Development of an Electrolabiograph Embedded in a Trombone Mouthpiece for the Study of Lip Oscillation Mechanisms in Brass Instrument Performance

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1. INTRODUCTION

The lips of a brass instrument player constitute a complex pressure-controlled valve from which the vibration of the air column originates. Due to their anatomical properties and the significant ability from the player to control their geometry and mechanical properties, lip valve systems display different vibratory behaviours across the traditional range of playing. In order to investigate lip mechanics on real performers, different *in-vivo* methods have been proposed. Lip opening area and frequency response have been evaluated on real players using high speed imaging [1]. This technique requires the use of a special transparent mouthpiece with cylindrical cup that allows the capture of undistorted images but may significantly affect the behavior of the lips. Lip vibratory mechanisms have been investigated using strain gauges placed between the lips and the mouthpiece rim [2]. This solution remains however quite invasive since the strain gauge is usually attached to the upper lip of the subject. Experiments have also been conducted on artificial lip systems which allow the use of highly intrusive measurement devices such as laser velocimetry or light transmission and video methods [1,3]. However, although artificial lips are becoming more accurate at reproducing the lip behaviour of human performers, they are still approximations of human lips and have not proven yet their ability to reproduce human players' behaviour over all registers of a trumpet or a trombone.

In this paper, we present a method for the investigation of lip motion in trombone players based on the measurement of lip conductivity. In the scope of this study, experimental data is evaluated regarding the phase relationship between the lip displacement and the acoustic pressure in the mouthpiece. This phase information provides knowledge about the predominant "outward" or "upward" striking characteristic of the valve as discussed in [4]. In order to evaluate the validity of our measurement device, results are compared to previous recordings obtained using different measurement techniques, as well as numerical simulations.

2. METHODS

2.1 Development of an electrolabiograph

For the purpose of *in-vivo* investigations on brass players' lips we developed an electrolabiograph (ELG) based on the principle electroglottography (EGG) as first presented by Fabre in 1956 [5]. Analogously to the EGG for the study of vocal folds contact, the ELG records the variations of electrical admittance between two electrodes by mean of a high frequency modulated current sent through the lips. The two electrodes are located across the lips (one electrode on the upper lip and one on the lower lip). Therefore, the ELG signal is assumed to be proportional to the degree of contact of the lips.

In order to reduce the intrusiveness of the system, the contact electrodes are made of tin-plated copper foil shielding tape glued on the mouthpiece rim. The resistance of the electrode pair is raised to 40Ω by a resistor and the electrodes connected to a commercial Voce Vista EGG signal conditioner. The analog output is sent then to a National Instrument converter. This system is therefore totally non-invasive, the main requirement being the use of a non conductive material for the mouthpiece; in this study, a plastic mouthpiece designed by CFMI Université Lille 3 (France) was used.

2.2 Determination of the valve mechanism

Since ELG amplitude is proportional to the degree of contact between the lips, when the ELG amplitude decreases, the contact area at the lip interface decreases and the lips tend to open. Therefore, we can reasonably assume that the ELG signal $\boldsymbol{E}$ and lip motion ξ are π out of phase, lip motion being defined as the distance between the center of mass of the two lips. Consequently, the inverse of the ELG signal is assumed to be in phase with the lip motion and thus in phase with the lip opening area $\boldsymbol{S}_{lip}$: $\varphi(-\boldsymbol{E}) = \varphi(\xi) = \varphi(\boldsymbol{S}_{lip})$.

The predominant "outward" or "upward" striking mechanism of the lips is given by the sign of the phase difference between $\boldsymbol{S}_{lip}$ and the acoustic pressure measured in the mouthpiece cup $\boldsymbol{P}_m$. In the case of a positive phase difference ($\varphi(\boldsymbol{S}_{lip}) - \varphi(\boldsymbol{P}_m) > 0$), lip opening anticipates the drop of mouthpiece pressure so the lips behave as an "outward" striking valve. If the phase difference is negative, the pressure drop occurs before the lips tend to open so the lips behave as an "upward" striking valve.

3. EXPERIMENTS AND RESULTS

Experiments were conducted on one subject on a King 2102 tenor trombone. Figure 1 shows the results obtained for an overtone series from F3 to D5 and back to D5 in the closed position of the slide. The top graphic represents the waveform of the downstream (or "mouthpiece") pressure and ELG signal. The bottom graphic represents the phase difference between the inverse of the ELG signal and the downstream pressure, calculated on a 512 samples sliding window with 448 samples overlap.

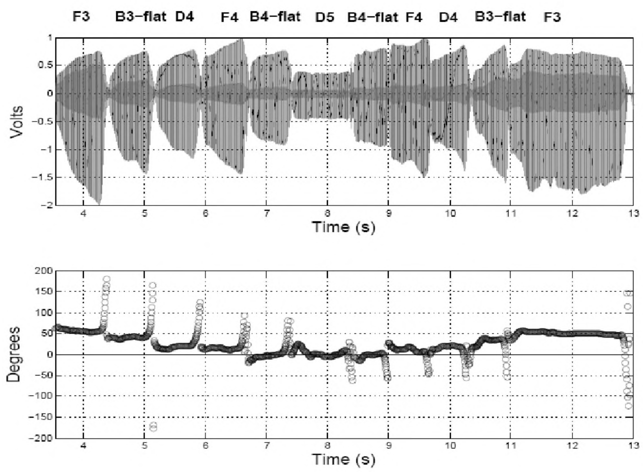

Figure 1. Top: downstream pressure (lighter line), inverse of the ELG signal (darker line). Bottom: phase difference between lip motion and downstream pressure.

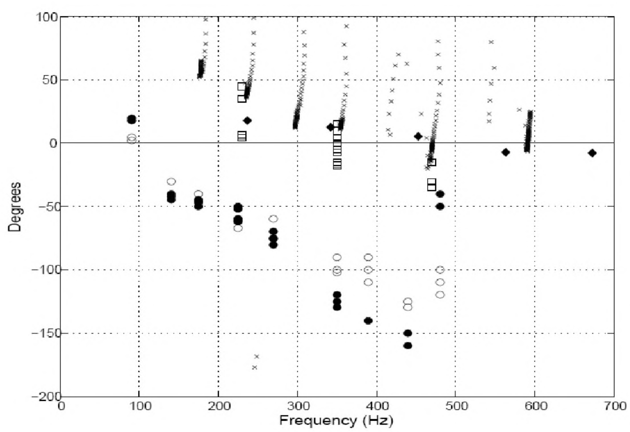

Figure 2. Phase difference between lip motion and downstream pressure in French horn (filled and empty circles), trumpet (empty squares), numerical simulation of trumpet (diamonds) and trombone (crosses).

The maximum phase difference is observed for the lower tone (F3) around 50 degrees and reveals a clear "outward" striking behaviour of the reed. The minimum value occurs for B4-flat and D5 for which the phase difference is near 0. Therefore, the tendency of a transition from an "outward" to an "upward" striking regime of oscillation is confirmed on this acquisition.

The phase data presented on Figure 1 is now plotted against the playing frequency on Figure 2. On the same graphic, the phase difference between lip motion and downstream pressure is plotted for a French horn and a trumpet as measured by Yoshikawa using strain gauges and human players [2]. The phase difference between lip opening area and downstream pressure in trumpet obtained from numerical simulations by Adachi and Sato [6] is also plotted on the same figure. Results from simulations and *in-vivo* measurements in trumpets are quite consistent, which suggests the two-dimensional lip model proposed by Adachi and Sato provides good results. Phase values obtained for the French horn are clearly lower than those obtained for the trombone and trumpet, possibility because of the specific geometry of the French horn bore and mouthpiece (conical bore). Results obtained for the trombone in this study are consistent with the tendency observed in previous studies with an order of magnitude close to values observed in trumpet.

4. DISCUSSION AND CONCLUSIONS

We have presented a new sensor for the measurement of lip electrical admittance in trombone performance. This method is non-invasive and provides a signal which is assumed to be proportional to the degree of contact of the lips. Moreover, the phase of this signal is robust to the phase of the lip motion and opening surface, which allows evaluation of lip vibratory mechanisms of real players, across all playing ranges. The results, which reveal a transition from an "outward" striking towards an "upward" striking regime of oscillation, corroborate previous work and support the validity of ELG in carrying information on lip motion. Although the scope of this paper is restricted to considerations on the phase of the ELG signal, the waveform displays some common features with EGG of vocal folds. Therefore, some techniques for the extraction of vocal folds parameters, such as the open quotient, may potentially be used for further investigation. Correlations between lip mechanisms, mouthpiece mechanical constraints and the acoustical influence of the vocal-tract are also part of future works.

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