Can the three dimensional motion of the lips account for the 'brassy' sound?

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Abstract

One distinctive feature of orchestral brass instruments is that there is a marked change in timbre with dynamic level. It is generally accepted that the explanation for this behaviour is shock-wave generation within the body of the instrument. However, it has also been suggested that changes in the nature of the players' lip vibration with increasing amplitude could play at least a small role in generating this distinctive 'brassy' sound. Previous studies have shown that the brassy sound cannot be accounted for by a dramatic change in the behaviour of the lip opening area during extremely loud playing. The experiments described here are designed to test the hypothesis that variations in the motion of the lip parallel to the airflow into the instrument may help produce the 'brassy' effect. A high speed digital camera and transparent mouthpiece are used to capture the motion of the lips in the plane perpendicular to the face of the player for different dynamic levels. Measurements have been taken over a variety of instruments and musicians and over a dynamic range from mezzoforte to fortissimo.

Introduction

The timbre of orchestral brass instruments is highly dependent upon the dynamic level at which the player chooses to play. At louder volumes, the energy of the higher harmonics increases dramatically, leading to the creation of a particularly distinctive 'brassy' sound. Musicians use this change of timbre as an added form of musical expression.

Sound production in the brass wind family comes from a forced oscillation of the lips of the player within the mouthpiece of the instrument. Air flows from the lungs of the player and the lips act as a valve, modulating the flow of air into the main body of the instrument. When this oscillation is matched to an air column of the correct length a self sustaining oscillation is developed at one of the resonant modes of the instrument. This paper presents an experimental study of the motion of the lips at varying dynamic levels.

The relationship between the the oscillation of the lips and the time-varying input impedance of the instrument is highly non-linear. This non-linear behaviour is reponsible for the complex form of the resulting pressure waveform in the mouthpiece of the instrument [1, 2].

It is now generally accepted that the increase in energy

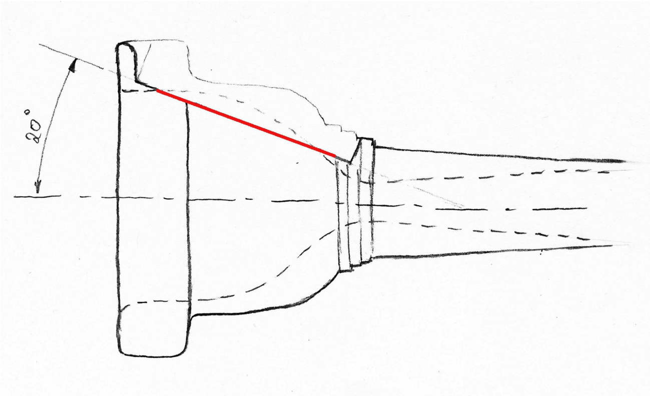

Figure 1: Schematic of the mouthpiece with side window. The external layer of perspex was machined down and replaced with an optical window (shown in red)

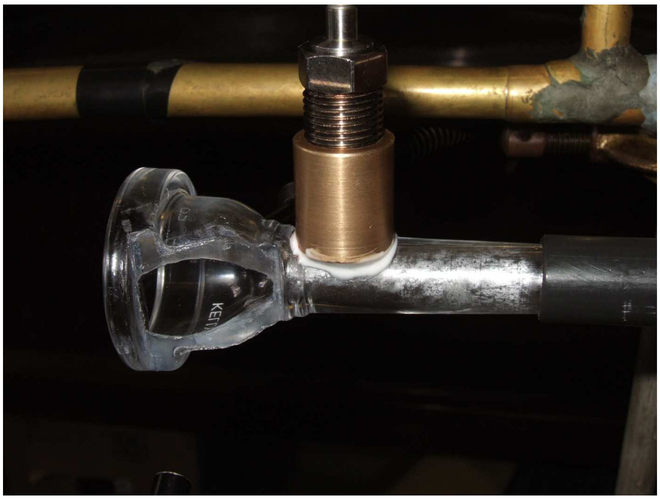

Figure 2: A photograph of the mouthpiece showing the window and PCB microphone adaptor

of the higher harmonics with dynamic level is caused by non-linear propagation of the acoustic wave within the body of the instrument, as demonstrated by Hirschberg *et. al.* in 1996 [3]. When high amplitude pressure oscillations are generated in the mouthpiece, the leading edge of the pressure wave steepens as it progresses through the body of the instrument. This effect causes a dramatic increase in the energy of the higher harmonics.

Several researchers, however, have suggested that a change in the motion of the lips at large amplitude could help to generate this brassy timbre [4, 5, 6]. If the lip motion becomes 'clipped' or 'saturated' during loud playing—perhaps because of a constraint of the lips

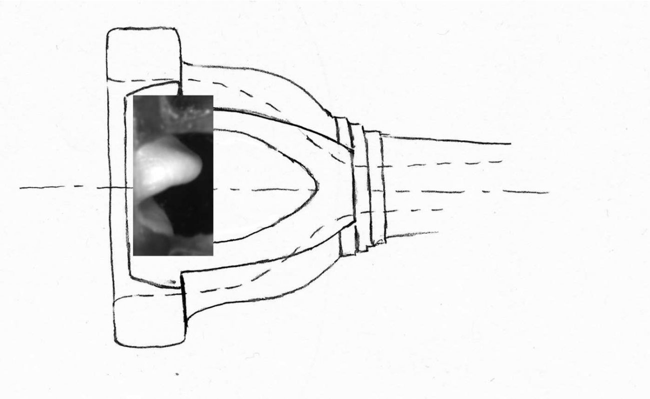

Figure 3: A significant portion of the lips can be seen through the window

by the rim or cup of the mouthpiece—then this would contribute significantly to the brassy sound. However, a recent study at the University of Edinburgh could not find any evidence of saturation of lip opening area for loud dynamic playing [7]. In fact, other than an increase in amplitude the time-varying lip opening area behaved very similarly for both brassy and non-brassy playing.

Copley and Strong [8] used a stroboscopic method to examine the transverse and longitudinal motion of the lip, but did not examine the case of extremely loud playing. This paper is an attempt to discover whether or not there is a significant change in the motion of the lips in the direction of the airflow during playing at extremely loud volumes.

Experimental Method

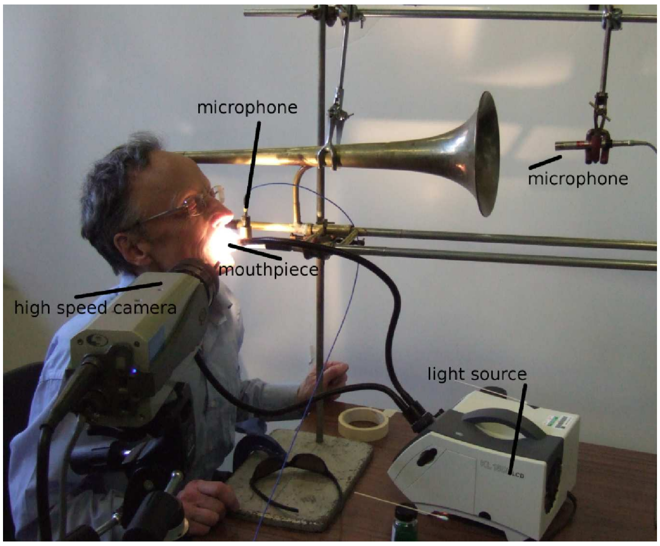

Figure 4: The complete experimental setup, showing the position of the mouthpiece, camera, and microphones

Measurements were taken on a tenor trombone, using three different musicans—amateurs with many years playing experience. Players were asked to sound notes of the same pitch but at varying dynamic level—the first at a *mezzo forte (mf)* level and the second as loudly as possible (*ffff*). The radiated sound was recorded at a distance of one bell radius.

In order to visualise the motion of the lips in the plane perpendicular to the face of the musician a special mouthpiece with transparent side window was developed. This mouthpiece was a modification of a commercial design by Kelly, in order to maximise the comfort and realism for the musicians. An adaptor for PCB microphone was added to the mouthpiece shank in order to capture the pressure signal in the mouthpiece. A schematic and photograph of this transparent mouthpiece can be seen in figures 1 and 2. The parts of the lips that could be seen are shown in figure 3.

A high speed digital camera (Phantom, Inc. v.4) was used to film the motion of the lips through the window in the mouthpiece at a framerate of 5000 frames per second. In order to obtain a clear image a Schott KL1500 cold light source was used to illuminate the lips. This cold light source is suitable for use in proximity to the face of a human. The complete experimental setup can be seen in figure 4. The footage from the camera was synchronised with the two pressure signals in order to allow comparison of the motion of the lips with the pressure generated in both the mouthpiece and radiated from the bell of the instrument.

Results

Figure 5 shows a complete cycle of the lip motion for the note $B\flat_2$ played at *mf* as well as the corresponding mouthpiece pressure signal. The red dot on the pressure signal shows the pressure at the precise instant the image was taken. It is immediately clear that it is the upper lip which demonstrates the majority of the motion. Choosing a point near the centre of the lip and following it over the cycle we see that it first moves ‘into’ the mouthpiece in the direction of the airflow before curving ‘upwards’. It then moves back in the direction opposite to the flow whilst moving ‘down’ again, effectively tracing out an elliptical trajectory. Once it returns to its initial position the cycle repeats. This is in agreement with the results of Copley and Strong [8]. Figure 7 shows the maximum distance that the upper lip moves in both the direction of the airflow (approx 5mm) and the vertical direction (approx 6mm).

Figures 6 and 8 show the same information for the same note played at a brassy *ffff* level. In this case, the motion of the lip appears to be much more dramatic than in the previous case. However, on following a single point on the lip, we see that it again traces out an approximately elliptical path much the same as in the non-brassy case. In the brassy case the amplitude of the motion is much larger—the lip travels almost a full centimeter into the mouthpiece—but in general terms the motion is the same for both cases. In addition, we do not see any evidence of the lip being constrained in any way. Given the large amplitude motion of the lip in the ‘brassy’ case, we would perhaps expect to see evidence that the ‘wobbling’ of the lip in the middle of the cycle would displace a large volume of air, creating a significant pressure in the mouthpiece. However, on examining the pressure signal, it appears that in the middle of the cycle, when the lip

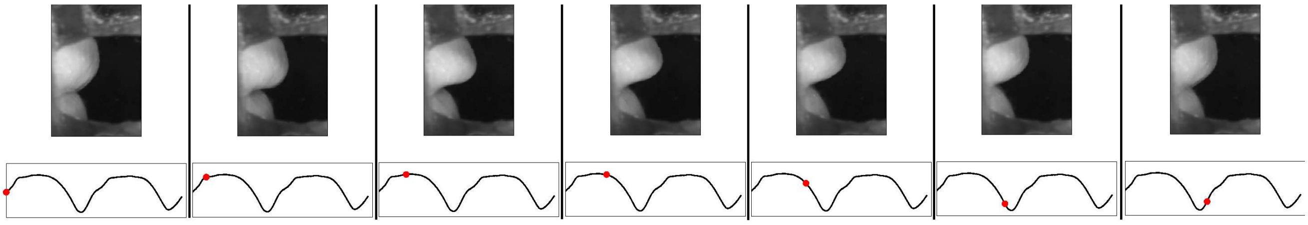

Figure 5: A complete cycle of the lip motion for the note $B\flat_2$ played at *mf*. The corresponding mouthpiece pressure signal is shown below. The red dot indicates the point in the cycle corresponding to the image above.

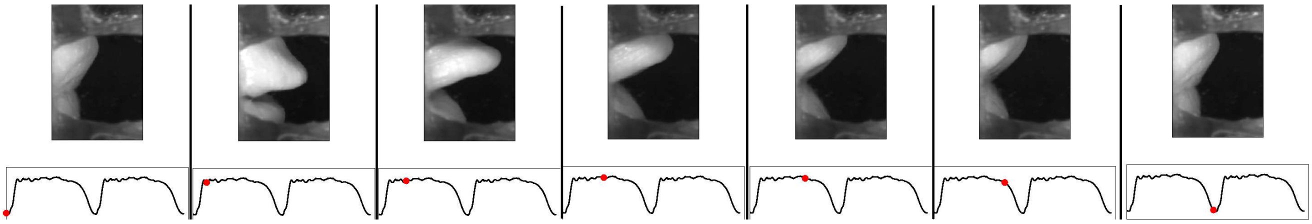

Figure 6: A complete cycle of the lip motion for the note $B\flat_2$ played at *ffff*. The corresponding mouthpiece pressure signal is shown below. The red dot indicates the point in the cycle corresponding to the image above.

is moving the most, the pressure signal is approximately flat. This suggests that the motion of the lip does not create a significant volume flow. Instead, the pressure signal in the mouthpiece seems to be controlled purely by the lip opening.

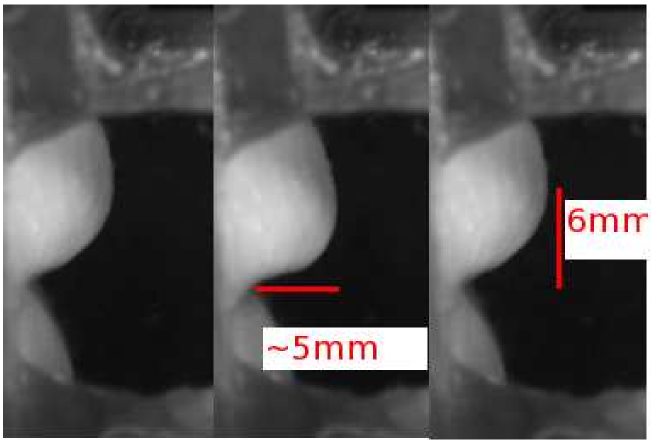

Figure 7: Three images showing how far the lip moves in the horizontal (middle) and vertical (right) directions from the 'fully closed' position (left). Note $B\flat_2$ played at *mf*. These images correspond to images 1,3,5 from the cycle in figure 5

Comparison of the results presented here with measurements taken over several other notes as played by three different musicians suggest that this behaviour appears to be highly consistent for different players. In all cases, it is the upper lip that exhibits the largest motion, and traces out an approximately elliptical path during the cycle. There does not appear to be constriction of the lip motion in any way at even the loudest playing dynamic.

Conclusions

Whilst playing a brass instrument, the lips of the player demonstrate an incredibly complicated motion, with the top lip moving the most. The top lip traces out an approximately elliptical motion for both *mezzo forte* and *ffff* playing, in agreement with the earlier measurements of Copley and Strong [8].

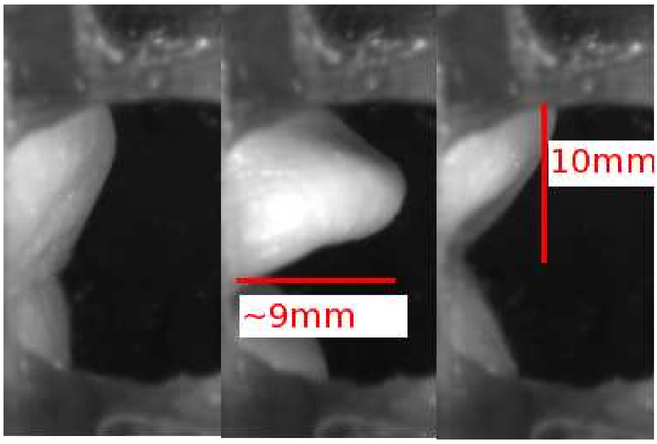

Figure 8: Three images showing how far the lip moves in the horizontal (middle) and vertical (right) directions from the 'fully closed' position (left). Note $B\flat_2$ played at *ffff*. These images correspond to images 1,3,5 from the cycle in figure 6

There does not appear to be any constriction of the lips for any playing dynamic. This suggests that if the motion of the lips contributes to the brassy sound then it is as a secondary effect and not as the primary cause.

Examining the footage of the lips in comparison with the corresponding pressure signals suggests that although the lips undergo a complicated three dimensional motion, the majority of this lip displacement does not correspond to any change in the pressure generated in the mouthpiece. Accordingly, we can conclude that the contribution to the mouthpiece pressure caused by the motion of the lips is controlled by the opening and closing of the lip, not the complicated motion that accompanies it.

Acknowledgements

This work was funded by a Ph.D. grant from EPSRC, UK. The authors would like to thank all the musicians for kindly offering their time. Thanks are also due to the technicians in the mechanical workshops of the School of Physics and School of Electronics and Engineering at the

University of Edinburgh for their assistance.

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