A PSYCHOACOUSTICAL INVESTIGATION INTO THE EFFECT OF WALL MATERIAL ON THE SOUND PRODUCED BY LIP-REED INSTRUMENTS

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1 INTRODUCTION

The question of whether the material of construction influences the sound produced by a lip-reed instrument remains a subject of debate. Both makers and players have claimed that they are able to distinguish between the musical qualities of instruments manufactured from different materials but scientific studies have been less than conclusive [1, 2, 3, 4].

The most likely way that the wall material might affect the sound produced is through its influence on the structural vibrations of the instrument. Recent experiments by Whitehouse et al have shown that blowing a lip-reed instrument excites vibrations in the instrument walls, primarily due to the motion of the oscillating lips against the mouthpiece [5, 6]. The amplitude of these vibrations depends on the material from which the instrument is made. However, the wall vibration amplitudes are small and it is unclear whether they have a perceptible effect on the sound produced by the instrument's air column.

This paper reports further experiments designed to investigate the effect, if any, of the material of construction on the musical properties of a lip-reed instrument. These experiments are carried out using five post horns of identical geometry and surface finish but manufactured from different copper alloys (red brass, gold brass, yellow brass, copper and nickel silver). The post horns are straight and comprise two sections; a cylindrical pipe and a bell flare, which slot together to give an overall instrument length of 1080 mm. Fitted into the input end of the cylindrical section is a 75 mm long receiver that is designed to centrally locate a trumpet mouthpiece. The bell section is 380 mm in length, with a spout gauge of 0.50 mm, and flare gauge of 0.70 mm.

In the first half of the paper, measurements are presented which confirm that the amplitudes of the wall vibrations induced when a post horn is blown depend directly on the structural response of the instrument (which in turn depends on the material of construction). Following this, in the second half of the paper, psychoacoustical tests are described that are designed to establish if the different materials of manufacture result in the five post horns having perceptibly different musical properties. Some initial findings are presented and discussed.

2 MEASURING WALL VIBRATIONS

2.1 Experimental Method

Figure 1 shows the experimental apparatus used to measure the wall vibrations of the five post horns. The post horn under test was mounted vertically on a rotating table housed within a semi-anechoic chamber. To fix the post horn in position, the mouthpiece receiver of the post horn was coupled to a trumpet mouthpiece embedded in the faceplate of an artificial mouth. The far end of the cylindrical section of the instrument could also be clamped if required. The apparatus allowed an almost 360° field of view over the test instrument.

Figure 1: The experimental apparatus

To establish its structural response, a mechanical shaker was used to drive the post horn (at a position approximately 10 mm from the mouthpiece end) at discrete frequencies from 10 Hz to 2 kHz. The wall vibrations excited at each of the driven frequencies were then measured, at predetermined locations along both the cylindrical section and the flaring bell section of the post horn, using a laser Doppler vibrometer. The frequency sweep signal sent to the shaker and the velocity amplitude information output by the vibrometer were respectively generated and acquired by a data acquisition system connected to a PC.

To measure the wall vibrations excited when the post horn under test was blown, the shaker was removed from the set-up and the air supply to the artificial mouth was activated. The latex lips within the mouth were adjusted until a stable note was produced. This note was recorded and analysed to establish its spectral content. The velocity amplitudes induced in the walls of the post horn at the frequencies present in the played note were measured using the vibrometer.

2.2 Results

2.2.1 Frequency Spectra of Notes Produced by the Five Post Horns

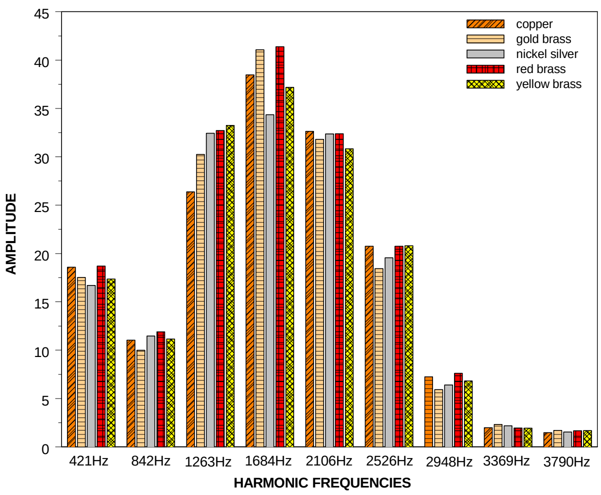

Figure 2: A comparison of the frequency spectra of the blown notes for the five instruments (recorded at a distance of 0.5 m from the bell).

Figure 2 shows the frequency spectra of the notes produced by the five post horns, plotted together on one graph. The notes were recorded at a distance of 0.5 m from the bells of the instruments. For all five notes, the first harmonic has a frequency of 421 Hz implying a note pitch of G#4. The amplitude of each harmonic has a small dependence on the post horn that produced the note. This is most evident for the third and fourth harmonics. It is also clear that, for all of the post horn notes, the strongest peak in the spectrum is the fourth harmonic (1685 Hz).

2.2.2 Wall Vibration Measurements at 4th Harmonic of Played Note (1685 Hz)

Previous experimentation has confirmed a strong correlation between the amplitudes of the wall vibrations induced when a lip-reed instrument is blown, and the structural responses at the frequencies present in the played note.

Figure 3 shows the velocity amplitude variation at the fourth harmonic of the played note (1685 Hz) along (a) the flare section and (b) the cylindrical section of the five post horns, excited when the instruments were blown by the artificial mouth.

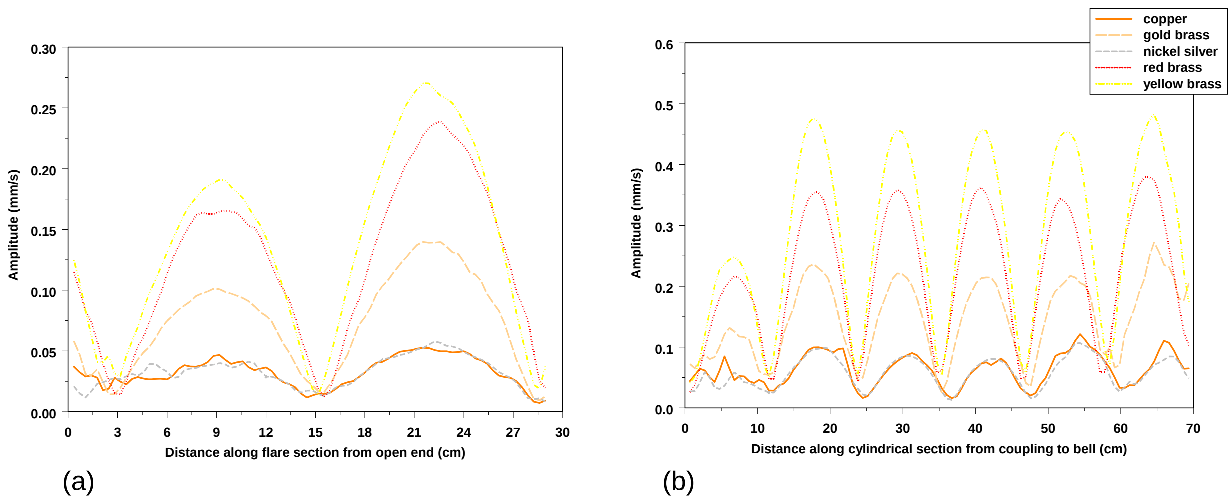

Figure 3: Velocity amplitude variation at 1685 Hz over (a) the flare section and (b) the cylindrical section of the five post horns when artificially blown

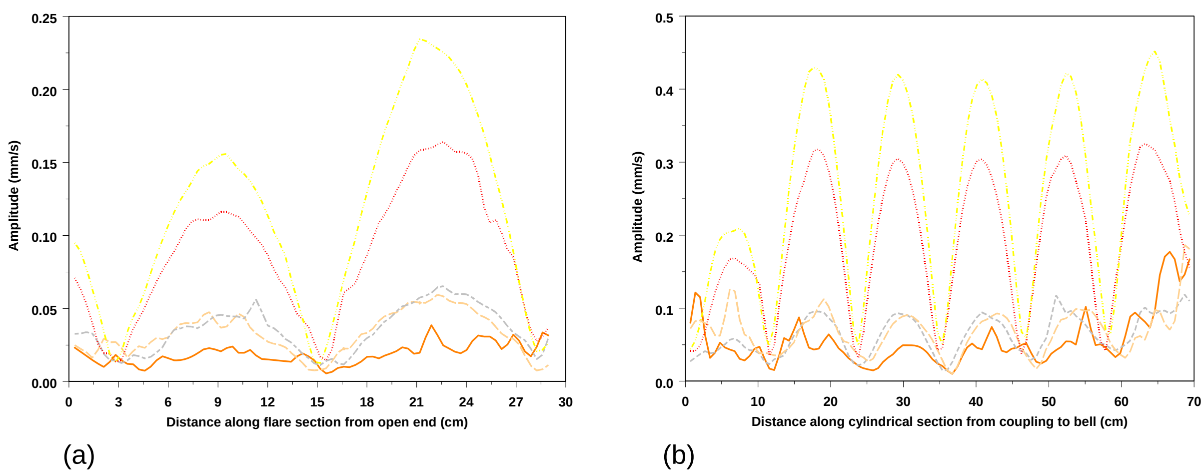

Figure 4: Structural response at 1685 Hz over (a) the flare section and (b) the cylindrical section of the five post horns

Figure 4 shows the structural responses of the post horns at the same frequency plotted over (a) the flare section and (b) the cylindrical section of the instrument.

Figures 3(a) and (b) show that the strongest wall vibrations were induced when the yellow brass and red brass instruments were blown (with peak velocity amplitudes in the flare section of 0.27 and 0.25 mm/s respectively and in the cylindrical section of 0.48 and 0.38 mm/s respectively). The wall vibrations excited when the gold brass post horn was blown are somewhat weaker. However, at 1685 Hz, by far the weakest wall vibrations occurred when the copper and nickel silver instruments were blown (with peak velocity amplitudes of around 0.06 mm/s in the flare section and 0.1 mm/s in the cylindrical section).

Examination of Figures 4 (a) and (b) reveals that the structural responses of the post horns at 1685 Hz follow a similar trend. Over both sections of the instruments, the yellow brass and red brass post horns have the strongest responses followed by the significantly weaker responses of the gold brass, nickel silver and copper instruments.

As expected, at the harmonic frequencies of the played note, there is a very good correlation between the magnitudes of the wall vibrations induced when the post horns are blown and the strengths of the structural responses.

3 PSYCHOACOUSTICAL TESTS

In the previous section, it was demonstrated that when the five post horns are blown there are small differences in the frequency spectra of the notes produced and there are differences in the wall vibration amplitudes. Any relationship between these two differences is hard to establish as the frequency spectra also have a strong dependence on the recording position. This is evident in Figure 5 which shows the frequency spectra for the five post horn notes, this time recorded at 0.1 m from the mouthpiece of the instrument ("the player position"). There are clear differences in the amplitudes of the peaks compared with the frequency spectra of Figure 2.

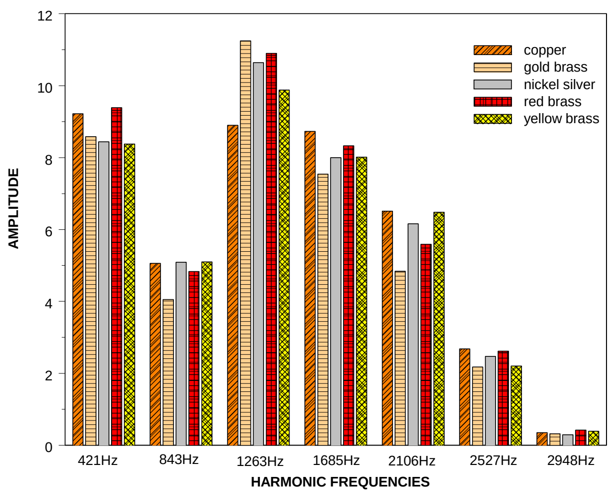

Figure 5: A comparison of the frequency spectra of the blown notes for the five instruments (recorded at a distance of 0.1 m from the mouthpiece – "the player position").

Of interest to the musician and listener is the question of whether these differences are perceptible, both in terms of the playing characteristics of the instruments and the sounds produced by them. To ascertain whether musicians can differentiate between the five post horns and whether listeners can discern any variation in tone between the sounds produced by the instruments, a series of playing and listening tests have been designed.

3.1 Playing Tests

Professional trumpet/post horn players are asked to play each instrument in turn (using the same mouthpiece and receiver for each) and rank them according to certain criteria; resistance to blowing, responsiveness, sound quality and overall preference (their choice if they had to make a purchase). Each musician is asked to perform wearing a blindfold to prevent any visual discrimination but, as their weights are approximately the same, no other measures are taken to disguise the instruments. The tests are carried out in a practice room and there are no time limits imposed.

This is an ongoing investigation. To date six professional musicians have taken part in the tests with the results tabulated in Tables 1-4. It should be noted that some of the players had difficulty ranking the post horns. Although there were times when they felt certain instruments to be noticeably different, the players often only perceived slight, if any, differences between them.

RESISTANCE

	LEAST → MOST
Player A	Gold, Yellow, NS, Red, Copper
Player B	Red , Gold, Yellow, Copper/ NS
Player C	Red, NS, Yellow, Gold , Copper
Player D	Gold, Red, Copper, Yellow, NS
Player E	Gold / Red, Copper , Yellow, NS
Player F	Gold, Copper, Red, NS, Yellow

Table 1: Resistance rankings for the five instruments

RESPONSIVENESS

	LEAST → MOST
Player A	Yellow, Copper, Gold, Red / NS
Player B	Yellow, Copper, Gold, Red, NS
Player C	Copper, Gold, NS, Red, Yellow
Player D	Yellow, Copper, NS, Red, Gold
Player E	Red, Gold, Copper, Yellow, NS
Player F	NS / Gold / Red, Yellow, Copper

Table 2: Responsiveness rankings for the five instruments

SOUND QUALITY

	WORST → BEST
Player A	Yellow, NS, Red, Copper, Gold
Player B	Gold, NS, Yellow, Copper, Red
Player C	Gold, Red, NS, Yellow, Copper
Player D	Yellow, NS, Gold, Copper, Red
Player E	Gold / Copper, Yellow, NS / Red
Player F	Copper, Yellow, Gold, Red, NS

Table 3: Sound quality rankings for the five instruments

OVERALL PREFERENCE

	WORST → BEST
Player A	Yellow, Copper / Red, Gold / NS
Player B	Copper, NS, Gold, Yellow, Red
Player C	Yellow, NS, Red, Gold, Copper
Player D	NS, Gold, Yellow, Red, Copper
Player E	Gold / NS / Red , Yellow, Copper
Player F	Gold, Copper, Yellow, Red, NS

Table 4: Overall preference rankings for the five instruments

At present, the sample is too small to enable any definite conclusions to be drawn. Further playing tests will allow a more rigorous statistical analysis to be performed. However, some interesting potential trends already appear to be emerging. These are more readily observed by assigning numbers from -2 to +2 (with -2 representing the least or worst and 2 representing the most or best) to the rankings shown in the tables. For example, Player A's judgements of the resistance to blowing of the five post horns would result in scores of gold brass = -2, yellow brass = -1, nickel silver = 0, red brass = +1, and copper = +2. Where a player couldn't judge any difference between two or more of the instruments, that group of instruments has been treated as a single item in the ranking list. When assigning the numbers in such cases, it was decided to maintain the numerical separation of 1 between the items and keep the listing centred around 0. For example, Player E's judgements of the resistance of the post horns would result in scores of gold brass = -1, red brass = -1, copper = 0, yellow brass = 0, and nickel silver = +1. Average scores with standard deviations can then be calculated for the resistance, responsiveness, sound quality and overall preference of each instrument. These are shown in Table 5.

	RESISTANCE		RESPONSIVENESS		SOUND QUALITY		OVERALL PREFERENCE	
	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Copper	0.67	1.3292	-0.5	1.1832	0.33	1.5055	0.33	1.6329
Gold brass	-1.17	1.2111	0	1.1402	-0.50	1.5166	-0.33	1.2111
Nickel silver	0.83	1.1255	0.67	1.4024	0	1.2649	-0.33	1.5055
Red brass	-0.83	1.1255	0.33	1.3292	0.83	1.1690	0.5	1.0488
Yellow brass	0.5	1.0	-0.33	1.7224	-0.67	1.2111	-0.33	1.0328

Table 5: Average scores with standard deviations for the resistance, responsiveness, sound quality and overall preference of each instrument

As far as resistance to blowing is concerned, Table 1 appears to indicate that the players generally found the gold brass and red brass post horns less resistive with the copper, nickel silver and the yellow brass instruments more resistive. This is borne out by the average scores shown in Table 5. This result is of particular interest as a variation in resistance to blowing would usually be attributed to variations in bore profile rather than material of manufacture. It is also worth noting that the resistance to blowing criterion exhibits the largest range of average scores (from -1.17 to +0.83) and generally smaller standard deviations than found for the other criteria. This is most likely a result of the less subjective nature of the criterion.

Table 2 appears to indicate the players generally found the copper post horn to be less responsive with the red brass and nickel silver instruments more responsive. Again, this is reflected in the average scores of Table 5. Interestingly, the yellow brass post horn appears to have provoked mixed reactions, with three players rating it the least responsive instrument and the other three players rating it either the first or second most responsive instrument.

The players' judgements of the sound qualities of the instruments are shown in Tables 3 and 5. It appears that in general the players preferred the sound produced by the red brass and copper post horns whereas they felt the yellow brass and gold brass post horns had a poorer sound quality. Some of the terms that the players used to describe the sound qualities of the instruments included, for the gold brass post horn, "harsh" and, for the copper post horn, "nice and bright" and "fuller sound". Further insights into the relative sound qualities of the five post horns are anticipated from the listening tests described in the next subsection.

As musicians have differing requirements when choosing an instrument it was anticipated that the overall preference ranking may show the greatest variation between the players. As shown in Table 4, across the six players the red brass instrument is most favoured, a fact reflected in its higher average score and low standard deviation (Table 5). There is a large spread of preferences in Table 4 but it should be noted that three of the players ranked copper first.

One other potential trend which emerges from both Tables 3 and 4 is that players who preferred the copper post horn (in terms of its sound quality or overall characteristics) were less likely to favour the nickel silver and vice versa. It is worth reporting that one player actually described the copper as producing more of a "trumpet-like" sound and the nickel silver as producing a more "cornet-like" tone.

As a final comment on Tables 3 and 4, it can be seen that Player F rated the nickel silver instrument highly for both its sound quality and overall characteristics, which was somewhat out of step with the rankings of most of the other players. Anecdotally, his musical director did actually mention that this player does have a preference for, and always plays upon, "silver" instruments.

3.2 Listening Tests

To ascertain whether any variations in tone can be perceived, a listening test has been devised using recordings from the five instruments. Three sets of recordings were made of the same note, one using a professional trumpet player in a regular room environment, the others using the artificial mouth in the anechoic chamber. The artificial mouth recordings were taken at two different locations, 0.5 m from the post horn flare and 0.1 m from the mouthpiece (representing the player position).

Using headphones, listeners compare sample pairs of notes from the five instruments (initially using recordings made 0.5 m from the post horn flare in the anechoic chamber). After listening to representative samples, they are asked whether they perceive any difference in tone and, if so, to rate that difference and comment. The test is then repeated using the other two sets of recorded notes. This is an ongoing experiment the results from which will be disseminated when sufficient samples have been taken for a significant result.

4 CONCLUSION

When a lip-reed instrument is blown, vibrations are excited in the walls of the instrument. The amplitude of these wall vibrations correlates with the structural response of the instrument at the frequencies present in the played note. As the structural response of an instrument depends on the material from which it is manufactured, the strength of the wall vibrations also depends to a certain extent on the construction material.

To assess any potential influence of these vibrations on the playing properties of the instrument, a series of psychoacoustical tests are underway to investigate whether players and listeners can discern differences between the musical qualities of five post horns made from different materials. Although the five instruments were manufactured to be as identical as possible, initial player tests indicate that there is a perceived variation in the playing characteristics of the different post horns.

Once the playing and listening tests have been completed and fully analysed, an attempt will be made to correlate the psychoacoustical data acquired with the differences in wall vibration amplitude observed between the instruments.

6 REFERENCES

1. J.M. Bowsher and P.S. Watkinson, 'Manufacturers' opinions about brass instruments', Brass Bulletin, Vol. 38. No.2. pp. 25-30. (1982).
2. F.R. Morral, 'Metals and alloys in musical instruments', CIM Bulletin, Vol. 79. No. 889. pp. 86-89. (1986).
3. R.W. Pyle Jr, 'The effect of wall materials on the timbre of brass instruments', Proceedings of the Acoustical Society of America, JASA, Vol. 103. pp. 753-754. (1998).
4. R. Smith, 'The effect of material in brass instruments; A review', Proceedings of the Institute of Acoustics, Vol. 3. No. 1. pp. 91-97, (1986).
5. J.W. Whitehouse, 'A study of the wall vibrations excited during the playing of lip-reed instruments', PhD Thesis, The Open University. (2003).
6. J.W. Whitehouse, D.B. Sharp and T.J.W. Hill, 'Wall vibrations in musical wind instruments'. Acoustics Bulletin (Institute of Acoustics), Technical Contribution, Vol. 28 No. 4 (July/August 2003).