DOI: 10.61782/fa.2025.0336

FORUM ACUSTICUM EURONOISE 2025

EMBOUCHURE PARAMETER VARIATIONS ACROSS BRASS MUSICIANS OF DIFFERENT LEVELS OF PROFICIENCY

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ABSTRACT

Sound production in brass instruments requires complex interactions between embouchure parameters such as blowing pressure, mouthpiece force, etc. This paper presents findings from the use of a custom-developed digital mouthpiece designed to efficiently acquire embouchure data. The digital mouthpiece is able to record the forces of the upper and lower lips separately, as well as air pressure both inside the oral cavity and inside the mouthpiece. Data from 31 trombonists of different levels of progress were recorded, including a wide range from beginners to experts. In this context, the study enhances and expands the existing understanding of forces exerted on the mouthpiece, by considering the forces of the upper and lower lip separately. The collected data demonstrate the widely-discussed pivoting movement during the performance of a brass instrument, and dominant types of playing can be seen with regard to the load conditions of the upper and lower lip.
In addition, data from the 31 participating musicians is shown, demonstrating the relationship between the mouthpiece force applied, the pitch, intensity and air pressure in the mouth under realistic playing conditions.

Keywords: *Brass Instrument Performance Variables, Mouthpiece Force, Embouchure*

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1. INTRODUCTION

Embouchure parameters, such as mouthpiece force and blowing pressure, are featured in studies across various contexts, contributing to a better understanding of sound production for acousticians, educators, and brass musicians.
For example, the force exerted on the mouthpiece has been used to investigate the acoustical behaviour of brass players' lips with the aid of strain gauges placed between the lip and mouthpiece [1, 2]. The measured phase difference between the acoustic pressure in the lip-driven cylinder and the strain demonstrated the outward and upward striking movements of the lips in relation to the tone height. Other studies investigated the relationship between the mouthpiece force, pitch and sound pressure level, with the result that the force increases with pitch and intensity [3–5]. Besides the perspective of various pedagogical embouchure concepts regarding mouthpiece force [6, 7] and medical studies on the effect of mouthpiece force on tooth position [8], the relationship between the force applied and the level of proficiency was also examined [4,9]. However, none of the experimental studies have separately examined the force exerted by the mouthpiece on the upper and lower lips. Observations of musicians indicate that a pivoting movement over the tone range is significant for the production of different pitches depending on the musician's embouchure technique [7]. The different angular positions of the mouthpiece of individual musicians and a pivoting movement were also observed in the MRI study on trumpet playing by Schumacher et al. [10]. Depending on the position of the jaw, this pivoting movement results in the mouthpiece being subjected to varying force distributions from the upper and lower lips.
The simultaneous measurement of multiple embouchure

parameters, as demonstrated by Bianco et al. [5], highlights that different combinations of input variables can result in the same output.
This paper gives insight into the data set of 31 trombonists of different levels of proficiency, in which the forces of the upper and lower lip, the oscillating air pressure in the mouthpiece, the air pressure in the oral cavity and the sound were recorded simultaneously. The study was approved by the ethics committee of the University of Music and Performing Arts Vienna.

2. STUDY DESIGN AND DATA AQUISITION

The study was conducted at music schools and music universities and lasted around 30 minutes per participant. After being informed about the study and giving their consent, the musicians had time to familiarise themselves with the measurement set-up. The musicians played a specified sequence of tones in two separate runs, which were recorded for analysis. Subsequently, they completed a detailed questionnaire. A set of sheet music, divided into three levels of difficulty and containing passages from contemporary literature, was developed as the specified sequence of tones. Each participant was required to play all sections corresponding to their level of proficiency.
An enhanced version of the measuring device described by Amann et al. [11, 12] was calibrated and employed for the data acquisition. This mouthpiece, equipped with four load cells and two air pressure sensors, among other components, allows for the recording of mouthpiece parameters without significantly affecting the playing experience. In addition, a clip microphone (Shure BETA98H/C) was attached to the bell to record the audio signal.
The recorded data from the measuring device with a sampling rate of approx. 1750Hz was then preprocessed using Matlab. For detailed analysis and comparability between musicians, it was necessary to assign individual data points to the corresponding notes played. To achieve this, the recorded audio signal was segmented into the individual tones of the .musicxml file of the sheet music using audio score alignment techniques [13]. Subsequent refinement of the segmentation using Sonic Visualiser was necessary. The continuously recorded time stamp from the measuring device with the segmentation enabled the assignment of all data points to their corresponding notes. Each note was labelled with specific attributes, such as articulation, note length, and other relevant characteristics. For the statistical analysis, features were extracted from the extensive data set using the computing Software R.

3. STUDY RESULTS

A total of 31 individuals participated in the study, out of which 9 identified as female and 22 as male. Regarding age distribution, 20 participants were between 18 and 35 years old, and 11 participants were over 35 years old. To differentiate between various levels of proficiency, a single factor "P" ranging from 0 to 6 was calculated based on responses from the survey and the musicians' ability to play part 1, parts 1 and 2, or parts 1, 2, and 3 of the music sheets. Although there is no clear distinction between beginners, intermediates, and experts, the differentiation based on the factor was defined as follows: a range of $0 \leq P \leq 2$ for beginners, $2 < P \leq 4.5$ for intermediates, and above 4.5 for experts. Accordingly, 14 beginners, 10 intermediate, and 9 experts participated in the study.

3.1 Upper and Lower Lip Mouthpiece Force

The forces referenced in this paper pertain to the mean force exerted by the upper and lower lips. For better comparability, the initial and final 25% of each note on a time scale were excluded from the calculation as they depend significantly on the articulation, which is not considered in this paper.
Figure 1 presents a box plot illustrating the forces exerted by the upper and lower lips, with each pair of boxes representing one participant. The lighter-coloured box indicates the force exerted by the upper lip, while the darker-coloured box represents the force exerted by the lower lip. In the plot, only those notes that are part of the easy excerpt and thus played by all participants are considered. The musicians are arranged from left to right according to their level of proficiency.
When considering the total mouthpiece force, no statistically significant differences between the applied forces and the level of proficiency can be observed. Although there are tendencies for higher mouthpiece forces and outliers among beginners, there are also musicians within this group who exert very low forces. The observed differences decrease when comparing the mouthpiece force of beginners in the easy excerpt with the mouthpiece force of experts in the hard excerpt.
After the data collection for beginners in music schools, the results were preliminarily discussed with their music teachers. Exceptionally high and very low forces exerted on the mouthpiece were not only revealed by the measurements but were also perceived by the teachers. High force values were commonly associated with the tense appearance of the student, while low force values were linked to

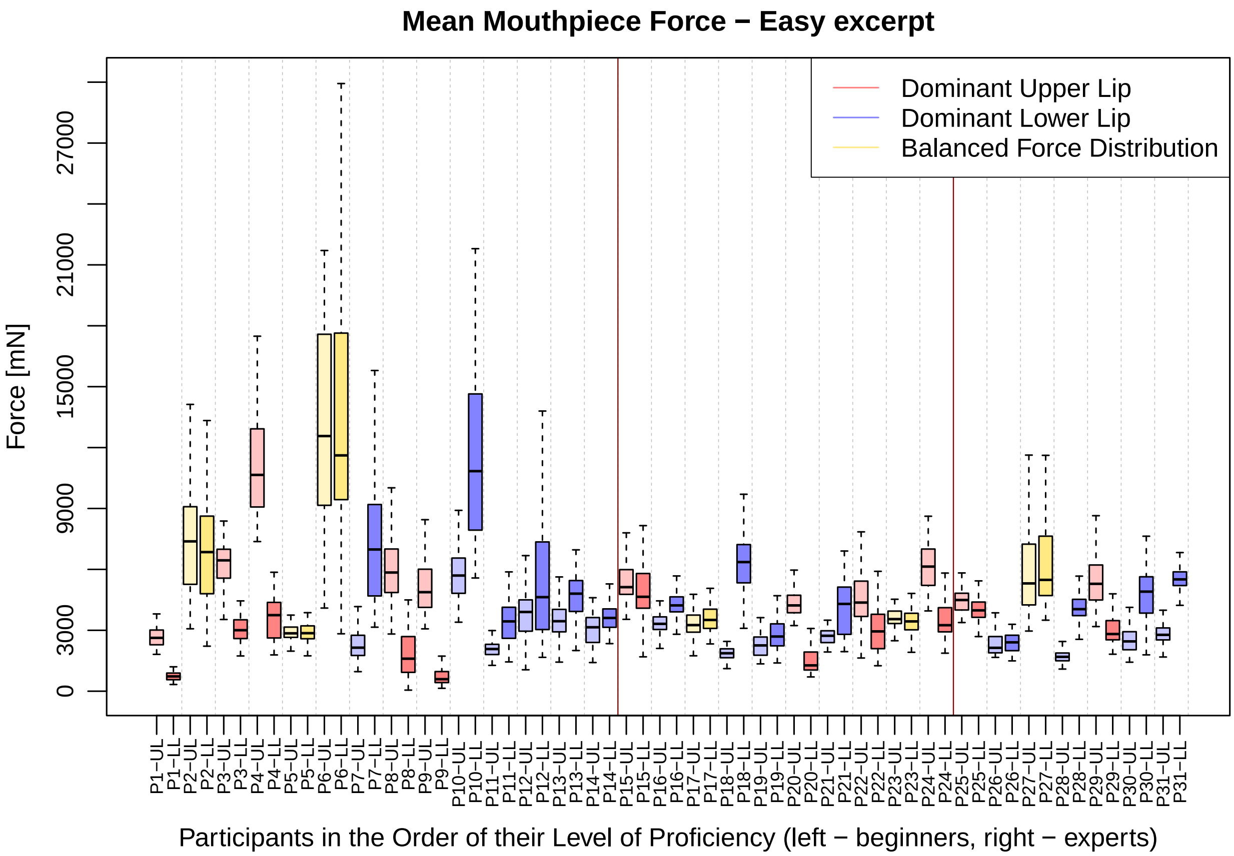

Figure 1. The Mouthpiece force of trombonists at different levels of proficiency is depicted, with UL and LL on the x-axis representing the force exerted by the upper and lower lips, respectively, for each individual. Participants 1 to 14 correspond to the beginner level, participants 15 to 24 correspond to the intermediate level, and participants 25 to 31 correspond to the expert level. The vertical lines separate the bars of the individuals (dashed) and the proficiency groups (red).

a lack of embouchure stability.

Different techniques and force distribution ratios are observed on average when comparing the forces exerted by the upper and lower lips. Musicians can be categorized based on their force distribution: those who apply more force to the upper lip (dominant upper lip, shown in red), those who apply more force to the lower lip (dominant lower lip, shown in blue), and those who maintain a balanced force distribution (shown in yellow). The distribution of forces can be caused both by a pivoting movement of the instrument relative to the head and by a displacement of the jaw. The ratio of the medians of the two forces is used as the threshold value to allow differentiation between the mentioned techniques. If the force exerted on the upper lip is 10% higher than that on the lower lip, the musician is classified as having a dominant upper lip embouchure. Conversely, if the force exerted on the lower lip is 10% higher than that on the upper lip, the musician is classified as having a dominant lower lip embouchure.

When examining the force distribution types in relation to pitch, some musicians exhibit a stable embouchure with minimal changes in force distribution. In contrast, others adjust their force ratios depending on the pitch significantly, resulting in noticeable variations. The change in embouchure when transitioning between different pitches, described by pedagogues as a tilting movement [7], can

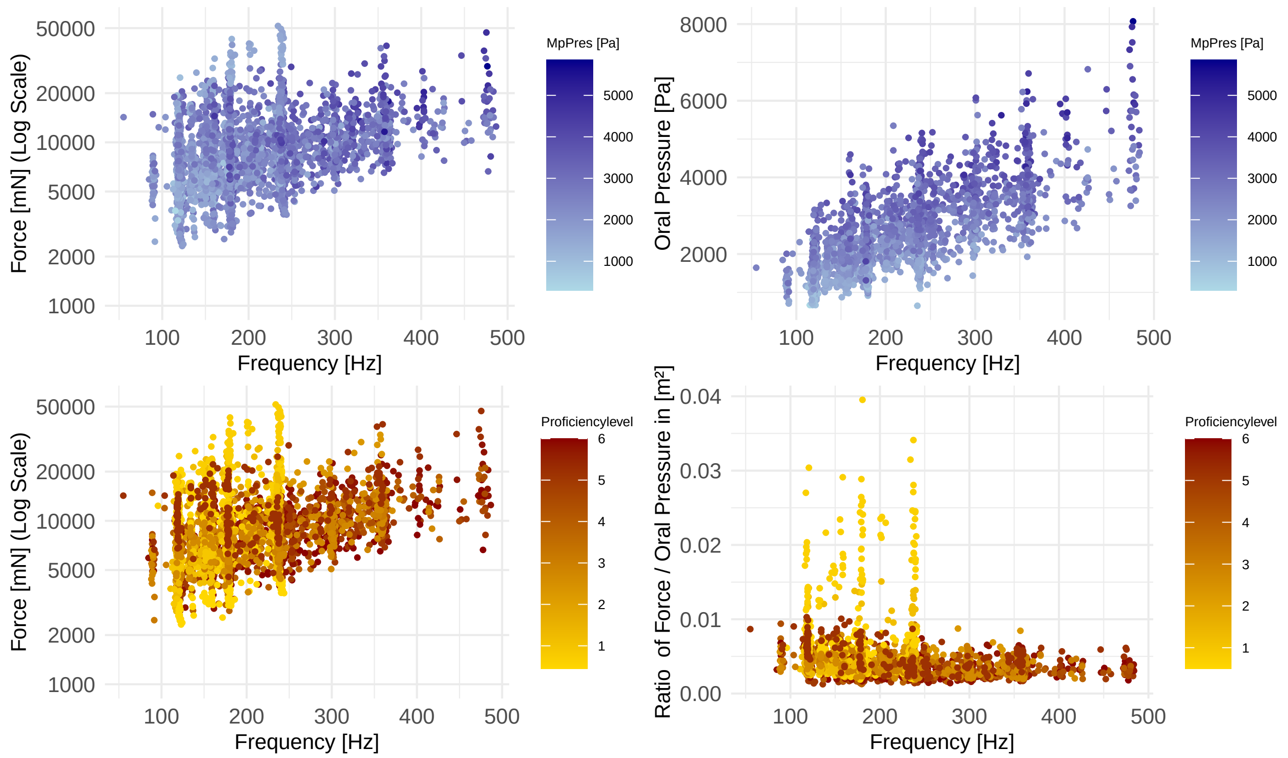

Figure 2. Relationships between force and frequency (top-left and bottom-left side), oral pressure and frequency (top-right side) and the ratio of force and oral pressure in relation to the frequency (bottom-right side) under realistic playing conditions. The colour of the upper plots indicates intensity: light blue for low RMS mouthpiece pressure values and dark blue for high RMS mouthpiece pressure values. The colour of the bottom plots correlates to the proficiency level of the musicians: yellow for beginners and red for experts.

be observed in the variations in the force distribution. The data do not support the popular assumption that certain embouchure techniques lead to increased success. Different force distribution types are observed across all levels of proficiency.

3.2 Interaction between Embouchure Parameters

The following section presents the results of the data analysis concerning the relationships between mouthpiece force, oral pressure, mouthpiece pressure, frequency, and proficiency level. Similar to the calculation of the shown force data, the oral pressure and root mean square (RMS) of the mouthpiece pressure values are derived from the middle 50% of the notes, thereby neglecting the note beginning and note ending.

As shown in Figure 2, the minimum mouthpiece force exerted by musicians to retain a note increases with frequency. When considering the data points of all musicians collectively, no relationship between intensity, represented by RMS mouthpiece pressure, can be discerned. Only by analyzing individual musicians separately does it become evident that, while some musicians maintain a constant force regardless of intensity, others increase their force as intensity rises.

When focusing on oral pressure, a clear positive correlation between frequency and oral pressure can be observed. The data in the lower frequency range align well with the results from brass instrument models regarding the minimum blowing pressure through linear stability analysis [14]. In the higher frequency range, however, the values achieved by musicians are significantly lower than predicted in [14].

The two bottom plots in Figure 2 pertain to the proficiency

level, ranging from 0 to 6, with red indicating high values and thus a high level of proficiency (experts). Since beginners were unable to achieve high notes, low levels of proficiency only extend up to the note Bb3 (approximately 233 Hz). It is notable that very low and very high mouthpiece forces in the lower pitch ranges are primarily utilized by beginners. Additionally, the maximum force values exerted by beginners when playing the note Bb3 are matched by expert musicians when playing Bb4.
In the bottom right plot, the ratio of force to oral pressure is shown as a function of frequency. What immediately stands out is that some beginners exert significantly more force on their lips relative to the corresponding air pressure in the oral cavity. Four individuals with a proficiency level between 0.5 and 1.2 (novice musicians) exceed a ratio of 0.11, while all others remain below this value.

4. CONCLUSIONS

In the paper, we examined the relationship between the embouchure parameters: mouthpiece force of the upper and lower lip, air pressure in the oral cavity, air pressure in the mouthpiece, in relation to pitch and proficiency level based on data from 31 trombonists. The separate examination of the forces of the upper and lower lip is a novelty and allows conclusions to be drawn about different playing techniques, with musicians exhibiting dominant upper lip force, dominant lower lip force, and balanced force distribution, similar to pedagogical methods regarding pivoting movements. A correlation between the dominant force distribution type and the level of proficiency cannot be established. It is also not statistically significant that beginners exert more force while playing than advanced and professional musicians. However, outliers among the beginners can be observed, who exert excessively high forces.
A limitation of this paper is that the force distribution between the upper and lower lip was not presented in relation to pitch and intensity. Musicians who tend to one of the three distribution types may change this distribution depending on the pitch, for example, through tilting. The detailed analysis will be presented in a future paper. Furthermore, the measurement system cannot record the placement of the mouthpiece and its changes during playing, which indirectly affects the force values of the upper and lower lip.
In relation to pitch, the data reveals a minimum necessary force and a minimum oral pressure required to sustain the notes (note initiation and note ending were not considered), which both increase with rising frequency. Additionally, the ratio of force to applied air pressure in the oral cavity is significantly higher for some novice participants. The presented data serve as a preliminary study for a larger study with more participants.

5. ACKNOWLEDGMENTS

We would like to express our sincere gratitude to the Austrian Research Promotion Agency (FFG) for funding the study. We also extend our heartfelt thanks to the musicians of Gustav Mahler Private University and the Carinthian Music Schools for their participation. Additionally, we are grateful to the Austrian mouthpiece manufacturer Breslmair for their crucial support in the development of the measuring device.

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