brass players and teachers that the movements of the articulators during brass playing closely resemble one of the most basic syllable structures of speech (cf. Dalla Casa, 1584; Loubriel, 2011), namely the consonant-vowel (or CV) pairing, disagreements abound on the exact nature of these movements (cf. Deye, 1947). Thus it is not surprising that x-ray imaging, or radiography as it was called in its early days, was soon applied to observing the articulators during brass playing. These studies showed lots of individual variation and when the results contradicted the widely-held belief of using different vowel tongue shapes throughout the register, the majority of the brass community did not seem to take notice (cf. previous section; Irvine, 2003). The following paragraph outlines those findings relevant to our current research.

The earliest study to look at brass playing was Hall's Ph.D. dissertation (1954). Even though the technology available at the time only allowed him to use still frames (instead of moving images as in the later studies), Hall tried to control for variation between different instruments by having all participants play on the same 'control trumpet.' He also produced spectrograms of the tones played while the individual images were taken, which unfortunately are unrecoverable today due to the scanned quality of the dissertation (along with the quality of the included x-ray images). Furthermore, images taken during the production of the extreme vowels /a/, /u/ and /i/ in three different pitch ranges allowed him to compare these tongue positions to the ones used during playing. The most "common formation" found among his participants "was that of "a" (ah)" but he added that "other players used the "u" (oo) formation or intermediate formations between these extreme vowels" (p. 246-247); performers tended to use "the same basic formation in every register," meaning that modifications while changing registers "were not large" (p. 247).

Subsequent studies by Meidt (1967), Hiigel (1967), Amstutz (1970), Frohrip (1972) and DeYoung (1975) mostly confirmed Hall's findings, in addition to observing a wider range of playing conditions including changes in dynamics and tongue placing for different types of articulation. Some of these studies included various brass instruments, while DeYoung (1975) observed trombone players exclusively. Perhaps as a result of the considerable inter-individual variation found in all the mentioned studies, Meidt (1967) reported a difference in results compared to Hall's (1954) findings with respect to register changes; some of his participants displayed large changes in tongue position with "the variations in formation […] usually approaching, if not actually reaching, the extreme "ah" and "ee" vowel formations" (p. 66).

Trying to investigate more closely the hypothesis that brass players use specific 'syllables' during playing, Hiigel (1967) asked his participants to 'think' prescribed syllables printed underneath the music while performing selected notes; he found no evidence "that thinking a syllable during performance will tend to simulate the tongue position resulting from the enunciation of that syllable" (p. 108). Similarly, significant differences were found "between the tongue placement for performance of the various pitches and styles and placement for the enunciation of the syllables" recorded separately, even for those performers who claimed to use those specific syllables during playing. The overall tendency was for the "tongue arch" to be placed higher with the tongue tip "farther forward" as compared to recitation (p. 107).

More recently, MRI and UTI have been applied to studying the articulators during brass playing. Kaburagi, Yamada, Fukui, and Minamiya (2011) investigated the effect of vocal tract resonances on the sound produced by a single professional trumpet player using MRI. Their results show that although vocal tract alterations accompanying changes in pitch occur all along the vocal tract (from the glottis to the lips), the position of the tongue plays a big part in changing vocal tract impedance. The single participant of this study was a speaker of Japanese who used a tongue position similar to /o/ for low and mid-range notes and positioned the tongue close to the tongue shape for the vowel /u/ (/ɯ/) for a high note.

MRI was also used in Germany by Schumacher et al. (2013) who investigated motor functions in the trumpet playing of 12 professional musicians. They found two general tendencies that held true across all of their subjects: "1. With increasing tone pitch in octave jumps and in playing natural tones, there was an increase in total free space of both the oral and pharyngeal cavity. The increase of both to achieve the higher pitch was greater in the pharynx than in the oral cavity." And "2. The increase in areas of oral cavity and pharynx are present also when switching from lower to higher loudness and when performing crescendo to decrescendo... However, no general different in change of oral and pharyngeal cavity can be observed (p. 1177). In the same year, the Freiburger Institut für Musikermedizin, where this research was conducted, also released an instructional DVD which shows the movements of the articulators during wind instrument playing (Spahn, Richter, Pöppe, & Echternach, 2013).

Finally, a new method of real-time MRI with a temporal resolution of up to 100 frames per second was pioneered very recently by American kinesiologist and French Horn player Peter Iltis in cooperation with researchers at the Max-Planck-Institut in Göttingen (Iltis et al., 2015). Unfortunately, no real brass instruments can be used inside MRI scanners so that the researchers in Japan and Freiburg used plastic replicas, while Iltis et al. used a custom-built, MRI-compatible horn consisting of a non-ferromagnetic bell with graduated plastic tubing covering the distance from just outside the scanner to the player's mouth; this fact limits the comparability of MRI-studies with the findings from other studies.

The earliest application of UTI to brass playing we could find is documented in Sram and Svec (2000) who took a more descriptive approach when compared with other studies and found the following divergent results regarding the function of the tongue: A series of studies showed that the vibrating tip of the tongue is a significant factor for sound production on brass instruments, which was especially pronounced for the low notes of the tuba. … In other cases, the tip of the tongue is positioned between the lips, especially at low frequencies, thereby helping to achieve the necessary tension. Another function of the tongue identified in their research is to enable regular lip vibration by continuously moistening them (p. 156).

Lastly, Zielke (2010) used UTI and video of the participants' lower face and neck to observe the tongue and motor activity of the neck and face while playing wind instruments; this study was conducted within the field of music medicine so that differences among the different groups of wind instruments and possible aberrations within the individual players' embouchures were of prime interest. Overall, Zielke found that 'tongue amplitudes' (meaning the displacement of the tongue during certain movements) were larger for players of brass instrument than flutists, for loud versus soft playing and for attacked notes versus slurred articulation.

C. Vocal Tract Influences on Brass Instrument Sound

The last decade has seen major advances in the research on brass instrument acoustics. While the evidence for brass playing is not as strong as for the saxophone (cf. Chen, Smith, & Wolfe, 2011) and didgeridoo (Wolfe, Tarnopolsky, Fletcher, Hollenberg, & Smith, 2003) where the use of vocal tract resonances is necessary to produce notes in the altissimo register and different timbres, respectively, the relevance of vocal tract impedance seems to increase for at least some brass players while they ascend to the higher partials of the instrument (Fréour, 2013; Wolfe et al., 2003). Matching the resonances to the vocal tract seems to be less of a requirement in the lower register, however, which led us to conclude in an earlier publication "that different tongue positions are possible in playing brass instruments (at least at the lower end of the register) and that they can lead to perceivable differences in timbre independent of the produced pitch" (Heyne & Derrick, 2014; p. 180).

II. AIMS

Our research aims to determine whether brass players' L1s influence the way they play on their instruments by observing their tongue movements during playing and speaking using UTI. This approach requires taking into account the structure of the languages in question, and testing specific, carefully crafted hypotheses. Currently, we are looking at whether a relationship exists between the midsagittal tongue shapes used when producing vowels in speech and while sustaining notes on an instrument. We hypothesize that at least beginning players use a tongue shape that is closely modeled on one of the vowel tongue shapes in their L1 while more advanced players might 'unlearn' this pattern with increasing practice.

III. METHOD AND PARTICIPANTS

A. Ultrasound Imaging of the Tongue (UTI)

UTI is a noninvasive and relatively inexpensive method for imaging the tongue and has previously been used to record midsagittal tongue shapes during wind instrument playing (see above; Gardner, 2010). Due to the need of having to control for a multitude of factors that can influence brass instrument sound (cf. Benade, 1978; Bertsch, 1998; Campbell & Greated, 1987; Carral & Campbell, 2002; Carral, 2011; Hoekje, 2013; Smith, 1986; Steenstrup, 2007) we decided to limit this study to trombone players, which is the main instrument of the first author. This necessitated developing a new method of head stabilization that would be applicable to trombone players who have instrument tubing running along the left side of their neck. We modified a non-metal jaw brace, previously designed at the New Zealand Institute of Language, Brain and Behaviour, and reduced its width to minimize the danger of it being bumped by the trombone tubing; for most players it now only touches a thin strap running along the side of the face, depending on head and jaw size. This brace stabilizes the ultrasound probe against the jaw and thus ties probe motion to jaw motion. An assessment of the motion variance of the system (Derrick, Fiasson, & Best, 2014; Derrick, Fiasson, & Best, 2015) showed that 95% confidence intervals of probe motion and rotation were well within acceptable parameters described in a widely-cited paper which traced head and transceiver motion using an optical system (Whalen, Iskarous, & Tiede, 2005).

B. Participants and Instruments

This paper includes plots of midsagittal tongue contours captured during speech and trombone playing for six participants recorded at the University of Canterbury; we have finished the analysis for two additional participants but have excluded these from the current study due to deviant mouthpiece placement, in one case, and the lack of comparable data for a single participant whose L1 is German, in the other case. The remaining six participants have the following language and playing backgrounds: S1 NZE is a speaker of New Zealand English (NZE) who reported speaking no other languages and who is a professional trombonist working across different styles of music; he served as our pilot participant and the size of his dataset is smaller when compared to the other data. S5 NZE is a monolingual speaker of NZE whose proficiency level on the trombone is semi-professional after having played the instrument for eighteen years; he is also active as a singer in a barbershop quartet. S24 NZE is a 25-year-old female speaker of NZE who can speak elementary German and spent some time living in the UK and Germany before finishing High School; her playing level might be best described as intermediate and she has played the trombone for nine years. S4 Tongan is a speaker of Tongan who grew up in Tonga and only acquired English upon arrival in New Zealand (NZ) as an adult; his playing proficiency is that of an amateur and he started playing various brass instruments as a secondary school student in his home country. S7 Japanese is a speaker of Japanese who has lived in NZ for eleven years and only started learning English a few years before relocating to New Zealand in his forties; his playing level is that of a very good semi-professional player. Finally, S13 Mexican Spanish is a 40-year-old highly successful professional trombonist working in the Los Angeles Latin music scene on the American West Coast; he grew up in Northern Mexico and emigrated to the USA before completing High School; his Second Language (L2) skills are almost native-like which led us to collect speech data in both his native language Mexican Spanish and AE, although the sample size is smaller for the AE tongue contours.

Note that the reduced dataset for this study includes trombonists with four different L1s; these languages were selected due to similarities in their vowel systems and can be split up into two groups: Naturally, the NZE participants share the same vowel inventory (with small differences for S13's AE data). In contrast, the Tongan, Japanese and Spanish all speak languages that have five-vowel systems without any vowels occupying a central position.

The trombone used for recording all participants was a plastic 'pBone' trombone provided by Warwick Music in the UK for the purposes of our research. All players except the pilot participant used the same standard 6 1/2 AL mouthpiece by Arnold's and Son's, Wiesbaden, Germany.

C. Recording Procedure

All participants were asked to come to a sound attenuated room on campus and given sufficient time to warm up and familiarize themselves with the 'pBone' as well as complete a short questionnaire on their language and playing proficiencies. They were then asked to put on the probe holder with the ultrasound transducer and adjustments were made to ensure a comfortable fit; at this point we also applied ultrasound gel to improve the image and used the settings available on our ultrasound machine for further optimization.

The first part of each recording session consisted of reading word lists in each participant's native language; for S13 this included words in both Spanish and English. The word lists were presented in sections of approximately 2.5 minutes length and blocks of three to five words were shown on a computer screen, advancing automatically; for the pilot participant the words were printed in similar groupings and read off the page.

In the second part of the experiment, all participants played an almost identical set of eight musical passages that included sustained notes at varying dynamics, in different registers, and different kinds of articulation including double-tonguing (for which a more retracted, secondary place of articulation has to be used) and lip slurs without slide movement. Only two of these exercises required the use of the slide to alter the fundamental pitch of the instrument; these were slightly modified original etudes written for the trombone.

The ultrasound machine used for the recordings was a GE Healthcare Logiq e (version 11), with a 8C-RS wide-band microconvex array 4.0-10 MHz transducer. Ultrasound tongue images were captured on a 2013 Macbook Pro or a 2012 HP Elitebook, both running Windows 7 in the 64-bit binary, from the machine's VGA output using an Epiphan VGA2USB pro frame grabber; simultaneously a Sound Devices LLC USB Pre 2 microphone amplifier with a Sennheiser MKH 416 microphone was also connected to the laptop to record audio. Both signals were written to the hard drive using an ffmpeg binary accessed through the Windows Command Line; the video codec was x264 for recordings on the Macbook and mjpeg on the HP Elitebook, while audio was encoded as uncompressed 44.1 kHz mono on both machines. Frame rates varied between 58 and 60 Hz and were encoded in a progressive scan yuv420p pixel format at 1024x768 pixels.

D. Analysis

Before exporting individual midsagittal tongue contours from the ultrasound videos we had to correct for slight misalignment of the video and audio tracks originating from simultaneously recording two different USB inputs. For this reason we asked participants to produce five /ta/ or /da/-syllables at the beginning and end of each of recording block of 2.5 minutes average length (except for the pilot participant). This allows us to align the exact video frame when tongue first starts dropping down from its place of articulation with a sharp rise in the audio waveform (see Miller & Finch,

2011) using ELAN (Wittenburg, Brugman, Russel, Klassmann, & Sloetjes, 2006).

We then performed an acoustic analysis of the speech and music data in Praat (Boersma & Weenink, 2014); for participants S24 NZE and S13's English words we used the HTK toolkit (Young et al., 2006) to perform automatic speech segmentation via its implementation in LaBB-CAT (Fromont & Hay, 2012). Individual video frames for contour export were selected at the midpoint of vowels and at one third of note duration for sustained notes; for the pilot participant this was done via the identification of tongue steady states in ELAN. Using the time stamps output by Praat, we then used the GetContours function (Tiede, 2014) in MATLAB (MATLAB Release 2013b) to extract individual tongue contours by clicking just below the visible contour. Average tongue contours were calculated by first transposing all data to polar coordinates using the transducer head as the vertex (Heyne & Derrick, 2015) and subsequently fitting an SSANOVA curve (Gu, 2014) using R (R Core Team, 2013). Finally, the average curves were re-imported to MATLAB and transposed back to the Cartesian plan before plotting speech and music data together.

IV. FINDINGS

Figures 1 and 2 on the following pages show the average midsagittal tongue contours for all participants discussed in this paper. The average curves are based on at least 21 individual tokens for each vowel and 33 tokens for the notes for participants S4, S5, S7, S24 and S13's Spanish data. For S1 the respective numbers are 5 and 36, except for the vowels /ʉː, e, ɒ, ɵː, oː/ with only two or three tokens each; for S13's AE data the minimum number for vowels is 10 except for /iː, ɔː, ʊ/ with 5, 2 and 7 tokens, respectively. The notes played on the pBone were conflated in the following way to make the graphs easier to read: 'high notes' include F4 and D4, 'middle notes' only Bb3 and 'low notes' F3 and Bb2, as per the US standard system for specifying pitch. Note that the NZE and AE plots look very crowded due to the large number of distinctive vowels in these language's sound systems. Similarly, plots can look quite different depending on ultrasound probe position and physical features such as tongue size, which vary widely among individual players.

Visual inspection of the four datasets included in Figure 1 indicates that the average position for playing sustained notes is very close to /o/ for the Tongan and Japanese players while it is located further to the front of the oral cavity and a bit lower for the two NZE participants included here. More specifically, the playing tongue shape seems to pattern in between the central /ɘ/ and /ə/ vowels for S1 and somewhat lower, in between /ə/ and /ɐ/, for S5. The fact that these participants all display a clear pattern was our reason for assembling their data in Figure 1.

For the data shown in Figure 2, however, no such patterns emerge. S24 places the back of her tongue close to the /oː/ vowel position while the front of tongue assumes a position equal to that used for uttering the /ʊ/ vowel; this position is clearly very different from what the other NZE participants (in Figure 1) are doing and bears more similarity to the pattern displayed by the Tongan and Japanese participants. For S13, it is even harder to establish a relationship between the vowel tongue positions used in speech and the tongue shapes assumed during playing; for AE data there exists some proximity to the /æ/, /ɪ/, and /ɘ/ vowels while /e/ and /u/ are the closest vowel tongue positions in his Spanish speech production.

An observation that applies to all semi-professional and professional participants (thus excluding S4 Tongan and S24 NZE) is that those players tend to raise the back of their tongues when playing higher notes while the pattern is the reverse for the amateur and intermediate players. The direction of changes in tongue positioning for the more proficient players thus agrees with the recommendations made by many brass teachers and method books advising the use of different 'vowels' to ascend to the high register but on average, these changes are of course much smaller than changing from, say, /ɑː/ to /iː/. Interestingly, the most successful player included in the dataset displays the biggest variations in this regard.

V. DISCUSSION

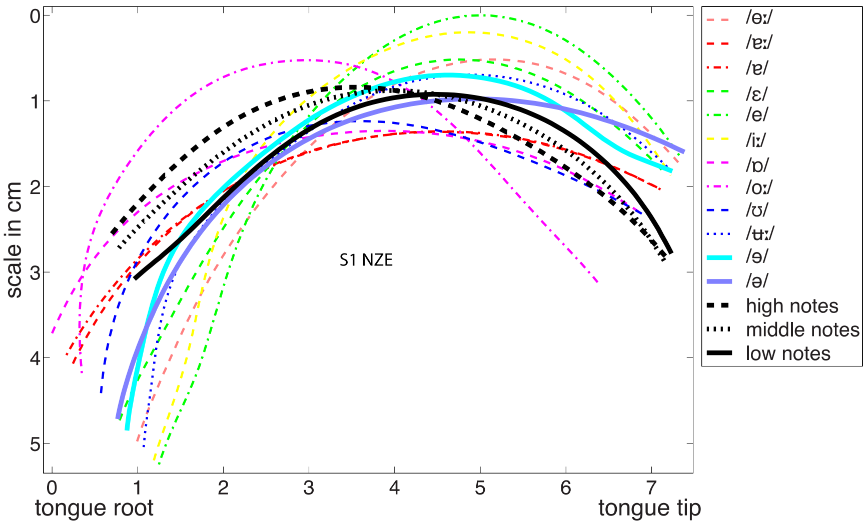
We believe that our findings presented above suggest that trombone players' First Languages constrain their availability of tongue shapes to be used in producing sustained notes. For some populations this might mean that they have different vowel tongue positions available from their L1 which are usable for brass playing, while for others there may be only one. We think that beginning brass players (who are seldom younger than age six) will resort to what they already know how to do: producing sounds in their native language.

Looking more specifically at the languages included in our study, tongue positions in the vicinity of the cardinal vowel /o/ form part of most of the world's languages so that they are also part of languages with smaller five-vowel systems such as Tongan and Japanese; central vowels like schwa (/ə/), however, are only available to our English-speaking participants. At this point, we do not have enough data to speculate why S24 NZE might be using a tongue position more similar to the one used by the Tongan and Japanese players, even though the more proficient NZE speakers seem to 'prefer' a more central position close to /ɘ/.

What we can suggest is that both vowel positions used by our participants included in Figure 1 may offer aero-dynamical advantages for brass playing. Early MRI research on speech production (Baer, Gore, Gracco, & Nye, 1991) has shown that for extreme vowels, meaning high front and low back vowels, the airway is heavily constricted in the oral and pharyngeal cavities, respectively, which would reduce airflow. Using a central vowel such as schwa (/ə/) certainly avoids such constrictions during playing, although Gick (2002) found for AE that, contrary to popular belief, the pharyngeal cavity is also somewhat more constricted for schwa than for the 'rest position.' Conversely, /o/ might simply be the best position to use for players who do not have a central vowel tongue position because it provides leverage for the tongue tip to perform consonant-like articulatory motions to begin (and end) notes and effects less of a constriction than the other two plausible options, /a/ and /u/ (/ɯ/ in Japanese).

Measurements of changes happening in the pharyngeal cavity reported in several of the x-ray and MRI studies cited above point to the necessity of considering this cavity in addition to the oral cavity when trying to find the optimal tongue position for brass playing. Considerable inter-individual variation exists between our participants in the amount of change in the position of the back of the tongue when rising from low to medium and high notes. It is entirely possible that some players simply make the required changes in cavity size by raising their tongue while others constrict their pharyngeal cavity. In fact, S5 NZE who is also a proficient barbershop singer, reports that he can feel his pharyngeal cavity narrowing when playing high notes. These observations contradict the findings of Schumacher et al. (2015) for professional trumpet players who consistently increased the cavity size in both the oral and pharyngeal cavities for similar changes in pitch. Nonetheless, it is possible that this indicates a real difference between trombone and trumpet players caused either by differences in the necessary air flow and pressure, or by different cavity shapes required due to vocal tract tuning.

Moving down even further along the vocal tract we can find another articulator that plays a role in speech production and brass playing: the glottis. Findings regarding glottis opening during brass playing suggest that proficient players use glottal constriction as a means of controlling airflow (Mukai, 1989; Yoshikawa, 1998) and make changes for playing in different registers according to the blowing resistance of the instrument (Carter, 1966). Less proficient players might be varying their tongue height to the same effect which could explain their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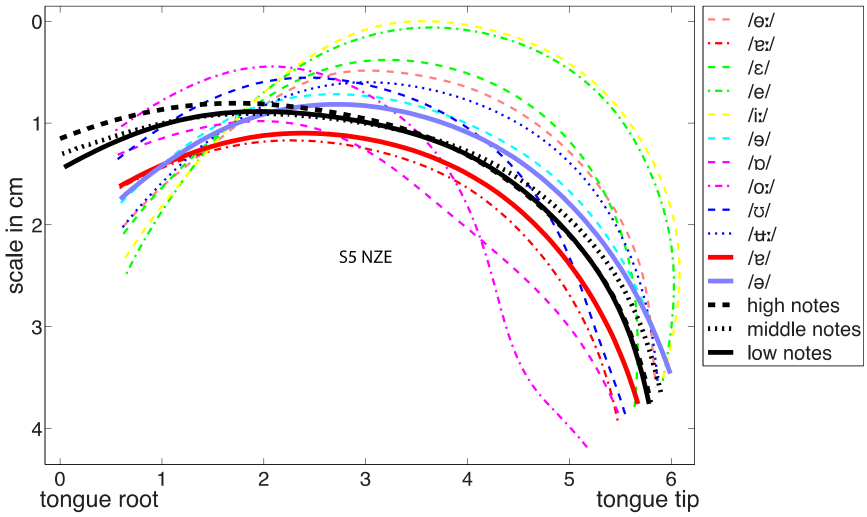
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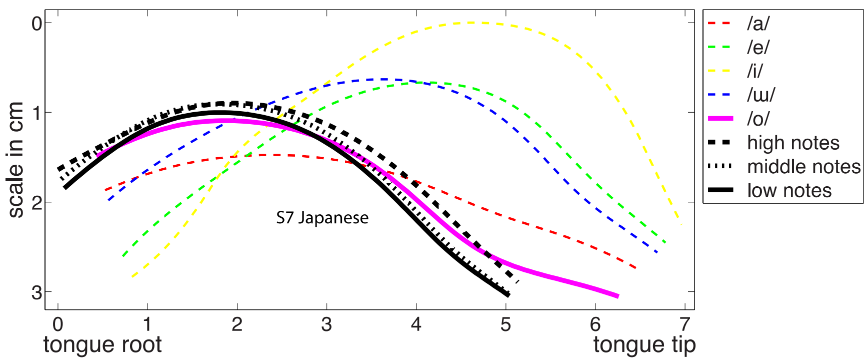
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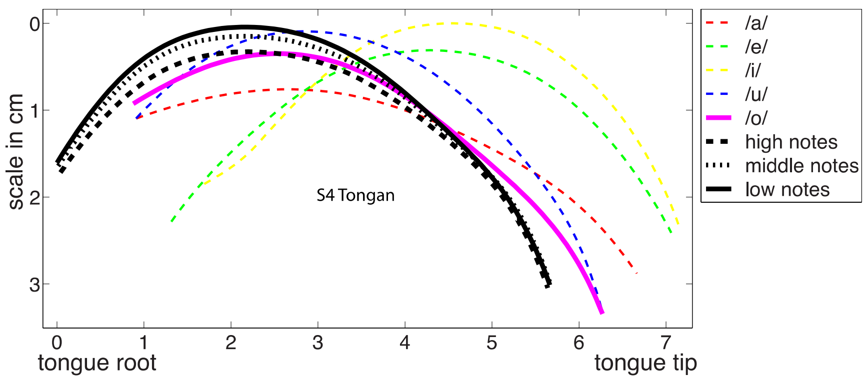
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Figure 1. Average midsagittal tongue contours for four of our participants who follow the pattern outlined in the discussion section.

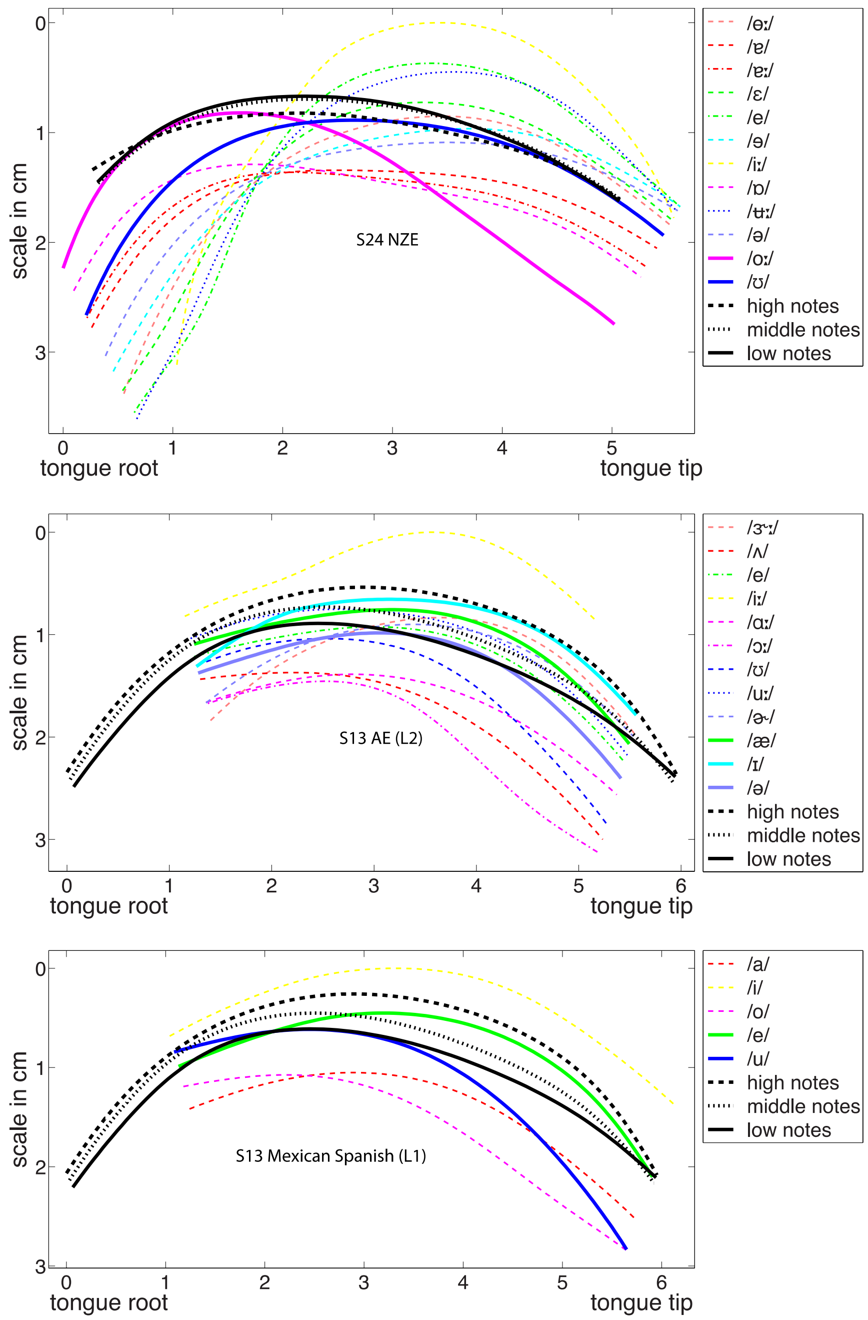

Figure 2. Average midsagittal tongue contours for two of our participants who do not seem to follow the pattern outlined in the discussion section.

pattern of lowering the tongue when ascending while blowing resistance increases.

Another interesting point to discuss are differences that seem to be related to players' proficiency levels on the trombone; in our earlier publication we hypothesized that "professional players of brass instruments [should] display less language influence than amateurs as these individuals spend countless hours practicing their instruments to improve their sound and articulation which should lead to the gradual 'unlearning' of tongue movement patterns acquired with their First Language" (Heyne & Derrick, 2014, p. 183).

This proposition seems to be supported by S13's behaviour in our new dataset; not only does his average tongue position for playing sustained notes fail to resemble any of his vowel tongue positions in either L1 or L2, the greater distance between his tongue shapes for playing in different registers may also show that he has learned to effect the necessary cavity changes almost exclusively within his oral cavity.

VI. CONCLUSION

Analysis of midsagittal tongue shapes recorded for six trombonists during speech production and sustained notes indicates that a relationship exists between a player's L1 and the average tongue position assumed during trombone playing. Specifically, players whose L1s have a standard five-vowel system seem to use a tongue position close to the cardinal vowel /o/ while players whose L1s offer central vowel tongue position have the option of using either of those. In the discussion we provided possible explanations for this behavior and discussed some differences between amateur and more proficient players.

In future work we plan to quantify our findings by analyzing more data which we have already recorded and investigating how the consonants of different languages affect the articulation on brass instruments.

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