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Lip vibrations in brass musicians

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Abstract

This experimental study investigates lip vibrations in brass musicians. Lip vibrations were observed with high-speed line-scanning and stroboscopic video sequences. Therefore mouthpieces with probe holes for the endoscope were used.

In a preliminary survey three devices for stroboscopic examination of lip vibrations were compared. For online analysis of lip vibrations a standardised device with fixed coupling between endoscope and camera on the one hand and mouthpiece with instrument on the other hand was most suitable.

In the main study this standardised device for observation of brass players' vibrating lips was validated and implemented. Typical values for the amplitudes of lip vibrations in different kinds of brass instruments and diverse playing techniques were measured and compared. The lip vibration cycle was scaled in different phases both with high-speed line-scanning and stroboscopy. In all subjects lip vibrations showed an increase in amplitude when lower or louder notes were played (and vice versa).

In brass musicians occupational lip injuries and overuse syndromes are relevant for health economics: Often it takes long-term rehabilitation programmes to restore the ability to play the instrument. In serious cases even an occupational disability can arise. It is useful and necessary to establish video-based imaging devices for functional and morphological assessment of these patients' lips.

Keywords: lip vibrations – brass players – kymography – stroboscopy – health economics

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1 Introduction

The physical parameters of brass playing were subject to pioneer investigations by Helmholtz in 1863 [1]. He reduced the lip vibrations to a one-dimensional model: the lip-reed acts as a valve striking outwards, driven by the increasing intraoral pressure in the direction of the airflow ("outward-striking model" or "outward-swinging model") [1],[2]. Since then, more complex models have been developed by Elliott & Bowsher [3], Yoshikawa [4] and Adachi [5].

When a brass player applies tension to his lips, he narrows his oral opening. The speed of the out blown airflow increases with a simultaneous decrease in pressure. Due to the Bernoulli effect the lip valve is passively closed for a short phase in the vibration cycle. As a result, the intraoral pressure rises above atmospheric pressure once more and pushes the lips open for the next vibration cycle [3],[4],[6].

This study aims to investigate the function of vibrating lips in brass players. It focuses on development, validation and clinical application of different techniques for the examination of vibrating lips while playing brass instruments. Suitable equipment for this purpose was designed in a preliminary survey. This standardised device made it possible to observe the lip vibrations of 50 brass players using high-speed line-scanning and stroboscopic video sequences. The vibration cycles were analysed and measured (including measurements of amplitudes in different frequencies and sound levels).

2 Preliminary survey

In order to gain insight into the examination of vibrating lips in brass players, a preliminary survey was conducted. Lip vibrations were observed in 13 brass players (aged 23 to 68 years), of which twelve probands were male and one female. The instruments played were: trumpet (eight probands), trombone (two probands), French horn (two probands) and alphorn (one proband). Eleven probands were professional musicians; two probands were amateurs.

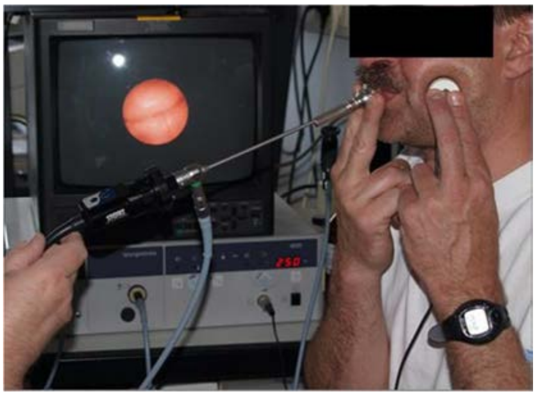
In the preliminary survey three different technical devices for the observation of vibrating lips were compared:

First, the vibrating lips were examined through a mouthpiece with cut-outs ("visualizer"). A rigid 90° magnifying laryngoscope with a stroboscopic camera was held freehand in front of the player's mouth (cf. fig. 1).

Source: (Mauersberger, 2016, [7])

Figure 1: Stroboscopic examination of a 57-year-old trumpet player using a visualizer

Secondly, a rigid 0° optic was inserted into the sh ank of a commercially available trombone mouthpiece (cf. fig. 2). It was not possible to connect the mouthpiece to the instrument.



Source: (Mauersberger, 2016, [7])

Figure 2: Stroboscopic examination of a 50-year-old proband through a commercially available trombone mouthpiece

Thirdly, the lips of a trumpeter were examined whilst playing by using a rigid endoscope inserted into a probe hole of the mouthpiece (cf. fig. 3). Thus, lip vibrations were observed with a stroboscopic and a kymographic camera.

Source: (Mauersberger, 2016, [7])

Figure 3: Examination of a 44-year-old trumpet player through a mouthpiece with a probe hole for the endoscope

For the observation of lip vibrations this standardised device with fixed coupling between endoscope and camera on the one hand and mouthpiece with instrument on the other hand was the most suitable. Thus, motion artefacts and air leaks could be avoided. For the main study, additional mouthpieces with probe holes were prepared for trumpets, trombones, French horns and tubas.

3 Methods

50 brass players (aged 17 - 71 years) took part in the main study of which 43 probands were male and seven female. The instruments played were: trumpet (21 probands), trombone (16 probands), French horn (eleven probands) and tuba (two probands). 23 probands were professional musicians, nine were music students and 18 probands were amateurs. A detailed explanation of the production of the examination equipment and the preparation of the mouthpieces can be found in the present book of abstracts (abstract number “ISMRA2016-83”).

Following an individual warm up phase, the actual investigation of lip vibrations began. The instrumentalists played various exercises that included passages with different sound levels (pianissimo to fortissimo), articulations (e.g. staccato and legato) and frequencies. The video frames were subsequently analysed by using the software programme rpSzene® (rpSzene® version 8.0 [2006-2010]/RehderPartner GmbH/Hamburg, Germany).

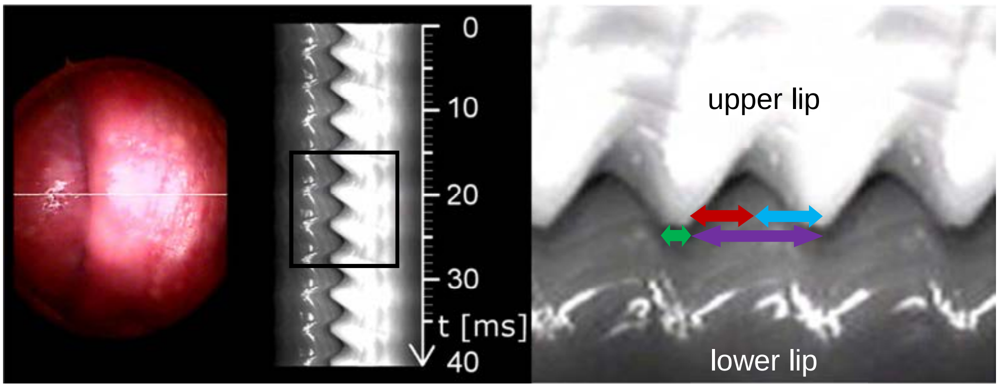
4 Results

4.1 Kymography

In the following kymographic frames (Figures 4-7) the upper lip is shown on the left and the lower lip is shown on the right.

4.1.1 Classification of phases

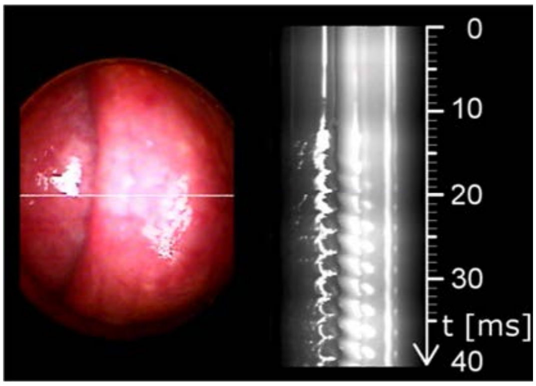
With videokymography it was possible to differentiate between the opening, closing, open and closed phases in the oscillatory cycle (cf. Fig. 4) in all 50 probands while a C4 was played at mezzoforte. This classification is based on kymographic analysis of vocal fold oscillations [8]-[11].



Source: (Mauersberger, 2016, [7])

Figure 4: kymographic frame with magnified view in a 44-year-old trumpet player (247 Hz, B3, mezzoforte); opening (red arrow), closing (blue arrow), open (purple arrow) and closed phase (green arrow)

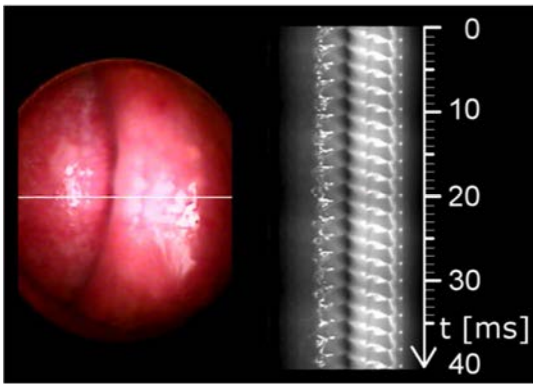
Additionally, an onset phase (cf. Fig. 5), a steady-state phase (cf. Fig. 6) and an offset phase (cf. Fig. 7) could be distinguished in all probands. The duration of the onset and offset phase is variable and depends on the sound level and frequency of each note.



Source: (Mauersberger, 2016, [7])

Figure 5: kymographic frame of the onset phase in a 44-year-old trumpet player

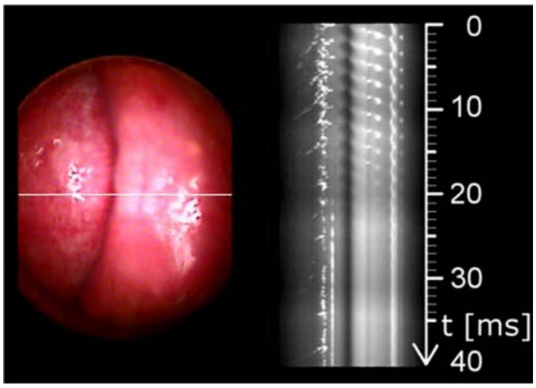
In the onset phase at the beginning of a musical note, the amplitude rises from zero. First, small oscillations occur, building up to larger oscillations until a uniform configuration of amplitudes has been achieved (steady-state).



Source: (Mauersberger, 2016, [7])

Figure 6: kymographic frame of the steady-state phase in a 44-year-old trumpet player (494 Hz, B4, mezzoforte)

In the steady-state phase the lips show constant amplitudes. The size of the oscillations is variable and depends on the sound level and frequency of each note. All measurements were made in this phase.



Source: (Mauersberger, 2016, [7])

Figure 7: kymographic frame of the offset phase in a 44-year-old trumpet player

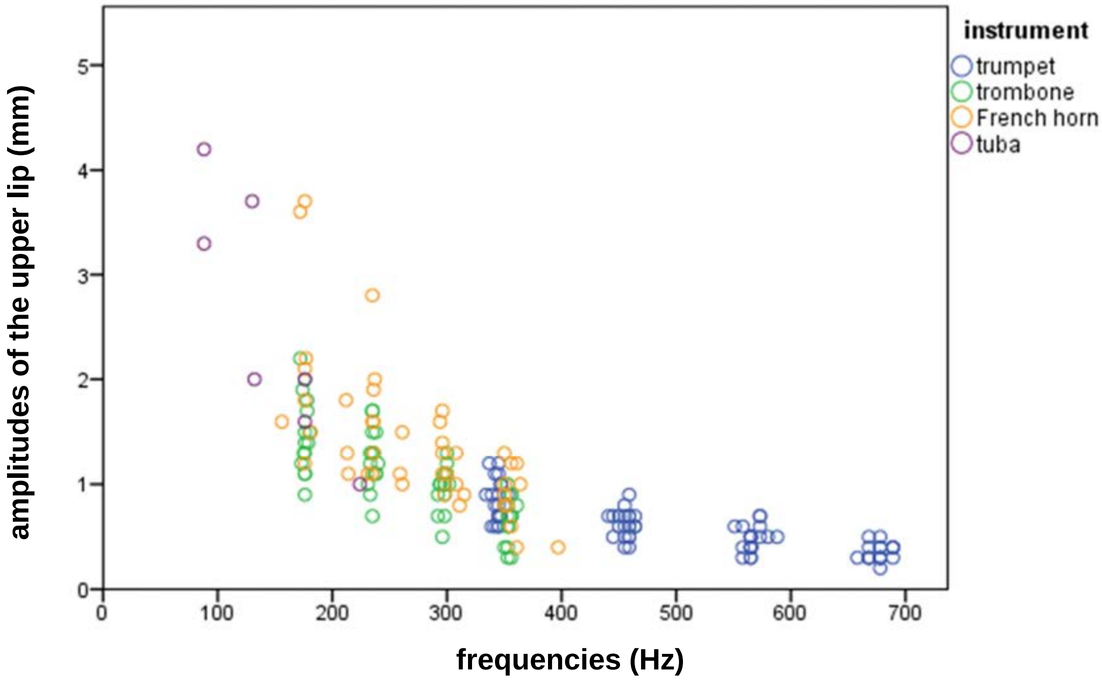
At the end of a note, in the offset phase, the lips oscillate with decreasing amplitudes.

4.1.2 Measurements of upper lip amplitudes

The amplitudes of the upper lip were measured in different kymographic frames with a multistep algorithm by using the software rpSzene® (rpSzene® version 8.0 [2006-2010]/RehderPartner GmbH/Hamburg, Germany) [7]. One trombone player had to be excluded from the measurements, because his upper lip was overlapped by his lower lip.

In 49 analysed musicians there was a negative correlation between the frequency of the note and the size of the amplitudes of the upper lip (Pearson´s correlation coefficient, $r = -0.728$, $p <$

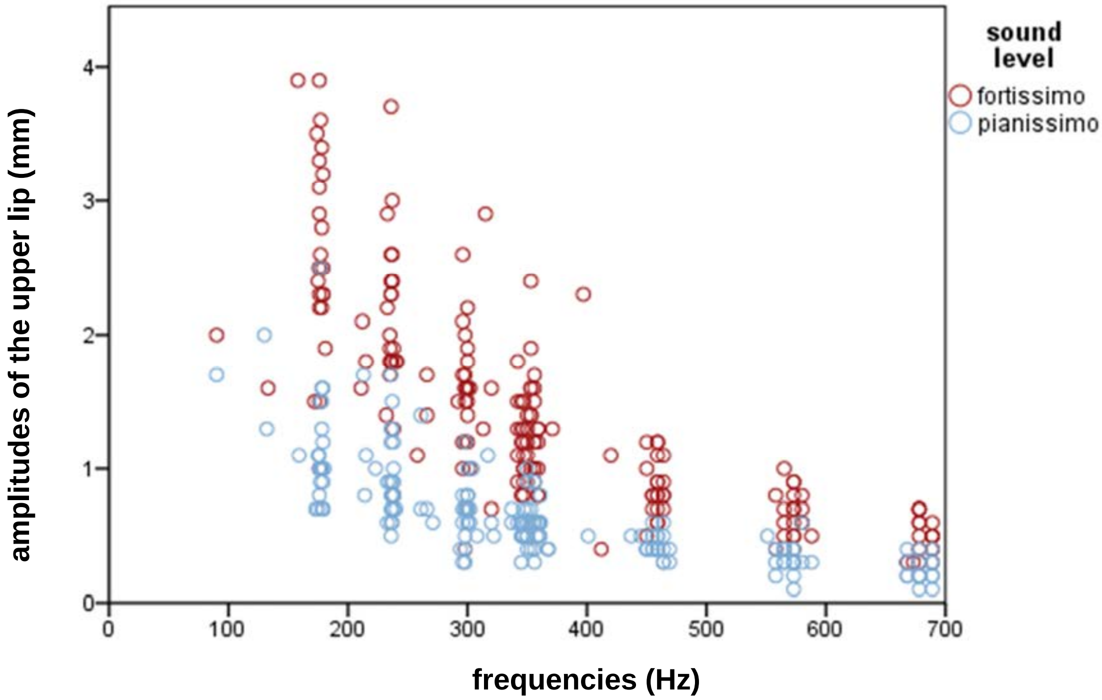
0.01, one-tailed): The higher the frequency, the smaller the amplitudes of the upper lip and vice versa (cf. Fig. 8).



Source: (Mauersberger, 2016, [7])

Figure 8: amplitudes of the upper lip as a function of the frequency, mezzoforte

The amplitudes of the upper lip of trumpeters, French horn players and trombonists were significantly larger when playing fortissimo (MV = 1.40 mm, SD = 0.810) than when playing pianissimo (MV = 0.65 mm, SD = 0.360; Mann-Whitney U Test, $p < 0.001$, one-tailed): The louder a note was played, the larger the amplitudes of the upper lip and vice versa (cf. Fig. 9).



Source: (Mauersberger, 2016, [7])

Figure 9: amplitudes of the upper lip as a function of the sound level, comparison between fortissimo and pianissimo

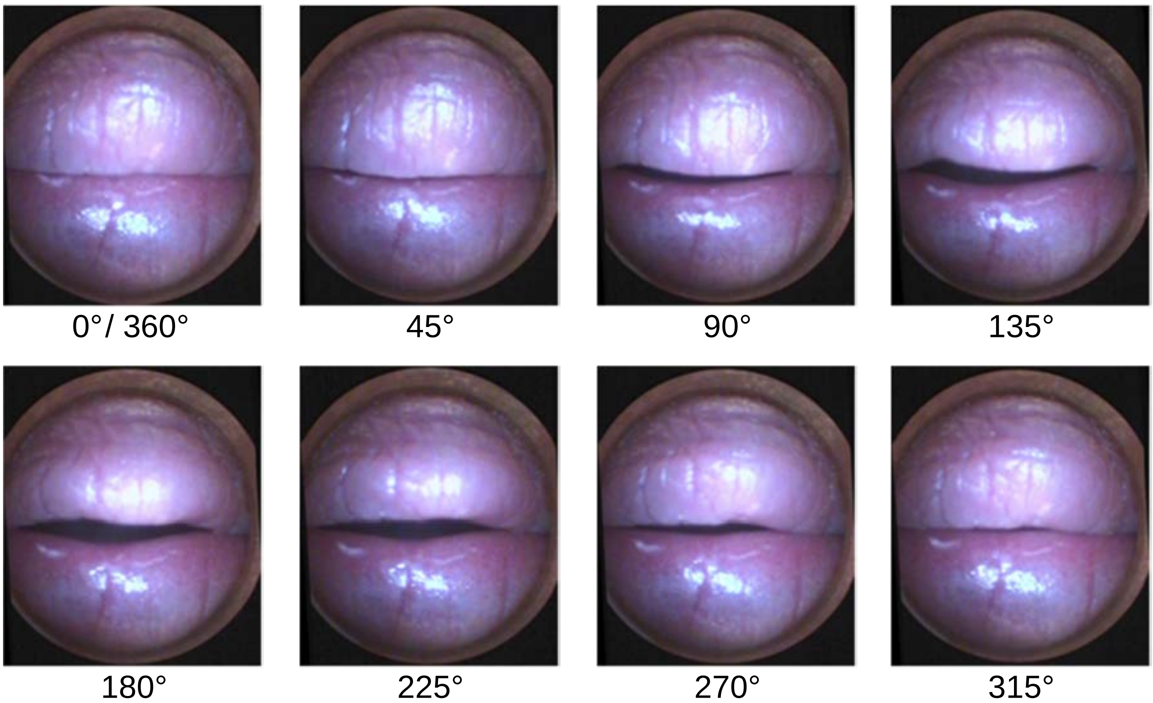
The instrument being played had no significant effect on the amplitudes of the upper lip when playing the note C4 at mezzoforte (tested with one-way ANOVA analysis of variance; two-tailed).

In summary, amplitudes of the upper lip decrease with higher frequencies and declining sound levels (pianissimo), and increase with lower frequencies and greater sound levels (fortissimo).

4.2 Stroboscopy

4.2.1 Classification of phases

Analoguous to the classification of phases in kymography, opening, closing, open and closed phase could be differentiated in the oscillatory cycle with stroboscopy in all 50 probands while a C4 was played at mezzoforte. In the following example (cf. Fig. 10) the opening phase is shown in pictures 45°-180°, the closing phase is shown in pictures 180°-315°, the open phase is shown in pictures 45°-315°, and the closed phase is shown in the picture 0°/ 360°.



Source: (Mauersberger, 2016, [7])

Figure 10: stroboscopic lip vibration cycle in a 49-year-old trumpet player (261 Hz, C4, mezzoforte)

5 Conclusions

Kymography and stroboscopy are non-invasive imaging techniques for real-time observation of vibrating lips. They allow a detailed functional analysis of lip vibrations whilst playing a brass instrument. By using mouthpieces with probe holes for the endoscope, motion artefacts and air leaks (which occur when playing with a visualizer) can be avoided. Kymography has the advantage over stroboscopy that every single vibration cycle can be observed along a defined line (syn. high-speed line-scanning). Moreover, kymography allows measurements of lip amplitudes. Contrary to high-speed video imaging techniques (e.g. [12],[13]) required data volumes and energy consumption (180 watt light source) are lower in kymography, so that longer musical passages (e.g. 30 sec) can be examined. The sampling rate of kymography (7200 lines per sec) is comparable to that of high-speed techniques. Stroboscopy is more suitable for a pictorial description than for the analysis and measurement of lip vibrations.

In medical practices and clinics providing specialised services for musicians, investigation of lip vibrations in brass players is important for the assessment of their embouchure. Problems with the embouchure, such as occupational lip injuries and overuse syndromes, are relevant for health and accident insurances, as well as for health economics: It often takes long-term rehabilitation programmes to restore the ability to play the instrument. In serious cases, even an occupational disability can arise. It is therefore both useful and necessary to establish video-based imaging devices for functional and morphological assessment of such patients' lips. A routine application of these embouchure examinations can be recommended for outpatient clinics that specialise in treating musicians.

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References

[1] Helmholtz, H. *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik.* Vieweg, Braunschweig (Germany), 5^{th} edition, 1896, pp. 158-168.

[2] Fletcher, NH. Excitation mechanisms in woodwind and brass instruments. *Acta Acust Acust*, Vol 43, 1979, pp. 63-72.

[3] Elliott, SJ.; Bowsher, JM. Regeneration in brass wind instruments. *J Sound Vib*, Vol 83, 1982, pp. 181-217.

[4] Yoshikawa, S. Acoustical behavior of brass player's lips. *J Acoust Soc Am,* Vol 97, 1995, pp. 1929-1939.

[5] Adachi, S. Trumpet sound simulation using a two-dimensional lip vibration model. *J Acoust Soc Am,* Vol 99, 1996, pp. 1200-1209.

[6] Wolfe, J. Acoustic department, school of physics, University of New South Wales. *Brass instrument (lip reed) acoustics: an introduction* [Internet].
URL: http://www.phys.unsw.edu.au/jw/brassacoustics.html
(access on 14^{th} March, 2016)

[7] Mauersberger, R. *Lippenschwingungen und Stimmgebung bei Blechbläsern* [inaugural dissertation]. Düsseldorf: Heinrich-Heine-University Düsseldorf (Germany), 2016.

[8] Gall, V.; Hanson, J. Bestimmung physikalischer Parameter der Stimmlippenschwingungen mit Hilfe der Larynxphotokymographie. *Folia Phoniatr*, Vol 25, 1973, pp. 450-459.

[9] Švec, J.; Šram, F.; Schutte, HK. Videokymografie: nová vysokofrekvenční metoda vyšetřování kmitů hlasivek. *Otorinolaryngologie a foniatrie (Praha)*, Vol 48, 1999, pp. 155-162.

[10] Švec, J.; Šram, F. Kymographic imaging of the vocal fold oscillations. In: Hansen, JHL.; Pellom, B. eds. *Proceedings of the 7^{th} International Conference on Spoken Language Processing*, Denver, CO, 16^{th} - 20^{th} September, 2002. pp. 957-960.

[11] Böhme, G.; Gross, M. *Stroboskopie und andere Verfahren zur Analyse der Stimmlippenschwingungen.* Median, Heidelberg (Germany), 2001.

[12] Bromage, S.; Campbell, M.; Gilbert, J. Experimental investigation of the open area of the brass player's vibrating lips. *Proceedings of the Forum Acusticum*, Budapest, Hungary, 29^{th} August - 2^{nd} September, 2005. pp. 729-734.

[13] Boutin, H.; Fletcher, N.; Smith, J.; Wolfe, J. Relationships between pressure, flow, lip motion, and upstream and downstream impedances for the trombone. *J Acoust Soc Am,* Vol 137, 2015, pp. 1195-1209.