Embouchure Control of Brassiness at Constant Pitch and Dynamic Level in Orchestral Horn Playing

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Introduction

The extent to which a musician is able to manipulate the timbre of a wind instrument by adjusting their embouchure is an interesting area to explore. Brass instruments are generally more receptive to embouchure control than those in the woodwind family because properties of the reed (e.g. the stiffness) in an instrument such as the clarinet or oboe are more or less fixed, whereas the brass player has a greater degree of control over the lips by changing the tension in the lip muscles, and the pressure and angle of the mouthpiece [1].

Brassy playing, or *cuivré* as it is sometimes referred to in compositions, calls on the musician to sound their instrument in such a way that the highest frequency components of the sound are strongly excited, thus generating a bright and brilliant timbre. This style of playing is achieved most easily at high dynamic levels where non-linearity in the behaviour of the sound wave in the bore of the instrument becomes increasingly evident [2]. Non-linear propagation of the wave however, is not merely confined to loud playing but has also been observed to some extent at softer dynamic levels. Interestingly, brass players often talk about playing with or without a brassy “edge” to the sound, but in reality the transition between a non-brassy and brassy timbre is not well defined [3].

There is currently much speculation about what causes and influences the onset of brassiness in the air column of an instrument. Previous research in this field has explored factors such as changes in the bore profile [4], mouthpiece dimensions [5], and construction material of the instrument [6]. The issue of player control of brassiness through embouchure manipulation is an area which is yet to be explored in any depth. Whereas the physical changes to the instrument can be measured in a relatively objective manner, the very nature and complexity of a player’s lips and vocal tract make systematic measurement and comparison of different players’ technique a great challenge.

Nevertheless, this paper aims to provide an initial investigation into the potential of embouchure control in the context of brassiness manipulation. An analysis has been carried out by comparing the pressure waveform in the mouthpiece of the horn with that of the radiated sound at the bell of the instrument in order to examine precisely how the spectral components of the waveforms differ. The steepness of the wave front in the mouthpiece has also been analysed and the rate of change of pressure plotted.

Experimental procedure

The relationship between the sound pressure in the mouthpiece and that of the radiated sound from the bell of the instrument was measured using two microphones: a PCB microphone recorded the pressure inside the mouthpiece as it is capable of withstanding large pressure fluctuations as a result of very loud playing. The microphone was screwed into a fitting soldered on to the outside of the mouthpiece. A small hole, drilled in the shank of the mouthpiece over which the fitting was positioned, allowed the microphone diaphragm to vibrate freely. The second microphone was mounted approximately one bell diameter in front of the plane of the bell, and recorded the radiated pressure, as shown in Fig. 1.

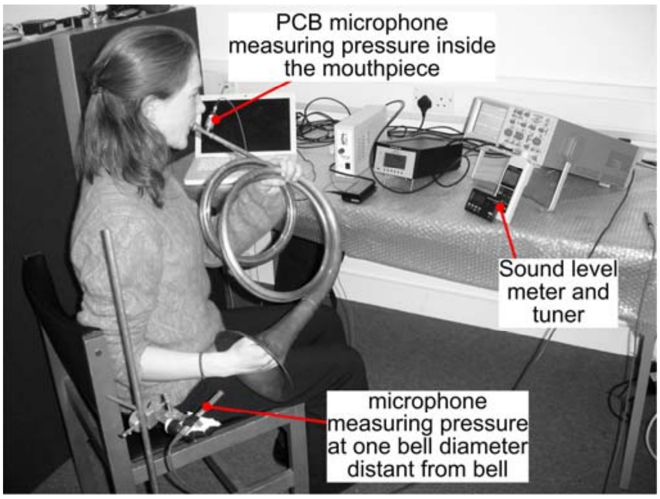

Figure 1: Experimental set up for brassy playing showing the positions of the microphones and sound level meter.

The complex nature of the human lip means that no two players are likely to manipulate a particular note with their embouchure in exactly the same manner, despite their best efforts. For this reason, three horn players were involved in this study in order to explore the variability of player technique.

A horn with a tube length corresponding to a nominal pitch D1 (approximately 4.42 m) was used for all experiments. This length of instrument was judged to be most amenable to player control of brassiness. Players were asked to produce six notes of approximate duration two seconds, and with a similar two second gap between each note. The first three notes were to be played non-brassy, followed by three brassy notes at the same dynamic level. The pitch D3 (4th harmonic, a mid range note for horn in D) was chosen as a comfortable note at which the threshold of the onset of brassiness could be manipulated most easily using only the embouchure.

One of the main challenges in carrying out this experiment was in trying to keep dynamic level and pitch constant at the same time. In order to do this a sound level meter and an electronic tuner were positioned where the player could easily monitor both whilst playing. The sound level meter was set to A-weighting. Experiments were also carried out where the sound level meter was removed from the players' view and they were required to judge for themselves what they perceived to be brassy and non-brassy notes of the same dynamic level.

Results and discussion

Fig. 2 shows examples of the frequency spectra of the radiated sound for a brassy and non-brassy tone, played at the same dynamic level. The increase in strength of the upper harmonics in the brassy tone compared with that of the non-brassy tone can clearly be seen, with significant peaks extending beyond 10 kHz in the lower graph. It should be noted that although the difference in timbre between the displayed brassy and non-brassy tones is significant and could easily be heard by the listener, these are by no means examples of the extremes of brassy and non-brassy playing. In these cases, differences in the spectra would appear much more pronounced.

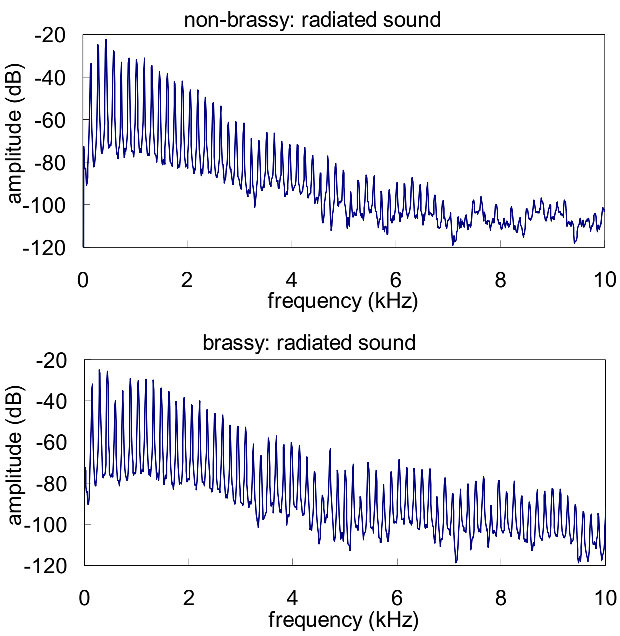

Figure 2: Frequency spectra of the radiated sound (measured at one bell diameter from bell exit) for a non-brassy tone (upper figure), and a brassy tone (lower figure), for the note D3. Both tests were played at the same dynamic level.

Fig. 3 shows the envelopes for the peak values of the frequency spectra for brassy and non-brassy pressure measured in the mouthpiece and at the bell of the instrument. Harmonic number is used as the scale for the x-axis rather than frequency in order to highlight more clearly the interesting dips in mouthpiece pressure for the brassy mouthpiece curve at harmonic numbers 4, 8 and 16. These harmonics correspond to the second, third and fourth octaves of the note D3 and therefore result in a spectra relatively weak in octave multiples of the fundamental.

It is to be noted that the increase in amplitude for both mouthpiece pressures above the 64th harmonic (approximately 10 kHz) can be explained due to an unintended whistle tone. The small hole drilled into the shank of the mouthpiece along with the cavity in the microphone fitting immediately beneath the microphone diaphragm was thought to act as Helmholtz resonator.

In order to explore the extent to which different components of the frequency spectra are altered in travelling from the mouthpiece to the bell of the horn, the graph in Fig. 4 was plotted and peak values for the harmonics with amplitudes less than the background noise level were discarded. This method of analysis has previously been adopted by Beauchamp [7] as early as 1980 and subsequently by Thompson *et al.* [8].

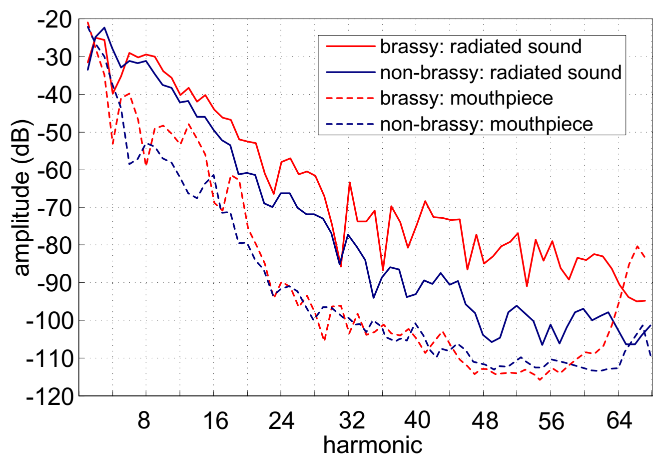

Figure 3: Spectral envelopes of brassy and non-brassy tones from mouthpiece and radiated sound. Notes D3 played at constant dynamic level on a 4.42m horn in D.

It can be seen from Fig. 4 that up until approximately 5.5 kHz (36th harmonic), the difference in amplitude between the harmonics in the mouthpiece compared with the radiated sound correspond relatively closely for both brassy and non-brassy tones. The first few harmonics in particular show a very strong correlation in amplitude difference. Above 5.5 kHz however, the amplitudes of the higher frequency peaks in the radiated brassy tone remain strong despite significantly reduced peaks in the mouthpiece frequency spectrum above approximately 3 kHz. This is evident in Fig. 4 as the brassy curve does not drop away unlike the non-brassy curve for which peak amplitudes in the radiated spectral frequencies are negligible above approximately 7 kHz.

Previous analyses of this sort by Beauchamp have revealed that differences in amplitude between the radiated spectral components and corresponding components in the mouthpiece are not constant over all dynamic levels due to increasing nonlinearity as sound intensity increases. Fig. 4 however, shows that even at approximately the same dynamic level, large differences in amplitude can clearly be seen where the two curves diverge. This would suggest that for a particular instrument, nonlinearity is to some extent dependant, not only on the intensity of the sound produced, but also on the way in which the player is able to control and alter the input waveform.

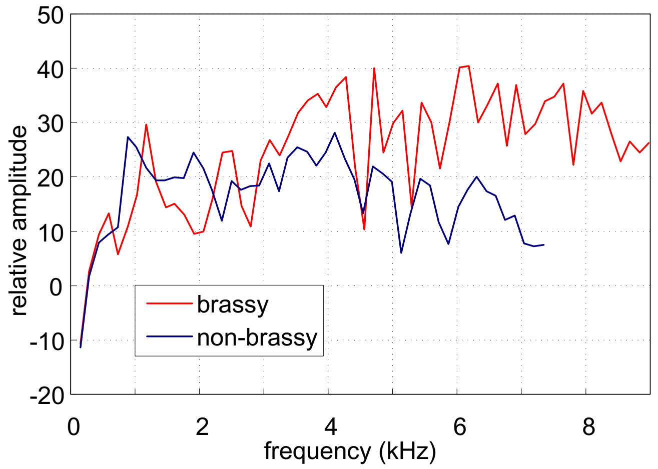

Figure 4: Amplitude difference between the peak values of frequency spectra measured in the mouthpiece compared to the corresponding values measured at the bell of the horn for brassy and non-brassy tones for the note D3. Both tones were played at the same dynamic level.

These results would suggest that when a player manipulates the tone of the horn with his embouchure in order to make the sound brassier, a steepening of the wave front occurs. The change in shape of the waveform is not as a result of an increase in dynamic level or pitch change, as these parameters have been kept constant, but is instead influenced by slight pressure changes in the mouthpiece. Figs. 5 and 6 show the pressure waveforms recorded in the mouthpiece for a non-brassy and brassy tone of pitch D3. The rate of change of pressure in the mouthpiece is also displayed.

Both waveforms (mouthpiece and radiated) in Fig. 5 are much smoother, with less sudden changes than the equivalent waveforms in Fig. 6. The smoother the curve, the more rapidly its frequency spectrum drops off with increasing harmonic number. This theory can be confirmed by comparing the radiated waveforms with the corresponding frequency spectra in Fig. 2.

Perhaps of greatest significance when examining these sets of graphs is the difference in the shape of the mouthpiece pressure waveform, in particular, the way in which the brassy waveform has a significantly steeper wavefront than the equivalent non-brassy waveform. This is highlighted by the middle graphs of each of Figs. 5 and 6 which show rate of change of pressure: for the non-brassy mouthpiece signal the gradient of the wavefront is shown to be slightly more than 10 MPa/s while the brassy mouthpiece signal displays a steepness gradient of more than 15 MPa/s. Thus the brassy wavefront is approximately 50% steeper than that of the non-brassy signal.

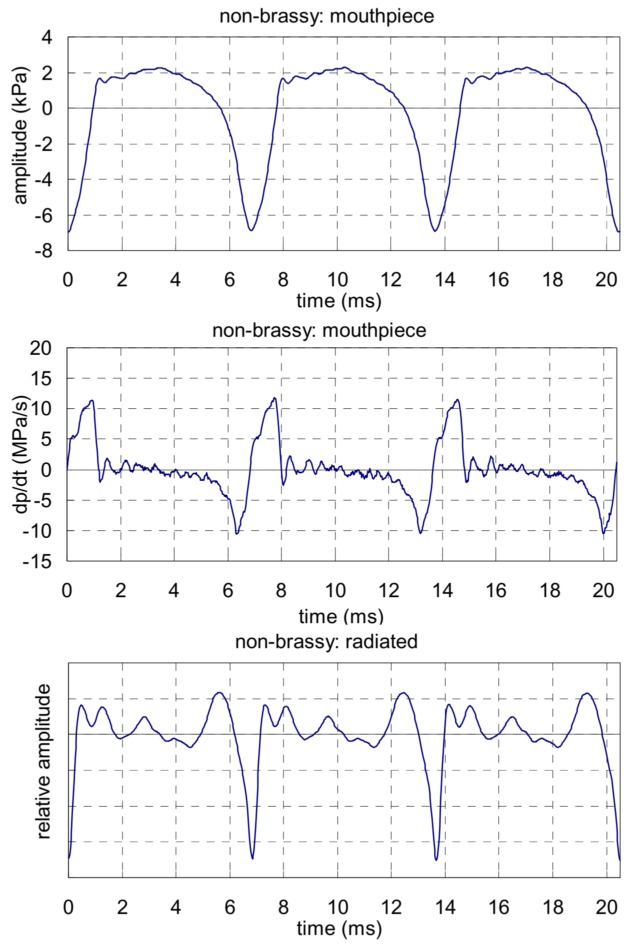

Figure 5: Measured data from non-brassy tests for the note D3. Top figure shows the mouthpiece pressure waveform; middle figure shows the rate of change of mouthpiece pressure; lower figure shows the radiated pressure waveform.

Wave steepening such as this has occurs more readily in instruments which have a significantly long section of narrow cylindrical tubing, hence the reason that trumpets and trombones generally sound brassier than euphoniums and bugles [4]. The latter two instruments have a greater proportion of flaring or conical tubing and this causes any build up of pressure from the proceeding cylindrical section to dissipate more rapidly as the diameter of the bore increases.

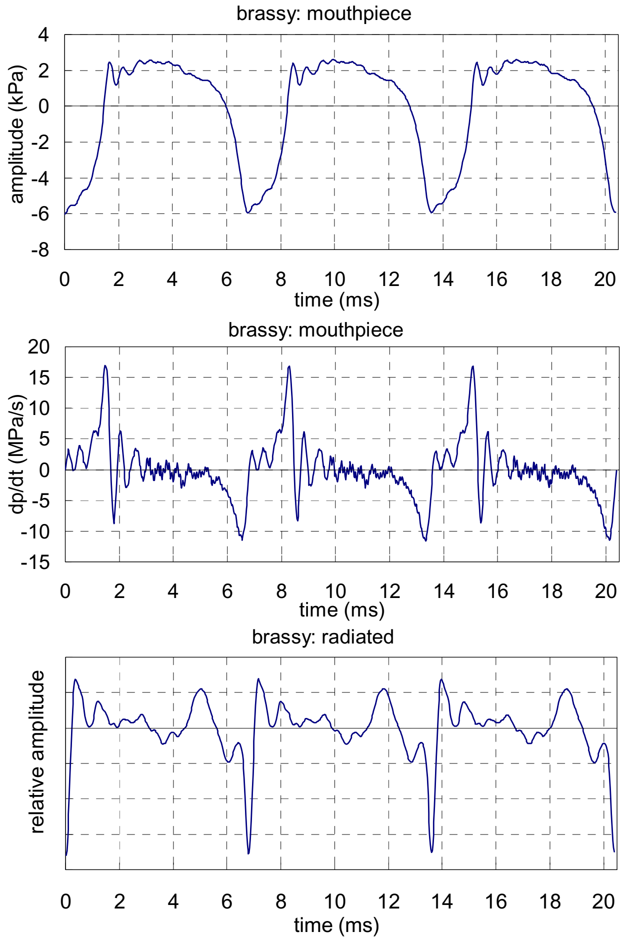

Figure 6: Measured data from brassy tests for the note D3. Top figure shows the mouthpiece pressure waveform; middle figure shows the rate of change of mouthpiece pressure; lower figure shows the radiated pressure waveform.

Conclusions and further work

The results from this study have shown that the player can have a significant degree of control over the timbre of a note without altering either the pitch or the dynamic level. The frequency spectra graphs reveal a marked increase in the energy of the upper harmonics for the radiated brassy tone and that this is consistent with a slight increase in upper harmonics in the mouthpiece also, when compared to the non-brassy tone. The extent of nonlinear behaviour can be observed more clearly in the graph in Fig. 4 in which the two curves are seen to diverge. This behaviour was previously thought to occur as a result of increased dynamic but has now been shown to occur as a result of embouchure control as well. Comparison of the waveforms for brassy and non-brassy tones confirms the assumption of nonlinearity for the brighter timbre and provides visual evidence in the form of wave steepening. In the tests carried out here, players were able to change the gradient of the wave front in the mouthpiece by as much as 50%.

Although these findings clearly show that player manipulation of brassiness is possible, exactly what role the embouchure plays in altering the pressure in the mouthpiece is still uncertain. Further research examining areas such as the effect on brassiness of the shape and volume of the vocal tract may help to explain this phenomenon. High-speed photography of the lips in motion during the onset of brassiness might also prove insightful.

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