Transient behaviour in the motion of the brass player's lips during a lip-slur.

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Introduction

In music, a 'slur' indicates a smooth transition between two notes. On a brass instrument, if these two notes are both resonant modes of the air column, the player achieves this slur by a combination of changing the tension in the lips, mouthpiece pressure, and air flow rate. This is often referred to as a lip-slur. Players have different approaches in practising to achieve lip-slurs.

Some players aim to move as quickly as possible between the two notes, while other players practise a more portamento transition, aiming to catch intermediate resonant modes between the two played notes [1] - these approaches are highly subjective.

Previous exploration in this area includes impedance measurements for slurred transients in valved instruments [2,3]. In the current study optical techniques were used to analyse the motion of the player's lips during varieties of lip-slur. The relationship between the motion of the player's lips, the pressure inside the mouthpiece, and the radiated sound pressure during the transition between notes by means of a lip-slur, on two different horns and with two different players was investigated. The experimental set up and techniques used are similar to those used in earlier studies of the starting transient [4,5].

When sounding a note on a brass instrument the player's lips open and close periodically. The initial frequency with which the lips vibrate is determined by the player's choice of embouchure, which influences the mechanical properties of the lips. When a player sounds a note on a brass instrument there is a strong coupling between the vibration of their lips and the resonant modes of the instrument air column. During a lip-slur the player is attempting to change the lip vibration from one strongly coupled steady state vibration to another. We expect that as the player changes the frequency of their lips in order to reach the target note there will be a finite time during which the oscillations of the lips and air-column will no longer be coupled.

The time taken for the lip oscillation and the air column resonance to couple is determined by the period of the acoustic wave within the instrument and the frequency at which the lips are vibrating. Say, for example, that the lips are vibrating at the frequency of a high number mode of the air column e.g. the sixth mode—the player is aiming to play at the sixth mode frequency of the tube. The period of the acoustic wave for a fixed length of tube is constant with respect to frequency, so in the time it takes for the wave to propagate to the end of the instrument and back, the lips will have completed six cycles; therefore for the sixth mode it will take approximately six cycles of the lips before the system is coupled to establish a stable regime of oscillation.

The work presented here aims to investigate the behaviour of the motion of the lips as they decouple from one mode of the instrument and then recouple to another.

The Instruments

Two horns were used for the experiment: an early 20th century narrow bore horn by Boosey and Hawkes and a modern wide bore horn by Conn. Two different players were used for this study, both skilled players with many years playing experience.

The mouthpiece design is similar to that used by Richards [6]. The cup of the mouthpiece is machined from Perspex and has a thin optical glass window which is approximately parallel to the player's face. In horn players the lip aperture is relatively small and the top lip overhangs to some extent; to allow better visual access the optical glass is angled. The mouthpiece that was used for this study is shown in Figure 1. This mouthpiece is based on the commercially available Paxman 4C, with the shank, cup volume and rim dimensions taken from this model in order to make it as familiar as possible for the musicians.

Figure 1: Perspex horn mouthpiece with optical glass window for visual access.

Measurements

Two different lip-slur transitions were chosen for this study: an octave interval between D3 and D4 and a perfect fourth interval between C3 and F3. The octave transitions were between the fourth and the eighth resonant modes of the horn in open D; and the perfect fourth transitions were between the third and the fourth resonant modes of the open F horn. In both cases the lip-slurs started from the lower note and finished on the upper. These measurements were repeated by both players on each of the two instruments.

Experimental Set Up

A Vision Research Inc. Phantom v4.1 camera was used to capture the motion of the lips. For this study the camera resolution was set to 256 x 128 pixels at 5000 frames per second. The exposure time and aperture of the camera were varied to give the maximum depth of focus while maintaining the quality of the image.

The filming of the lips requires a strong light source to produce video footage appropriate for computational analysis. A Schott KL 1500 LCD lamp was used to create the desired illumination—this is a cool light source for use in close proximity to the player's face.

The mouthpiece pressure was measured using a PCB microphone with a probe attachment that was inserted into a small hole drilled in the rim of the mouthpiece. The radiated sound was measured using a Brüel and Kjær 4132 microphone that was placed one bell radius from the bell of the instrument. The microphone pressure signals were synchronised with the high speed camera using a triggering system. The experimental set up is shown in Figure 2.

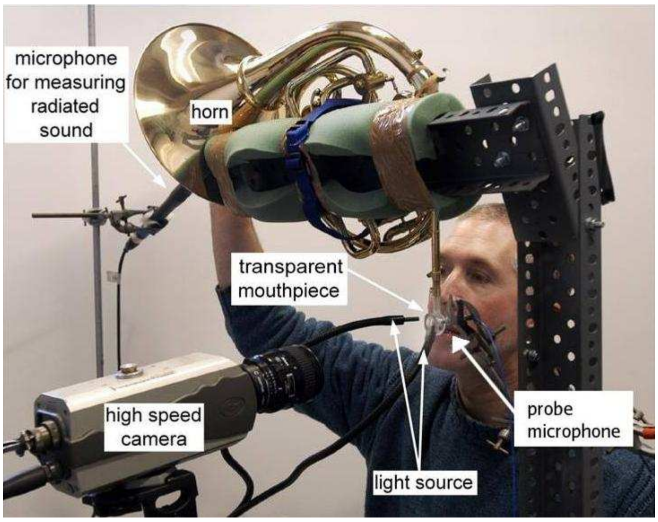

Figure 2: Experimental set up.

Analysis

The (greyscale) video footage of the lips was edited such that one image was produced per frame of the video; these images were cropped as to only show the relevant parts of the lips. A threshold grey level was chosen so that a 'binarisation' could be performed on each image; each pixel below the threshold is set to 'black' and each pixel above the threshold is set to 'white'. Figure 3 shows an example of this process. Using MATLAB the number of black pixels were counted for each image and the opening area plotted as a function time. The pressure signals from the mouthpiece and radiated sound were synchronised with this opening area data.

The 'instantaneous' frequency of the lip opening area was calculated using MATLAB code that first located the maxima of the peaks in the opening area vector and then calculated the 'period' between successive peaks. In this way, a 'frequency' could be assigned to each cycle of lip opening and closing. It was found that the relatively low sample rate of the video footage created unwanted local maxima in the area data because of the effect of aliasing. In order to remove these discrepancies, the opening area data was resampled using an FIR filter. Careful checks were made to confirm that the resampling process did not add or remove any important features of the data.

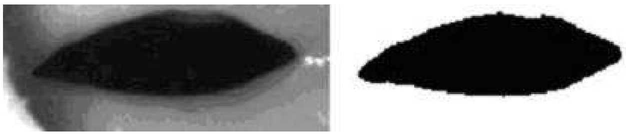

Figure 3: An image of the lip open area and the corresponding 'binarised' image. The opening area appears black.

Results

Figure 4 shows the synchronised opening area data and pressure signals for an octave lip-slur by player A. It can be seen that the open area of the lips decreases relatively steadily in amplitude until around 0.1s. There are around 15 cycles of the lip motion where the amplitude is significantly smaller until around 0.18s; at this point the amplitude starts to build up steadily to the second steady state motion of the new resonant mode. During this lip-slur transition period the pressure in the mouthpiece has rather erratic behaviour until it begins to build up to a steady state at around 0.16s. The external pressure signal drops in amplitude between 0.08s to 0.18s but retains a significant amplitude showing that there was no break in sound during the lip-slur.

The synchronised signals for the same octave slur on the same horn by player B are shown in Figure 5. This Figure shows many of the same characteristics as that of player A although the number of small amplitude peaks in the open area plot is significantly less than that for player A. There is again a steady decrease in amplitude of the open area but there are only 5-6 peaks which are significantly smaller in amplitude. The mouthpiece pressure signal for player B is much less erratic than that of player A during the transition between the two notes, although between 0.12s and 0.15s the amplitude of the signal is relatively small. The external pressure signal differs from that of player A significantly; during the transition from 0.14s to 0.17s the amplitude of the signal is extremely small indicating that there was more of a break in the sound

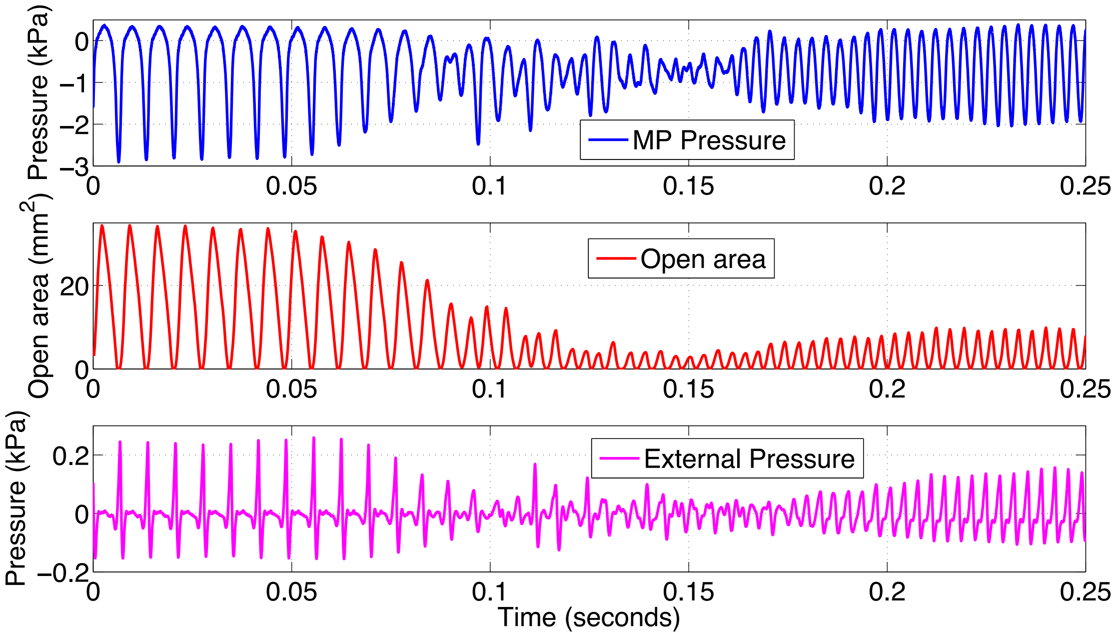

Figure 4: Synchronised signals for lip-slur from D3 to D4 by player A.

between the two slurred notes.

At this point it is interesting to note the approach with which each of these players takes to playing lip-slurs. Player A practises slowly playing each of the resonant modes of the instrument between the two slurred notes, and then builds up this speed to hopefully create a portamento transition. Player B, however, takes the opposite approach to lip-slurring in that they aim to make the transition as fast as possible and latch immediately onto the second note of the slur.

The corresponding 'instantaneous frequency' of the lip open area of player A can be seen in Figure 6. It can be seen that the time between steady frequencies i.e. between the two slurred notes, is around 0.1s. This time was found to be consistent for all lip-slurs performed by player A.

There are four well defined peaks in the frequency within the transition period. Analysis of a number of measurements shows that some of these frequencies lie on or around resonant frequencies of the instrument. However, a number of them do not appear to correspond to any resonant modes of the instrument.

Figure 7 shows the same result for player B. This figure again shows much of the same characteristics as for player A. However, it can be seen that the intermediate frequency peaks are less well defined than those for player A. It is thought that these characteristics could be attributed to player A intentionally attempting to access the intermediate frequencies between the resonant modes of the slur in order to produce a smoother transition. The time between steady states for player B in this case was shown to be around 0.08s, shown on the figure between 0.15s and 0.23s.

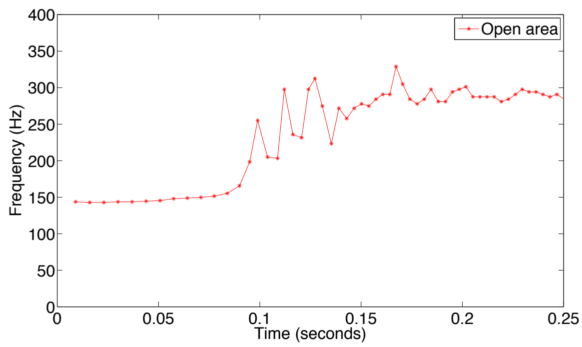

Figure 6: Open area instantaneous frequency for lip-slur from D3 to D4 by player A.

All of the results presented here were obtained using the modern wide bore horn. It was found that there were no notable differences in measurements taken on the different instruments. The main characteristics that were shown in the results, for both players, were consistent across both types of horn.

Experimental data from slurred transition between C3 and F3 showed similar trends and characteristics. The time for a lip-slur is consistent for different intervals as are the differences between players.

Conclusions and Future Work

In this study the transient behaviour in the motion of the brass player's lips during a lip-slur was investigated. We have compared two different players and two different approaches to lip-slurs on two different horns.

It has been shown that the average time for a lip-slur and for the lip motion to change from one steady state resonance to another is between 80ms and 100ms. The time taken for a lip-slur seems not to vary significantly

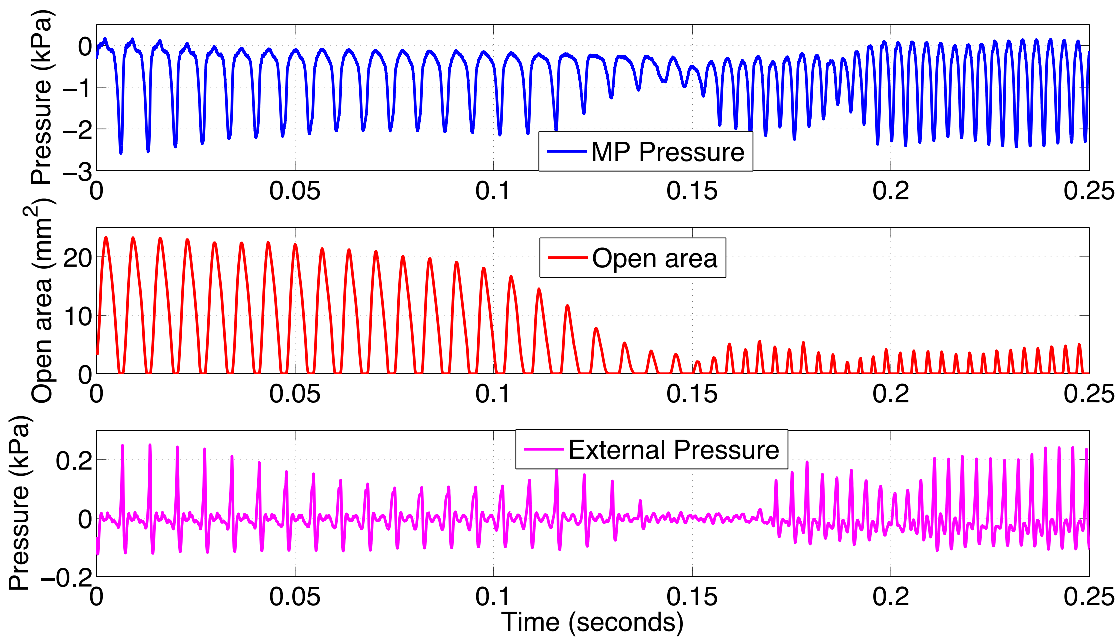

Figure 5: Synchronised signals for lip-slur from D3 to D4 by player B.

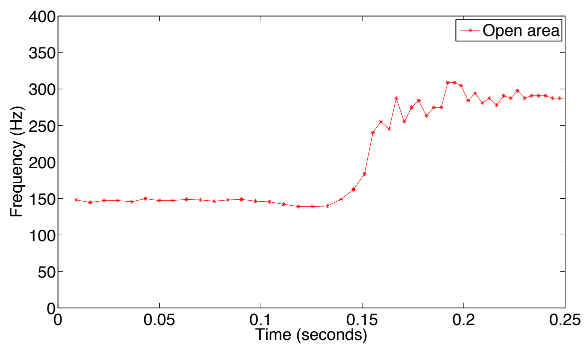

Figure 7: Open area instantaneous frequency for lip-slur from D3 to D4 by player B.

from player to player or for slurs over different ranges. The results seem to be broadly in line with the previous work into starting transients; the time for a lip-slur is of the same order of magnitude as twice the time for a starting transient.

At the mid point of the lip-slur transient we can see similar behaviour as that of a starting transient; initially a small amplitude lip oscillation which increases significantly after the time for one round trip of the pressure pulse. After the time for one round trip within the instrument constructive reinforcement from the bell can be seen to reinforce the lip oscillation and couple to produce a new steady state oscillation.

Future work on this subject will be concerned with gaining more measurements of a range of players to determine what makes a 'good' lip-slur; assessing playability of brass instruments through looking at the ease of slurs and determining problems in instruments which are deemed as having lower playability; and ultimately to create a time domain model with which these physical results can be compared.

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