Relationship of Airway Anatomy and Trumpet Performance

Relação Entre Anatomia das Vias Aéreas e Desempenho do Trompete

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Abstract: The goal of this research study was to determine the relationship between the airway anatomy of university trumpet players and their performance skills. Following reliability studies, three-dimensional cone beam computed tomography scans of 66 university Caucasian trumpet players were analyzed. The most constricted area of the airway (MCA), airway dimensions (length and volume) of the nasal cavity, nasopharynx, oropharynx, maxillary sinuses, prevertebral soft tissue thickness, and neck circumference were measured. The same players played a quantitative skills test to measure their technical performance skills (flexibility; single, double, triple and flutter tonguing; endurance; and high and low range). The results of the skills test and airway measurements were compared (Spearman's correlation) accepting a 5% significance level for all comparisons. Results: The nasal cavity volume significantly correlated with flexibility, double and triple tonguing and flutter tonguing in high range. Measurements of oropharynx volume, total airway volume, and most constricted area significantly correlated with low range skill. High range skill significantly correlated with multiple measurements: soft tissue thickness AA, soft tissue thickness CV 2ia, airway length, and neck circumference. Airway length also significantly correlated with flutter tonguing in high range and endurance skills. Although the significance levels were all high, the correlations were weak in many cases. Conclusion: Various aspects of the airway anatomy were related to technical skills of trumpet performance. Further studies need to be conducted for better understanding of these relationships involving airway anatomy and trumpet playing.

Keywords: Trumpet performance; airway anatomy; music education

Resumo: O objetivo deste estudo de pesquisa foi determinar a relação entre a anatomia das vias aéreas de trompetistas universitários e suas habilidades de desempenho. Após estudos de confiabilidade, foram analisadas tomografias computadorizadas tridimensionais de feixe cônico de 66 trompetistas universitários caucasianos. Foram medidas a área mais contraída das vias aéreas (ACM), as dimensões das vias aéreas (comprimento e volume) da cavidade nasal, nasofaringe, orofaringe, seios maxilares, espessura dos tecidos moles pré-vertebrais e circunferência do pescoço. Os mesmos jogadores realizaram um teste quantitativo de habilidades para medir suas habilidades de desempenho técnico (flexibilidade; língua simples, dupla, tripla e vibrante; resistência; e alcance alto e baixo). Os resultados do teste de habilidades e das medidas das vias aéreas foram comparados (correlação de Spearman) aceitando um nível de significância de 5% para todas as comparações. Resultados: O volume da cavidade nasal correlacionou-se significativamente com a flexibilidade, língua dupla e tripla e *flutter tonguing* na faixa alta. As medições do volume da orofaringe, do volume total das vias aéreas e da área mais contraída correlacionaram-se significativamente com a habilidade de baixa amplitude. A habilidade de alto alcance correlacionou-se significativamente com múltiplas medidas: espessura dos tecidos moles AA, espessura dos tecidos moles CV 2ia, comprimento das vias aéreas e circunferência do pescoço. O comprimento das vias aéreas também se correlacionou significativamente com a vibração da língua em habilidades de alcance alto e resistência. Embora os níveis de significância fossem todos elevados, as correlações eram fracas em muitos casos. Conclusão: Vários aspectos da anatomia das vias aéreas foram relacionados às habilidades técnicas de execução do trompete. Mais estudos precisam ser realizados para melhor compreensão dessas relações que envolvem a anatomia das vias aéreas e o toque do trompete.

Palavras-chave: Desempenho de trompete; anatomia das vias aéreas; Educação musical

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1. Introduction

In most basic terms, trumpet playing involves excitation of the air column inside the instrument by blowing air through vibrating (buzzing) lips. As a result, sound is produced and utilized for music making (BERKOPEC, 2013; HERBERT and WALLACE, 1997). As simple as this sounds, a series of physical activities are needed for production of quality sound and efficiency to create music. Much of these activities require a well-trained "interplay of the individual elements such as lips, mouth and facial musculature, teeth, tongue, palate, base of the tongue, larynx and respiratory organs" (SCHUMACHER *et al,* 2013). Therefore, these parts of the body and their proper usage play a vital role in trumpet performance.

Many studies were conducted by Berkopec (2013), Schumacher *et al* (2013), Amstutz (1970), Itis *et al* (2015), Merriman and Meidt (1968), Kaburagi *et al.* (2011), Fréour (2013) and Nichols *et al.* (1971) in order to understand the physical mechanisms of brass instrument performance. The earliest studies, which occurred in the late 1960's and early 1970's used the imaging technologies of the time, in order to understand the physical activities during performance. Both Meidt[10] and Nichols *et al.* (1971) used cinefluorographic imaging in their studies to investigate the activities of the tongue and other organs in the oral cavity. Meidt (1967) reported tendencies regarding supra-laryngeal adjustments, and Nichols *et al.* (1971) suggested, "the control movements of the true vocal chord are the most important for the production of sound and sound interruption in trumpet playing." Meidt (1967) and Nichols *et al.* (1971) also attempted similar investigations to observe teeth aperture, instrument pivot, and tongue arch during trumpet performance using videofluorographic imaging and reported various changes in the observed elements during performance but no interaction/relationship between them.

Several later studies used more modern medical technology. Angerstein *et al.* (2009) and Zielke *et al.* (2012) used sonography to compare the tongue movements of the brass, reed and flute players during performance and found that the brass players demonstrated the largest tongue movement during performance. Kaburagi *et al.* (2013) used static MRI to observe the changes in the vocal tract area of a trumpet player during performance, and reported that anterior cross-sectional area decreased and posterior cross-sectional area increased as the players played higher notes. Schumacher *et al.* (2013) used high-speed real-time MRI technology to observe mouthpiece placement and angle, velopharyngeal movements, and changes in oropharyngeal areas in trumpet players. They found that the volume of the oropharyngeal cavity increased as the played notes got higher and louder.

Fréour (2013) stated that during trumpet performance, an additional resonance occurred in the areas inside the mouth and throat. He claims that, "In wind instruments, the vocal tract can be considered as an auxiliary resonator placed in series with the downstream resonating system formed by the instrument air column." He continues to explain: "Because its geometry can be significantly varied (during speech production for instance), the 'acoustical load' of the vocal tract perceived by the lips is subject to change and may produce different effects on the vibrating lips" (FRÉOUR, 2013).

The well-known trumpet player and brass instrument manufacturer R. O. Schilke (1980) suggested that the volume of the oral cavity also has some influence in brass instrument performance:

> At the last point of rarefaction, which occurs in front of the bell of the instrument, a standing node is formed which gives a rescinding node going back through the instrument and culminates itself in the larynx of the performer. This is the reason why performers with different sized oral cavities will play the over-all pitch of the same instrument differently. (Schilke, 1980).

Although the exact functioning of the airways and the organs within the airways during trumpet playing is still a topic of investigation, it is clear that they have a substantial influence on trumpet performance. The main goal of this exploratory research study is to determine if the anatomy of the airways has any relationship to trumpet performance skills.

2. Methods

2.1 Participants

Following IRB approval of 11 universities (Indiana University, University of Cincinnati, Indiana State University, Ball State University, University of Louisville, Northern Kentucky University, University of Indianapolis, Wright State University, Butler University, Miami University, Bowling Green State University), written informed consent from 66 Caucasian trumpet players (52M:14F; mean age 23.0 + 0.5 yrs.) were obtained. Each student performed the trumpet skill tests and had a three-dimensional cone beam computed tomography (CBCT) scan taken.

2.2 Airway Measurement

All subjects were scanned using the same iCAT 3D Imaging system (Imaging Sciences International, Hatfield, PA) with the following scan settings: 120 kV, 20 mA, 17X23 cm field of view, 0.3 mm voxel size and a scanning time of 8.9 sec. The orientation of all 3D images was standardized prior to measurements (Table 1).

Table 1. Image orientation

Plane	Definition
Mid-sagittal plane	Plane based on Nasion to Pogonion through Basion
Axial plane	Plane based on Frankfort horizontal (right Porion to right Orbitale)
Coronal plane	Plane centered on the bifurcation of the maxillary first molars

The most constricted area of the airway (MCA), airway dimensions (length and volume) of the nasal cavity, nasopharynx, oropharynx, maxillary sinuses, prevertebral soft tissue thickness, neck circumference and total airway volume and length were measured

(Table 2; Figs. 1-4) using Dolphin 3D Imaging Software version 11.8 (Dolphin Imaging and Management Solution, Chatworth, CA).

Table 2. Airway boundaries used for 3D measurement (Figures 1-4)

	Midsagittal section	Coronal section
Nasal Cavity	Nasion to Anterior Nasal Spine (ANS) to Posterior Nasal Spine (PNS) to Sella	Widest outline of the nasal cavity from crista galli running downward toward the nasal floor and passing through the side walls of the right and left nasal cavity
Nasopharynx	PNS to sella to the most superior tip of the odontoid process	
Oropharynx	PNS to the most superior tip of the odontoid process to the most posterior superior portion of the fourth cervical vertebrae (C4sp) to the most anterior point of the hyoid bone	
Maxillary sinus		Superior, lateral, inferior, and mesial borders of the sinus extended as necessary throughout the slices in order to obtain the entire sinus volume
Soft Tissue Thickness	Most anterior portion of the atlas vertebrae (AA), the most anterior inferior portion of the second cervical vertebrae (CV2ia), the most anterior superior portion of the third cervical vertebrae (CV3sa), the most anterior inferior portion of the third cervical vertebrae (C3ia), and the most anterior superior portion of the fourth cervical vertebrae (C4sa) to the posterior soft tissue wall of the pharynx	
Airway length	Line of best fit of points midway between the anterior and posterior pharyngeal walls using the following boundaries	Superior boundary – Sella to PNS Inferior boundary – most posterior-superior point on the fourth cervical vertebrae (C4sp) to the most anterior point of the hyoid bone
Neck Circumference	Line passing arround the external outline of the neck at the level of the cervical vertebrae (CV4)	

Fig. 1. 3D CBCT showing the boundaries of the airway segments: I) Nasal cavity, II) Nasopharynx and III) Oropharynx. A. shows landmarks and areas for each lateral airway segment; B. shows frontal landmarks for segmentation process of nasal cavity; C. shows lateral segmentation of nasal cavity, nasopharynx, and oropharynx.

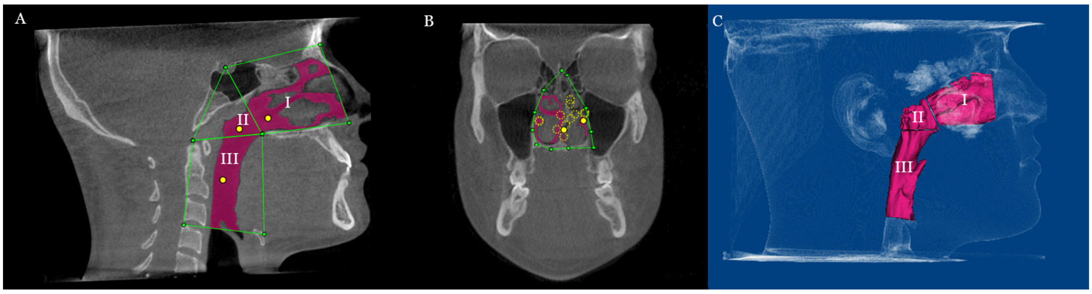


Fig. 2. Maxillary sinus volume (right and left) showing A. segmentation landmarks in lateral view and B. sinuses in the CBCT after segmentation

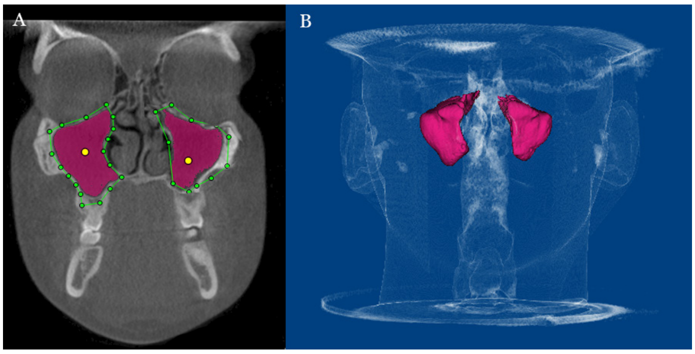


Fig. 3. Lateral view of 3D CBCT showing soft tissue thickness measures of the airway at: AA - ; CV2ia – cervical vertebra 2 inferior anterior point; CV3sa – cervical vertebra 3 superior anterior point; CV3ia – cervical vertebra 3 inferior anterior point; and CV4sa – cervical vertebra 4 superior anterior point

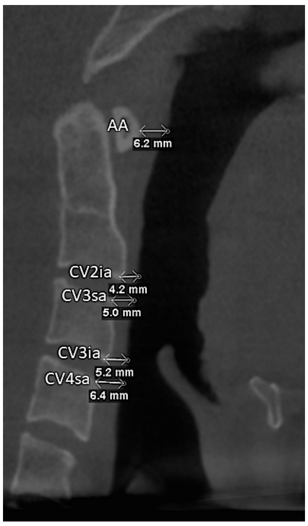
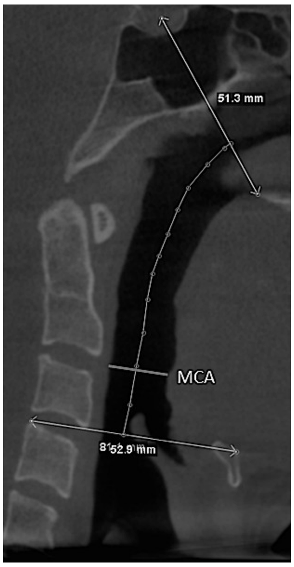


Fig. 4. Airway length and MCA (Most constricted area)



Prior to measurement of subject CBCTs, one investigator measured 10 randomly selected and coded 3D CBCTs of subjects not in the study and one week later remeasured the rerandomized CBCTs to determine reliability. Intraclass correlations >.9 were considered acceptable to proceed with measurement of coded study 3D CBCTs.

2.3 Performance Skills Measurement

Prior to the CBCT scanning procedure, the same players played a skills test that measured their technical performance skills. The skills test was designed to produce quantitative scores. It included exercises testing some of the basic technical skills needed for trumpet performance: flexibility, articulation, endurance, and range.

All tests were conducted in the same soundproof recording room using a microphone (MD421 II unidirectional microphone, Sennheiser GmbH & Co. KG, Wedemark, Germany), a sound recorder (Zoom H4n handy recorder, Samson Technologies Incorporation, Hauppauge, NY, USA), a camcorder (DCR-DVD650, Sony Corporation, Tokyo, Japan), a metronome software application, and a decibel-meter (Digital Sound Level Meter Catalog no: 33-2055, RadioShack Corporation, Fort Worth, TX, USA). The settings of the equipment such as recording level, distance from the bell of the trumpet to the microphone, were kept the same for each participant.

Flexibility is one of the key skills in trumpet performance. It allows the player to move between overtones in a flawless manner. Generally, flexibility exercises in trumpet literature require the player to move between different overtones on the same finger position in a slurred manner without the help of different finger positions. The more the player masters this skill, the faster they are able to play the flexibility exercises. Thus, testing of flexibility included three exercises (A, B, C) at different difficulty levels (Fig. 5). Each exercise involved playing a different set of overtones in the same finger position (open) in a slurred manner. The fastest tempi in beats per minute (bpm) the player could play each exercise determined the player's score.

Fig. 5. Skills Test

There are different types of articulation techniques used in trumpet performance. The main ones are called single, double, triple and flutter tongue. In single tongue articulation, the player uses the 'tu' syllable; the tongue articulates a single attack, creating a single note. In double tongue, 'tu-ku' syllables are pronounced. This way, a double attack is articulated and two notes at a time are created. In triple tongue, 'tu-tu-ku' syllables are pronounced, which allows the player to articulate a triple attack and create three notes at a time. As these articulation techniques are mastered, the player is able to articulate the notes in a faster manner.

Flutter tonguing, on the other hand, requires the tongue to "flutter" inside the mouth during playing. While for some players it is easy to apply this technique at different sound registers, for others, it is difficult to acquire this technique outside of the middle register, or even not possible at all. Thus, in the skills test, the skill of flutter tonguing was determined by the width of the register player can apply the technique.

Articulation exercises involved evaluation of single, double, triple and flutter tonguing techniques (Fig. 5). While single, double and triple tonguing exercises (A, B, and C exercises) were played on a single note, the flutter tonguing exercises (D-high and D-low) required the players to play as high and as low as possible while flutter tonguing.

The scores for articulation A, B, and C exercises were determined by the highest tempi (beats per minute) players could play the exercises. For flutter tonguing exercises, a scoring scale starting from the middle G (G4) was created (Fig.6). The score of the G was determined as 1, and it was increased by 1 in each half step the player could play higher or lower depending on the range tested.

Fig. 6. Scoring scale used for range and flutter tonguing scoring

G6	25	G1
F♯6	24	G♯1
F6	23	A1
E6	22	A♯1
D♯6	21	B1
D6	20	C2
C♯6	19	C♯2
C6	18	D
B6	17	D♯2
A♯5	16	E2
A5	15	F2
G♯5	14	F♯2
G5	13	G2
F♯5	12	G♯2
F5	11	A2
E5	10	A♯2
D♯5	9	B2
D	8	C3
C♯5	7	C♯3
C5	6	D3
B4	5	D♯3
A♯4	4	E3
A4	3	F3
G♯4	2	F♯4
G4	1	G4

High Range

Low Range

In order to determine the scores for range skill, players were asked to play notes in the lower and higher ranges of the trumpet (Fig. 5). For the low range skill, they began playing from the low C (C3) and continued to play as low as they could. For the high range skill, they began playing from the middle C (C5) and continued as high as they could. They could take breaths as they needed. For scoring the exercises, the scale used for flutter tonguing was applied (Fig. 6). The players received two scores for high range and for low range, depending on the highest and lowest notes they could play.

Endurance exercise (Fig. 5) required the players to play a five-note pattern in mid-high range of the trumpet continuously, while keeping the sound volume above a predetermined level with the help of a decibel-meter. They were instructed to take short breaths as they needed without stopping. The number of seconds the players could continue to play determined their endurance scores.

2.4 Statistical Analyses

Descriptive statistics (mean and standard deviations) for all measures were developed and the results were correlated using Spearman's test. A significance level of 5% was accepted. A correlation below .40 was considered weak; moderate between .40-.70; and strong greater than .70.

3. Results

The means and standard deviations for the airway measures are shown in Table 3.

Table 3. Descriptive statistics for airway measures of trumpet players (n=66)

Airway structure	Mean ± SD*	Minimum	Maximum
Nasal cavity volume (mm³)	18028 ± 4834	5719	30426
Nasopharynx volume (mm³)	7452 ± 2553	2233	14516
Oropharynx volume (mm³)	22240 ± 8473	7698	54061
Total airway volume (mm³)	29534 ± 10103	13149	68404
Most constricted area (mm²)	248 ± 111	71	615
Maxillary sinus volume right (mm³)	16646 ± 5250	6784	32397
Maxillary sinus volume left (mm³)	16693 ± 6631	15062	34273
Airway length (mm)	79.6 ± 6.1	67.5	92.5
Soft tissue thickness AA (mm)	4.6 ± 2.3	1.8	12.5
Soft tissue thickness CV 2ia (mm)	3.3 ± .8	1.8	6.1
Soft tissue thickness CV 3sa (mm)	4.6 ± 1.0	2.1	7.9
Soft tissue thickness CV 3sia (mm)	3.6 ± 1.1	2.1	8.5
Soft tissue thickness CV 4sa (mm)	5.0 ± 1.5	2.6	10.6
Neck circumference (mm)	466.6 ± 40.4	360.8	565.9

Numerous correlations between airway anatomy and performance were found to be significant (Table 4). The nasal cavity volume significantly correlated with flexibility B and C, double and triple tonguing, as well as flutter tonguing in high range. Nasopharynx and total maxillary sinus volumes significantly correlated with flexibility C exercise. Oropharynx volume, total airway volume, and most constricted area significantly correlated with low range skill. The most constricted area of the pharynx negatively correlated with flutter tonguing in low range. Pharyngeal soft tissue thickness CV3ia positively correlated with flutter tonguing. High range skill significantly correlated with multiple measurements: soft tissue thickness AA, soft tissue thickness CV2ia, airway length, and neck circumference. Airway length significantly correlated to flutter tonguing in high range and endurance skills.

Table 4. Significant correlations+ (r) between airway measure and skill variable

Airway variable	Flexibility			Articulation					Range		Endurance
	A	B	C	Single tongue	Double tongue	Triple tongue	Flutter tongue low	Flutter tongue high	Low	High	
Nasal cavity volume		.43	.34		.39	.32		.28			
Nasopharynx volume			.34								
Oropharynx volume									.26		
Total airway volume									.25		
Most constricted area							-.27		.26		
Maxillary sinus volume (total)			.25								
Soft tissue thickness AA										.28	

Soft tissue thickness CV2ia						.29				.29	
Soft tissue thickness CV3ia							.26				
Soft tissue thickness CV4sa											
Airway length								.30		.27	.27
Neck circumference										.31	

+ *(Spearman's correlations, accepting p < .05 as significant)*

4. Discussion

4.1 Nasal Cavity & Performance Skills

The most interesting finding of the study is the relationship of the nasal cavity volume and various performance skills. Results suggest highly significant relationships between flexibility (B and C exercises) and multiple tonguing (double, triple and flutter tonguing in high register) scores and nasal cavity volume of the participants; however, the correlations are weak. It appears that both flexibility (exercises B and C) and articulation skills are affected by nasal cavity volume so that the larger the volume, the better the performance scores are.

It should be noted that this relationship is between the skill and the nasal cavity volume of the nose, not the size of the nose. The software, Dolphin, measures the air volume, which can be influenced by hard and soft tissue as well as fluid. One of our previous studies showed significantly reduced nasal cavity volume of trumpet players compared with gender and ethnic matched subjects who had never played brass instruments (GHONEIMA *et al.,* 2015). However, the amount of soft and hard nasal tissue plus fluid was not measured. Although it is difficult in a cross-sectional study to determine cause-effect relationship, it is possible that the pressure of airflow by a trumpet player during playing could influence the soft tissue thickness of the nasal cavity. Additional studies are needed to determine the cause of the differences in nasal airspace since it is associated with trumpet performance.

Since sound production on trumpet does not involve the use of nasal cavity, a physical relationship between produced sound and this space is not very likely. However, it may be possible for the volume of this space to have an indirect effect on playing technique.

For instance, in vocal performance, the resonance in different parts of the body (most importantly nasal cavity, pharynx and larynx) plays an important role in performance technique. This phenomena, which is referred to as *vocal resonance,* is described as 'the process by which the basic product of phonation is enhanced in timbre and/or intensity by the air-filled cavities through which it passes on its way to the outside air,'[16] and it is commonly utilized by singers to enhance their performance.

World-renowned flute player E. Pahud advocates a similar idea for producing quality sound on flute. In his Master Class at the Carnegie Hall he explains what he calls 'the wasabi technique,'

> To keep the intensity in the tone, I think what you have to think is also to still go on sending the air all the way up, so that it goes through your nose.[...]This is gonna open up the upper part of the throat and it is gonna open up a

> whole lot of resonance possibilities in your head, just like the singers are using them to project the voice, and the tone is gonna be richer. (PAHUD, 2012).

Pahud further explains that, he refers to this technique as 'wasabi technique,' because the area he suggests directing the air is the area where the burning sensation after consuming wasabi is felt the most (PAHUD, 2012).

The nasal cavity is most likely not a part of the physical process of performance for singers or flute players. However, if utilizing the nasal cavity, directly or indirectly, promotes improvement of performance, the anatomy of this area may possibly have some influence on performance too. In depth research about this subject would give further details and better understanding of this relationship.

4.2 Airway Length & Performance Skills

Another interesting finding was the significant relationship between airway length and flutter tonguing in high range, high range, and endurance skills. The longer the airway were, the higher performance scores were. The relationships between multiple performance skills and airway length, although weakly correlated, were repeated and are worth further investigation in order to understand the nature of the relationships.

4.3 Soft Tissue Thickness & Performance Skills

The measurements of soft tissue thickness in the Cv2ia area had significant relationships with multiple tonguing scores (double and triple tongue, flutter tongue in high and low range) and the high range score.

In trumpet performance, during utilization of multiple tonguing techniques (double, triple, and flutter tonguing) the back of the tongue is used actively. During the use of double and triple tonguing techniques, the player pronounces 'tu-ku' and 'tu-tu-ku' (or in some cases 'tu-ku-tu') syllables continuously in a fast manner. Especially while pronouncing the 'ku' syllable, the back of the tongue is used actively.[5] Similarly, in flutter tonguing technique, the back of the tongue is used in a raised position.

Although high range playing is a completely different skill than flutter tonguing, the back of the tongue is also active in this aspect of trumpet performance as well. Studies show that trumpet players, whether or not intentionally, raise the back of the tongue at different rates as they play higher notes (AMSTUTZ, 1970; FRÉOUR and SCAVONE, 2019).

As a result, although for different purposes, both multiple tonguing techniques and high range playing involve the use of the back of the tongue. Since the rear portion of the tongue is located near the Cv2ia area, it is natural to suspect that the thickness of the soft tissue in this area may influence the performance skills that require using the back of the tongue.

Also, the increase in oropharynx soft tissue can indicate inflammation. Ghoneima *et al*. (2015) showed significantly greater soft tissues in various areas of the posterior walls of the oropharynx of university trumpet players as compared to non-brass players. Speculation as to the cause includes performance methodology or amount of practice.

4.4 Others

The findings also reveal that oropharynx volume, total airway volume, and the most-constricted area are significantly related to the low-range scores.

Regarding vocal performance, McKinney[16] mentions that 'in general, the larger a resonator is, the lower the frequency it will respond to; the greater the volume of air, the lower its pitch.' Similarly, it is generally known that producing lower notes on wind instruments requires more air and an open throat. Therefore, it is possible to suggest that, with larger airway volume in the mentioned areas, it may become easier to produce the lower notes on the trumpet.

Another result that is worth mentioning is the significant relationship of the neck circumference measurements and high range skills. The enlargement of neck circumference may be the result of increased muscle thickness during high range playing due to production of higher air pressure. However, it is difficult to rationalize the relationship of this measurement to high range playing skills; further investigation may reveal information about this relationship.

5. Conclusion

No previous literature regarding the relationship of intra-oral anatomy and trumpet performance was located. Being the first in this topic, this study carries an exploratory nature. Therefore, it is not possible to speculate definitively concerning the causes of this study's findings. On the other hand, a number of striking relationships were discovered and additional investigation should be made. For instance, the highly significant relationships of the nasal cavity volume and almost all of the performance skills are interesting and well worth further investigation. Likewise, the airway length, soft tissue thickness (especially at the Cv2ia), airway volumes, and neck circumference have consistent significant relationships to several performance skills scores.

As a result, the findings of this exploratory study reveal new data about the relationship of airway anatomy and trumpet performance skills. Although the findings were highly significant, they were also mostly weak to moderate in correlation. Therefore, further studies would be beneficial to investigate the details of the relationship of airway anatomy and trumpet performance. Investigation of each anatomical aspect and performance skill separately, and a longitudinal study on trumpet players starting from earlier stages of their music education may shed more light on the topic and give more detailed information.

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