

OROFACIAL STRENGTH AND ENDURANCE IN  
SKILLED TRUMPET PLAYERS

By

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A thesis submitted in partial fulfillment of  
the requirements for the degree of

MASTER OF ARTS IN SPEECH AND HEARING SCIENCES

WASHINGTON STATE UNIVERSITY  
Department of Speech and Hearing Sciences

MAY 2013

To the Faculty of Washington State University:

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## ACKNOWLEDGMENTS

I would like to express my deepest appreciation to my committee chair and friend, Dr. Nancy Potter, for not only her academic support, but her emotional and spiritual encouragement as well. I am truly grateful for her mentorship and for the opportunity to learn from such a strong, godly woman.

Thank you to my committee members, Dr. Mark VanDam and Dr. Amy Meredith, for your time and energy you've dedicated to seeing me through this project especially in the final stages. Thank you for keeping your office doors open to me.

Thank you to my uncle, Dr. Stephen Johnson, for his interest in my research and his substantial contribution of statistical analysis. I am grateful for his continued encouragement over the years to pursue my academic dreams.

A big thank you to Andrew Plamondon, the Professor of trumpet at Eastern Washington University and member of Spokane Jazz Orchestra, for his help in recruiting participants and for introducing me to his network of talented musicians. Of course, thank you to all of the participants, who volunteered their time and energy to this investigation and for providing me with research worth writing about.

I would like to thank my colleagues and friends Kasey Weeks and Allison Gilbert, both for their assistance in data collection and for the wonderful memories we've shared throughout our program together. I am overjoyed that we will be nearby each other as we begin our careers.

Thank you to my family for their prayers and words of encouragement, and for always believing in me. Most of all, thank you to my loving husband Joel, for supporting me in my graduate school adventures while providing for our family. I only hope I can provide the same solid foundation for you now that it is your turn to pursue your academic dreams.

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SKILLED TRUMPET PLAYERS

Abstract

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May 2013

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Individuals who are particularly skilled in the use of a given muscle group, such as trumpet players, may demonstrate increased strength and endurance beyond that of regular users in orofacial muscle regions. The purpose of this study was to determine if trumpet playing individuals differed from non-trumpet playing individuals in 1) cheek strength and endurance, 2) tongue strength and endurance, and/or 3) lip strength and endurance.

This is a case-control study of 16 trumpet players and 16 healthy non-trumpet playing controls balanced for age and sex. Strength and endurance of cheek, tongue, and lip muscles were measured using the Iowa Oral Performance Instrument. Maximum strength was recorded as the greatest pressure value of three encouraged trials and endurance was recorded as the length of time the participant was able to sustain 50% of their maximum strength pressure.

The trumpet players had greater cheek strength and greater lip endurance than controls. Tongue strength and endurance did not differ between the trumpet players and the controls. Tongue strength was negatively associated with age which is consistent with previous studies.

The findings indicate that a functional activity, such as trumpet playing, can increase facial strength and/or endurance and this increase can be objectively measured using commercially available equipment. Objective strength and endurance measurements have the potential to quantify facial nerve function in clinical populations.

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## **INTRODUCTION**

Facial movement is the result of 23 paired muscles innervated by branches of cranial nerve VII (CN 7), the facial nerve (Cronin & Steenerson, 2003). Lip movement alone is managed by approximately ten paired muscles innervated by the buccal and mandibular branches of CN 7. Unlike skeletal muscles, which originate on bone and insert to bone, most facial muscles originate on bone and insert into the skin or cutaneous layers of the face (Barlow & Netsell, 1986). The primary muscle responsible for closing and puckering the lips, the orbicularis oris (OO) muscle, is a sphincter muscle comprised of both intrinsic and extrinsic muscle fibers. This muscle does not originate on bone; rather its origin and insertion are within other facial muscles. The intrinsic fibers are exclusive to the lips, coursing from one corner of the mouth to the other and can be further divided into four interlaced independent muscles that originate on the maxilla (right and left superior OO) or the mandible (right and left inferior OO). The muscles extrinsic to the lips insert into the OO and can be divided into three groups including transverse muscles (buccinators and risorii), angular muscles (levator labii superior, depressor labii inferior, zygomatic major), and vertical muscles (mentalis, depressor anguli oris, levator anguli oris). The interdigitations of the face and lip muscles result in collaborative function necessary for fine lip and cheek movement (Gray, 1977; Zemlin, 1998). The buccinator is a paired extrinsic contributor to the musculature of the lips and serves as the principal muscle of the cheek. Upon contraction, this deep facial muscle compresses the lips and cheeks against the teeth as well as draws the corners of the mouth laterally.

Integrity of the facial musculature can be examined through visual assessment of the degree of normal and abnormal facial movement using the Facial Nerve Grading System (FNGS; House & Brackmann, 1985) and Facial Nerve Grading System-2 (FNGS-2; Vrabc, 2009).

Integrity of facial musculature may also be assessed by measuring the pressure generated by compressing a bulb or pressure transducer between the lips or between the lips/cheeks and teeth (Crow & Ship, 1996; Perry, Potter, Rambo, & Short, 2011).

Facial strength can be increased through facial strengthening exercises. Perry et al. (2011) reported that a single participant, with long-standing (13 years post-injury) facial nerve damage resulting from a motor vehicle accident, significantly increased strength in four facial muscle regions on the affected side following a six week intensive facial strengthening exercise program. A randomized controlled trial by Manikandan (2007) found that patients with Bell's palsy who participated in facial neuromuscular re-education exercises for three sessions per day, six days per week, for a period of two weeks experienced improved facial symmetry. Brach and VanSwearingen (1999) reported success with neuromuscular re-education exercises with a 71 year old patient recently diagnosed (2 weeks from start of program) with complete left facial paralysis secondary to Bell's palsy. With exercise, this patient significantly increased her composite FNGS score over a 13 month period.

Tongue strength and endurance can be increased through exercise. Repetitive use resulting from an eight week lingual exercise program has been found to increase tongue strength in healthy individuals (Robbins, Gangnon, Theis, Kays, Hewitt, & Hind, 2005). Repetitive use resulting from a functional activity such as trumpet playing or competitive debate has been found to increase tongue endurance in healthy individuals as compared to age and sex-matched controls (Robin, Goel, Somodi, & Luschei, 1992).

A commercial unit, the Iowa Oral Performance Instrument (IOPI Medical LLC, Carnation, WA), originally designed to measure tongue strength and endurance, has also been used to measure cheek and lip strength. Clark and Solomon (2012) examined sex- and age-

related differences in orofacial strength. Results favoring men were found to exist in lip and cheek strength but no differences were discovered with tongue strength. Cheek and lip strength was not found to differ significantly with age but tongue strength demonstrated an age-related decline. This finding is supported by existing literature that older adults have weaker tongue strength as compared to younger adults (Adams, Mathisen, Baines, Lazarus, & Callister, 2013; Clark & Solomon, 2012; Crow & Shipp, 1996; Neel & Palmer, 2011; Robbins, Levine, Wood, Roecker, Luschei, 1995; Stierwalt & Youmans, 2007; Vitorino, 2010; Youmans, Youmans, & Stierwalt, 2009).

Endurance has been defined as the length of time 50% of maximum pressure can be sustained (Adams et al., 2013). Studies examining tongue endurance report that endurance is related to the percent of maximal strength required for task completion but report no significant differences in tongue endurance with age (Crow & Ship, 1996; Vitorino, 2010; Stierwalt & Youmans, 2007).

Trumpet players use several orofacial muscles in order to produce and manipulate sound through the instrument. Primarily, the tongue is used to shape and articulate airflow while the OO and the buccinators are the most involved in creating a proper embouchure (Bianco, Freour, Cossette, Bevilacqua, & Causse, 2012). The term embouchure is used to describe the purposeful arrangement of the facial muscles to produce a sound on a wind instrument. Fundamental frequency, perceived as pitch or a musical tone, can be changed through tightening of cheek and lip muscles, minutely altering the amount of fine muscular contraction of the embouchure. Producing musical tone relies on the control of the pressure at the lips, the contact force on the mouthpiece, intra-oral air pressure, and the lingual articulatory movements. Orofacial musculature must maintain a high level of physical integrity to resist an intense, focused column

of air. Highly skilled trumpet players exercise their lip muscles to develop a strong embouchure, capable of enduring hours of strenuous muscle activity.

Individuals who are particularly skilled in the use of a given muscle group, such as trumpet players, may demonstrate increased strength and endurance in orofacial muscle regions beyond that of regular users. The purpose of this study was to determine if trumpet playing individuals differed from non-trumpet playing individuals in 1) cheek strength and endurance, 2) tongue strength and endurance, and/or 3) lip strength and endurance.

## **METHOD**

### **Participants**

Participants in this case-control study, as summarized in Table 1, included 32 participants, 16 trumpet players and 16 age- and sex- balanced healthy controls. The younger trumpet players (younger than 27 years of age) were students from a university music department and the older trumpet players (older than 45 years of age) were professionals from a jazz orchestra. Inclusion criteria for trumpet players required self-reporting a minimum of 8 years experience playing the trumpet, at least 6 hours per week of practice time, and instrumental rest for 12 hours or more prior to data collection to prevent possible muscle fatigue. Due to strict inclusion criteria, there was a limited sample population and age groups were not evenly represented. No individuals between 27 and 45 years of age volunteered to participate in the study. Control participants were from a university and from the community. Inclusion criteria for controls required self-reporting no experience playing a wind instrument. All participants were required to perform within normal limits on an orofacial structure-function exam as judged by the examiner and self-reported a negative history of neurological impairment. One participant from the trumpet player group reported a history of Bell's palsy. Due to his history of neurologic

impairment, his data were excluded from the group analysis; however, his results will be discussed as they are of clinical interest. The Institutional Review Board of Washington State University approved this study and each participant provided written consent.

Group	Male (n)	Female (n)	Mean age (SD)	Experience in years (SD)	Mean practice hours/week (SD)
Trumpet players	14	2	28.7 (17.4)	18.5 (16.7)	12.9 (7.4)
Young	11	2	21.1 (2.7)	11.2 (2.6)	14.2 (7.6)
Old	3	0	61.7 (15.0)	50.0 (15.0)	7.3 (2.3)
Controls	14	2	28.9 (16.6)	N/A	N/A
Young	11	2	21.6 (3.2)	N/A	N/A
Old	3	0	60.3 (13.4)	N/A	N/A

Table 1. Demographics of trumpet players and controls.

## Instrumentation

The IOPI was used to obtain orofacial strength and endurance measures. The IOPI is a hand-held device that measures pressure generated against a soft PVC air-filled bulb and includes a peak-hold function and a timer. The results are displayed in kilopascals (kPa) on a digital screen or by a light array in 10% increments. A bulb-holder adapter, consisting of a plastic stick featuring a flat oblong plate on one end, can be adhered to the IOPI bulb with a piece of double-sided surgical grade tape. On either side of the stick, silicone rubber pads serve as bite cushions to secure placements of the bulb and holder.

## Procedures

### *Strength measurements*

For strength measured in kPa, participants were instructed to press against the bulb with maximum effort. Peak pressure values of three trials were recorded and the greatest pressure value was used as maximum strength. Measurements were collected for right and left cheek strength, lip strength, and tongue elevation strength.

### *Endurance measurements*

For endurance measured in seconds, participants watched a light array while sustaining 50% of their maximum strength pressure for as long as possible. Each trial began when 50% of maximum pressure was achieved and ended when a persistent drop of greater than 10% was observed.

Measurements were collected with rest periods between regions in the following order; left cheek strength, right cheek strength, left cheek endurance, tongue strength, tongue endurance, right cheek endurance, lip strength, and lip endurance.

### *Bulb placement*

Cheek strength and endurance were assessed with the IOPI bulb attached to the bulb-holder adapter and placed in the lateral position with teeth lightly clamped on the bite cushions. The IOPI bulb faced laterally toward the left and then the right buccal surface and participants were instructed to isolate and squeeze each cheek against the bulb.

Tongue elevation strength and endurance were assessed with the IOPI bulb positioned just posterior to the participant's upper incisors. Participants were instructed to elevate the anterior portion of their tongue against the bulb and keep the teeth parted to avoid biting down on the IOPI tubing.

Lip strength and endurance were assessed with the IOPI bulb sandwiched between two wooden tongue blades. This configuration reduced the possibility of incorrect placement due to possible movement of the smooth surface of the bulb against the lip and distributed the pressure exerted on the blades evenly across the entire surface of the bulb (Clark & Solomon, 2012). The participants were instructed to lightly place their teeth together, separate and protrude their lips, and squeeze on the blades which were placed at midline.

## DATA ANALYSIS

Two-tailed *t*-tests are reported for data meeting parametric assumptions and two-tailed Mann-Whitney *U*-tests are reported for lip endurance, which was not normally distributed due to negative skewness. Pearson and Spearman correlation tests were used to assess association between variables of interest. For all tests, an uncorrected alpha-criterion of 0.05 was used.

## RESULTS

### *Cheek*

The possibility of a difference in right and left cheek strength was examined. Although as individuals, trumpet players and controls varied between their right and left cheek strength by as much as 25% ( $\Delta M = 3.47$  kPa,  $SD = 2.97$ , range = 0-13 kPa), the difference was not significant within the trumpet playing group ( $t(30) = 1.00$ ,  $p = 0.33$ ), within the control group ( $t(30) = 0.45$ ,  $p = 0.65$ ), or within the pooled group ( $t(62) = 0.98$ ,  $p = 0.33$ ). Therefore, maximum pressures from right and left cheeks were averaged within individuals to produce a single measure of cheek strength for each participant. As shown in Figure 1, trumpet players had greater cheek strength than the controls ( $t(31) = 2.65$ ,  $p < 0.02$ ). Cheek endurance did not differ between trumpet players and controls; older trumpet players did not differ from the younger trumpet players in cheek strength or endurance; neither cheek strength nor endurance was found to be associated with age or experience; all  $ps > 0.05$ .

### *Tongue*

Neither tongue strength nor endurance differed between the trumpet players and the controls. Although observed to be within normal limits of palatal arch structure and function,

some participants had a higher palatal arch compared to others. Participants with the high palatal arches had difficulty holding the IOPI bulb in a steady location for tongue strength and endurance. Tongue strength was negatively correlated with age across all participants ( $r = -0.37$ ,  $p < 0.05$ ). Neither tongue strength nor endurance was found to be associated with age or experience.

### *Lip*

Lip strength did not differ between trumpet players and controls. As shown in Figure 2, trumpet players had greater lip endurance than controls ( $U(31) = 2.98$ ,  $p < 0.01$ ). Greater lip strength was negatively associated with lip endurance for both the trumpet players and the control group ( $r = -0.45$ ,  $p < 0.02$ ). As shown in Table 1, the trumpet players who were older also had more experience. Greater lip strength was associated with age ( $r = 0.61$ ,  $p < 0.02$ ) and experience ( $r = 0.62$ ,  $p < 0.02$ ).

### *Participant with Bell's palsy*

The trumpet player with a history of unilateral Bell's palsy on his left side demonstrated a 15% reduction in cheek strength on his affected side (right cheek = 42 kPa, left cheek = 36 kPa) and 31% reduction in endurance on his affected side (right cheek = 198 sec, left cheek = 137 sec). Evidence of contralateral variability in lip strength could not be determined because the measurement was taken in a central position. His tongue strength was not found to be significantly different from that of the trumpet players or the control group ( $p < 0.05$ ).

	Cheek	Tongue	Lip
<i>Mean strength in kPa (SD)</i>			
Trumpet players	36.3 (7.8)*	63.8 (11.0)	19.6 (3.3)
Controls	29.6 (6.3)	58.5 (9.8)	20.2 (3.2)
<i>Mean endurance in sec (SD)</i>			
Trumpet players	105 (51)	39 (20)	284 (248)*
Controls	106 (45)	35 (32)	98 (53)

Table 2. Mean strength and endurance measurements and standard deviations in three muscle regions for trumpet players and controls. \* =  $p < 0.05$

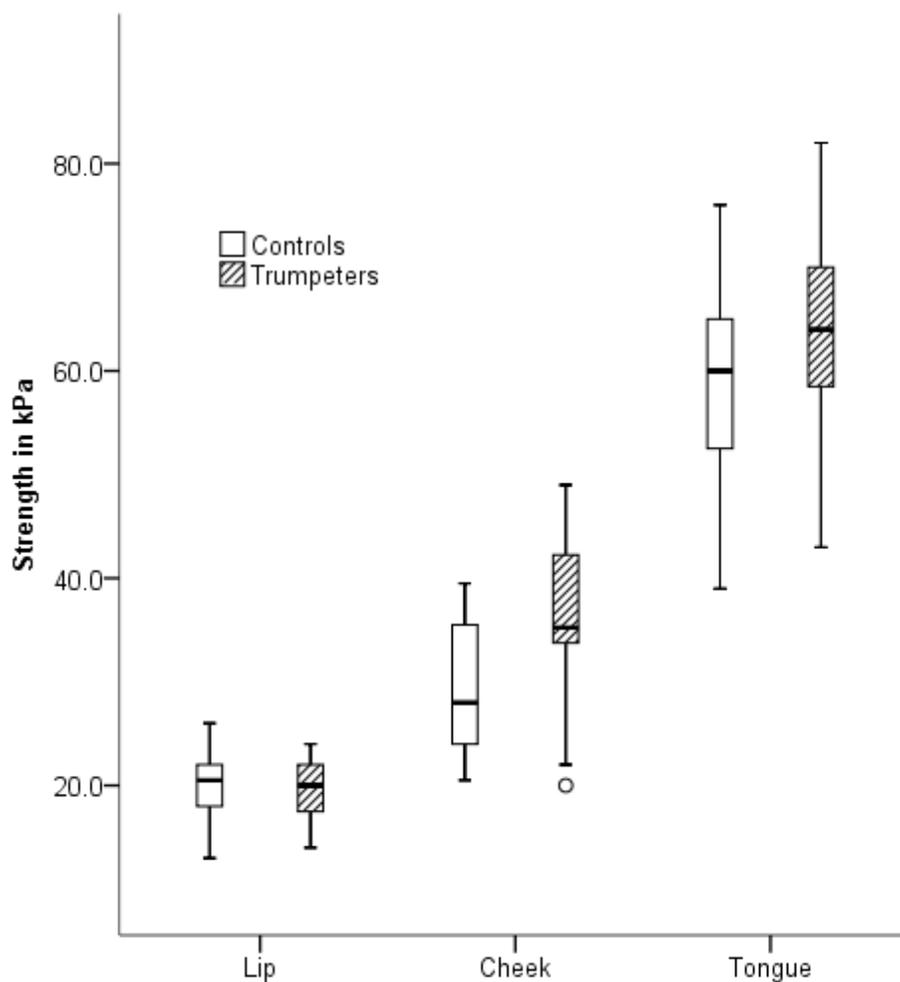


Figure 1. Strength measurements for trumpet players and control group in the three muscle regions. The median is shown by the horizontal line located within each box. Quartiles 2 and 3 are shown by the box. The whiskers show the 95% confidence interval. The outlier is shown by the open circle. Only group differences by cheek strength were significant ( $p < 0.05$ ).

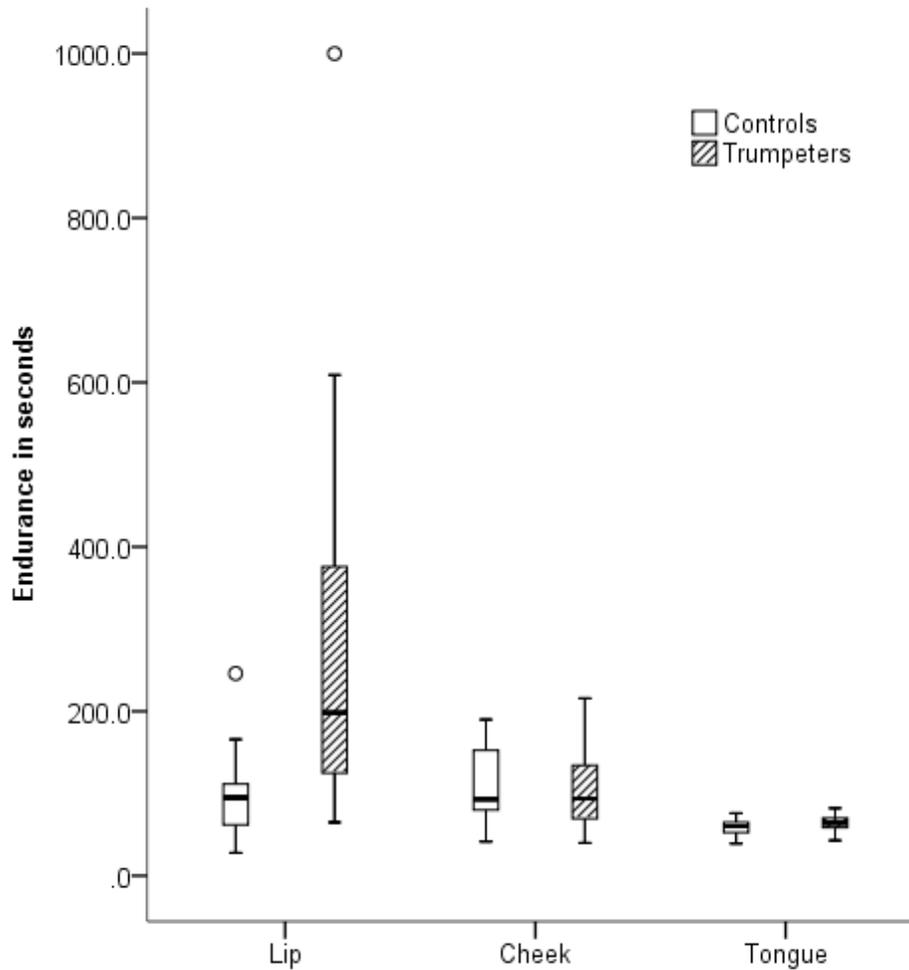


Figure 2. Endurance measurements for trumpet players and control group in the three muscle regions. The median is shown by the horizontal line located within each box. Quartiles 2 and 3 are shown by the box. The whiskers show 95% confidence intervals. Outliers are shown by open circles. Only group differences by lip endurance were significant ( $p < 0.05$ ).

## DISCUSSION

This study compared orofacial strength and endurance measures of trumpet players and controls. Because maintaining a strong embouchure and controlling minute alterations in muscular contractions is required for highly skilled trumpet playing, we predicted trumpet

players would demonstrate greater lip and cheek strength and endurance compared to the controls. As demonstrated in previous studies, we predicted trumpet players would demonstrate greater tongue endurance but no difference in tongue strength (Robin et al., 1992). Tongue strength was predicted to be negatively associated with age across all participants (Adams et al., 2013). We found trumpet players did have greater cheek strength and greater lip endurance as compared to the controls, and tongue strength was negatively affected by age across all participants. However, contrary to our predictions, trumpet players did not have greater cheek endurance or greater lip strength compared to the controls and no differences were found in tongue strength or endurance between groups. Experience and age were found to be associated with increased lip strength.

#### *Cheek*

For the endurance measurement, pressure was held at 50% of the individual's maximum cheek strength. Therefore, the trumpet players had to maintain higher levels of pressure than the controls for the endurance task. The difference in the required pressure levels was evident in the shorter endurance measures observed in the trumpet players with the greatest cheek strength. This finding is consistent with previous studies reporting subjects maintaining longer endurance measures when held at lower levels of pressure (Crow & Ship, 1996; Robin et al., 1992). If the endurance measurements had been collected at a standard pressure, independent of the individual's maximum strength, trumpet players may have shown greater endurance than the controls.

#### *Tongue*

We predicted that trumpet players would have similar tongue strength but greater endurance than controls. This prediction was based on the results of a previous study (Robin et

al., 1992) which found no difference in tongue strength but increased endurance in 12 trumpet players and 5 debaters. The results of the present study found that tongue strength and endurance did not differ between the trumpet players and the controls. This difference may have been due to age of participants or instrumentation, as Robin et al. (1992) used an earlier model of the IOPI to assess strength and endurance. Due to the different instrumentation the measurements from the present study could not be directly compared to those of Robin et al. (1992).

Previous studies have reported that oral structures require no more than 20% of their maximal force-generating capacities to produce speech (Bunton & Weismer, 1994; Neel, Palmer, & Gass, 2008). Similar to speech, trumpet playing is likely a submaximal task requiring only a small portion of total pressure that the tongue can exert. The negative correlation between tongue strength and age found in this study was consistent with results of previous studies reporting that tongue strength declines with age as reviewed in Adams et al. (2013).

### *Lip*

Contrary to our predictions, lip strength in trumpet players was not found to be different from lip strength in controls. Therefore, both groups maintained similar pressures for the lip endurance task (50% of maximum strength) yet trumpet players demonstrated greater lip endurance. This may be explained by the fact that trumpet performance requires players to train their embouchure to withstand high levels of pressure for extended periods of time. The results of the present study suggest that repetitive sustained contractions of the lips are successful in developing greater lip endurance.

Lip endurance was affected by lip strength for both groups. Greater strength pressures were sustained for less time and lower strength pressures were able to be sustained for a greater amount of time. This relationship was evident in the trumpet player with the lowest lip strength

(14 kPa), who sustained 50% of his maximum lip strength for 1000 seconds (shown by the outlier in Figure 2). Although he was stopped at the request of the examiner, he reported that he could have held this pressure indefinitely.

### *Experience & age*

All trumpet players began playing their instrument between the ages of 7 and 16 and on average 10 years of age. Therefore, the trumpet players who were older had more experience. Years of experience was related to increased lip, but not cheek or tongue, strength in the trumpet players. It is possible that lip strength continues to increase with age, but this question would be best answered with a longitudinal study.

### *Participant with Bell's palsy*

As mentioned earlier, a 52 year old male trumpet player volunteered to participate but was excluded from the group analyses due to a previous history of unilateral Bell's palsy on his left side eight years prior to this study. He reported that his trumpet playing was impaired during the acute stage of Bell's palsy but that he was able to return to professional playing two years post-onset. This participant demonstrated a reduction in cheek strength and endurance on his affected side compared to his unaffected side. Interestingly, this difference was no more than the differences found between right and left cheek strength and endurance in trumpet players without a history of facial nerve damage. It was evident to the examiner during conversation that this individual's left cheek and lip had reduced range of motion; however, on his orofacial structure-function exam, range of motion was symmetrical across sides. This finding could be accounted for with the phenomenon of learned non-use. Learned non-use is characterized by a functional decrease in range of motion after the underlying problem is adequately resolved (Perry et al., 2011). It is likely that the trumpet player with Bell's palsy had become accustomed to limited

movement on his affected side and this non-use continued after recovery. If lip strength had been measured on each side, differences may have been detected; however, in the present study lip strength was only taken in a central position for all participants. In this participant, tongue strength would not be expected to be affected since motor control of the tongue is innervated by cranial nerve XII (CN 12), the hypoglossal nerve, as opposed to the lip and cheek, which are innervated by CN 7.

### *Clinical implications and future studies*

The findings from the present study indicate that trumpet players have increased cheek strength and increased lip endurance. This raises the question of whether a functional activity such as trumpet playing could be utilized as a therapeutic activity for facial rehabilitation. Production of a musical tone could be explored as a form of biofeedback and patients could participate in a functional activity while increasing facial strength and endurance.

Objective measurements of muscle strength and endurance, using the IOPI, have the potential to quantify facial nerve function during recovery from illness or injury. These objective measures may be a beneficial addition to subjective measures in assessment and reassessment in individuals with unilateral or bilateral damage to the facial nerve. The most widely used assessment of facial movement, the FNGS-2, is a subjective measure that has practical limitations due to its low reported reliability of 67.9% (Vrabec, 2009). Reliability of the FNGS-2 is high at the ends of the continuum, measuring normal facial movement and no appreciable facial movement, but has limited reliability in measuring partial facial movement.

Future studies would benefit from larger and more diverse samples of participants in order to examine sex- and age-related effects on orofacial strength and endurance. Investigators wishing to compare endurance measures should consider using a set pressure level independent

of an individual's maximum strength. A multiple baseline design could be used to look at the effects of strengthening exercises with the IOPI or trumpet practice.

### *Limitations*

Due to the strict inclusion criteria, the trumpet playing group was limited to a non-randomized convenience sample. Age groups were not evenly represented with the majority of the participants between the ages of 18-27 and more men than women volunteered to participate in the study. Although all participants were provided with the same instructions and encouragement, it was apparent to the examiners that some participants were more enthusiastic and competitive than others. It is possible that motivation to perform strength and endurance tasks could have contributed to individual variation in results.

## REFERENCES

- Adams, V., Mathisen, B., Baines, S., Lazarus, C., & Callister, R. (2013). A systematic review and meta-analysis of measurements of tongue and hand strength and endurance using the IOPI. *Dysphagia*, Advance online publication.  
<http://www.ncbi.nlm.nih.gov/pubmed/23468283>
- Barlow, S. & Netsell, B. (1986). Differential fine force control of the upper and lower lips. *Journal of Speech and Hearing Research*, 29, 163-169.
- Bianco, T., Freour, V., Cossette, I., Bevilacqua, F., & Causse, R. (2012). Measures of facial muscle activation, intra-oral pressure, and mouthpiece force in trumpet playing. *Journal of New Music Research*, 41(1), 49-65.
- Bunton, K. & Weismer, G. (1994). Evaluation of reiterant force-impulse task in the tongue. *Journal of Speech & Hearing Research*, 37(5), 1020-1032.
- Brach, J. & VanSwearingen, J. (1999). Physical therapy for facial paralysis: A tailored treatment approach. *Physical Therapy*, 79(4), 397-404.
- Clark, H. & Solomon, N. (2012). Age and sex differences in orofacial strength. *Dysphagia*, 27, 2-9.

- Cronin, G. & Steenerson, R. (2003). The effectiveness of neuromuscular facial retraining combined with electromyography in facial paralysis rehabilitation. *Otolaryngology–Head and Neck Surgery*, 128(4), 534-538.
- Crow, H. & Ship, J. (1996). Tongue strength and endurance in different aged individuals. *The Journals of Gerontology*, 51(5), 547-550.
- Gray, H. (1977). Muscles and fasciae of the cranium and face. In T. Pickering & R. Howden (Eds.), *Gray's Anatomy* (297-313). New York, NY: Crown.
- House, J. & Brackmann, D. (1985). Facial nerve grading system. *Otolaryngology - Head and Neck Surgery*, 93(2), 146-147.
- IOPI Northwest. Iowa oral performance instrument: User's manual. Carnation, WA: IOPI Northwest; 2005.
- Manikandan, N. (2007). Effect of facial neuromuscular re-education on facial symmetry in patients with Bell's palsy: A randomized controlled trial. *Clinical Rehabilitation*, 21, 338-343.
- Neel, A., Palmer, P., & Gass, C. (2008). Can IOPI be used to measure tongue pressure for speech sounds? *Journal of Medical Speech-Language Pathology*, 16(4), 235-241.

Neel, A., & Palmer, P. (2011). Is tongue strength an important influence on rate of articulation in diadochokinetic and reading tasks? *Journal of Speech, Language, and Hearing Research*, 55(1), 235-46.

Perry, E., Potter, N., Rambo, K., & Short, R. (2011). Effects of strength training on neuromuscular facial rehabilitation. *Developmental Neurorehabilitation*, 14(3), 164-170.

Robin, D., Goel, A., Somodi, L., & Luschei, E. (1992). Tongue strength and endurance: Relation to highly skilled movements. *Journal of Speech and Hearing Research*, 35, 1239-1245.

Robbins, J., Gangnon, R., Theis, S., Kays, S., Hewitt, A., & Hind, J. (2005). The effects of lingual exercise on swallowing in older adults. *Journal of the American Geriatrics Society*, 53(9), 1483-1489.

Robbins, J., Levine, R., Wood, J., Roecker, E., & Luschei, E. (1995). Age effects on lingual pressure generation as a risk factor for dysphagia. *Journal of Gerontology*, 50(5), 257-262.

Stierwalt, J. & Youmans, S. (2007). Tongue measures in individuals with normal and impaired swallowing. *American Journal of Speech-Language Pathology*, 16, 148-156.

Vrabec, J. (2009). Facial nerve grading system 2.0. *Otolaryngology–Head and Neck Surgery*, 140, 445-450.

Vitorino, J. (2010). Effect of age on tongue strength and endurance scores of healthy Portuguese speakers. *International Journal of Speech-Language Pathology*, 12(3), 237-243.

Youmans, S., Youmans, G., & Stierwalt, J. (2009). Differences in tongue strength across age and gender: Is there a diminished strength reserve? *Dysphagia*, 24, 57-65.

Zemlin, W. (1997). The articulators and associated structures. In S. Dragin (Ed.), *Speech and Hearing Science: Anatomy and Physiology*, 4<sup>th</sup> Edition (233-238). Needham Heights, MA: Allyn and Bacon.