Investigating perceptual differences between two trumpets of the same model type

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Abstract

Two mass-produced trumpets of the same model type have been shown to exhibit significant acoustical differences [6] due to the presence of a tiny leak in the bore of one of the two instruments. In this paper, psychophysical experiments are presented which demonstrate that these acoustical differences do not necessarily result in perceptible differences in the playing characteristics of the two trumpets. In particular, during a listening test, very few musicians discriminate successfully between sounds produced by each trumpet. Similarly, only a small number of trumpet players successfully distinguish between the instruments when subjected to a playing test, although those that do are shown to be able to provide distinct and consistent quality assessments for each one.

1 Introduction

Producing musical instruments in a consistent manner is a crucial aim for large-scale instrument manufacturers. Any physical differences between instruments will most likely lead to differences in their acoustical properties which, in turn, may result in perceptible differences in their playing characteristics. While this may be a desirable situation for makers of hand-crafted bespoke instruments, manufacturers concerned with the mass-production of instruments generally prefer their products to behave in an essentially identical manner.

It is not always clear what effect a physical disparity might have on the playing characteristics of an instrument. Small physical differences between instruments can result in large perceptible differences in their playing properties. Conversely, large physical differences may be perceived by musicians as having little impact on the playing properties of the instruments. Any study of the consistency with which musical instruments are made therefore needs to examine not only physical and acoustical differences but also perceptual differences.

For a set of brass instruments, any differences between the internal geometries of the instruments will cause their resonance properties to vary and may result in musicians perceiving differences in how the instruments play or sound [1, 12, 13, 11]. In a previous paper, [6] measured the resonance properties of two mass-produced, low cost B♭ trumpets of the same model type (Pearl River MK003). They showed that the two trumpets were extremely similar, both physically and acoustically, for all fingerings in which the third valve was pressed down. However, for those fingerings in which the third valve was not pressed down, the two trumpets were shown to have quite different resonance properties. An example of this behaviour can be seen in Figure 1 (taken from [6]) which shows input impedance magnitude curves for the two trumpets with (a) just the third valve pressed down and (b) no valves pressed down. For clarity, the envelopes of the curves are also plotted. In Figure 1(a) the two impedance curves are very similar. However, in Figure 1(b), much larger differences can be observed between the two curves. These differences in the resonance properties of the instruments were identified as being primarily due to one of the trumpets having a tiny hole in the wall of the lower channel of the third valve (this channel forms part of the bore of the instrument when the valve is in the unpressed position). A small-scale playing test showed that a semi-professional musician was able to consistently discriminate the two trumpets.

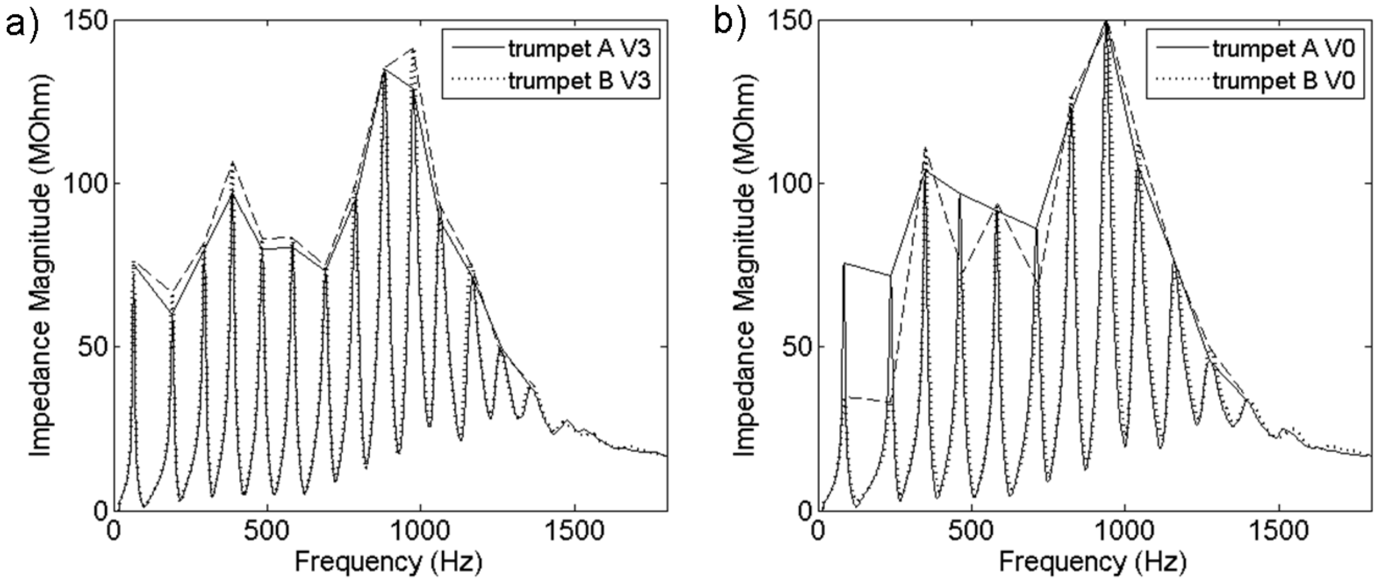

Figure 1: Input impedance magnitude curves and envelopes for two Pearl River MK003 trumpets with (a) the third valve pressed down (i.e. V3) and (b) no valves pressed down (i.e. V0)

In this paper, much more extensive psychophysical testing involving the two trumpets is reported, following the methods described in [7]. Listening tests are undertaken to examine the ability of a group of musicians to discriminate between notes produced by the two trumpets. Further playing tests are implemented in order to establish whether the differences in playing properties are perceptible by a large number of trumpeters and whether the ability to distinguish between the instruments is related to the standard of the player. In addition, the subjective evaluations and preferences of the players are gathered and analysed.

2 Listening tests

A series of listening tests was carried out to investigate the abilities of musically trained subjects to discriminate between recordings of notes played on the two Pearl River trumpets. For convenience, from now on the trumpet without the leak will be referred to as trumpet A while the trumpet containing the leak will be referred to as trumpet B.

2.1 Preparation of stimuli

Recordings of notes produced on the two trumpets were made in an anechoic chamber under constant temperature conditions. Although this is not the usual listening environment for a musical instrument, it ensures there is no colouration of the sound from the room itself. A cardioid microphone (AudioTechnica AT4033) was placed in line with the axis of the instrument under test at a distance of 30 cm from its bell. The microphone was connected to a preamplifier (M-audio Profire 610 24-bit sound card) which in turn was connected to a computer equipped with the software recording package, Logic Audio.

An artificial mouth, rather than a human player, was used to blow the instruments. Artificial mouths enable brass instruments to be played in a reproducible manner [3] and can aid the detection of any acoustical differences between instruments [8]. They are particularly useful when constructing listening tests, as they allow single tones to be steadily sounded over long periods [14]. Comparison of the results of listening tests based on sounds produced either by trumpet players or by an artificial mouth shows that the latter source of excitation is more consistent and reliable [11].

Four different note pitches[1] were chosen for use in the listening tests: G4 and C5 (which are played with no valves pressed down), and E4 and A4 (played, for the purposes of these tests, with valve three pressed down). These notes represent both the situation where the resonance properties of the two trumpets differ significantly and the situation where the resonance characteristics are in close agreement.

With trumpet A coupled to the mouthpiece of the artificial mouth, the lips of the mouth were adjusted until a stable note of pitch G4 was achieved. Using a sampling frequency of 44100 Hz, a recording of the note was made. Trumpet A was then removed from the artificial mouth and trumpet B was attached. Provided that the note remained stable, a further recording was made. Following this, trumpet B was uncoupled from the mouth and trumpet A was reattached. Again, provided the note remained stable, one more recording was made. This procedure was then repeated for the other three note pitches (E4, A4 and C5) selected for use in the listening tests.

Steady-state sections of length 1.6 seconds were selected from each recording and processed to produce a 40 ms fade-in/fade-out at the start/end of the selected portion. The sounds were then organised into pairs of the same pitch, produced using either the same trumpet (trumpet A) or using different trumpets (trumpets A and B).

These note pairs were then used to construct the listening test. Pairs of notes produced using the same trumpet (control pairs) were included in the test in order to verify that the artificial mouth had produced notes in a reproducible manner. Pairs of notes produced using different trumpets (comparison pairs) were included to investigate the listeners' abilities to consistently distinguish between sounds produced by the two instruments. For each of the four pitches, ten repetitions of the comparison pair were used as well as one repetition of the control pair. In total, therefore, the listening test comprised forty four note pairs.

It is worth noting the lack of starting and ending transients in the sounds selected for use in the listening test. Although transients can play an important role in how sounds are perceived, their absence here is an unavoidable consequence of using an artificial mouth to blow the trumpets. While using an artificial blowing device of this type provides the required level of reproducibility in terms of the excitation of the instruments, such devices are not yet sophisticated enough to accurately mimic the intricacies of tonguing or note onsets in general.

[1] The B♭ trumpet is a transposing instrument. When it plays a note that is written at a particular pitch on a musical score, it actually produces a note that sounds a tone lower. All the pitches referred to in this paper are written pitches.

2.2 Design and procedure

Forty musicians (including fifteen trumpet players) took part in the listening tests (see Table 1). The participants were all volunteers and received no payment for their input.

Sample	Trumpet players	Non trumpet players	All
Male	11	20	31
Female	4	5	9
All	**15**	**25**	**40**

Table 1: Listening test participants

The listening test involved subjects making judgements on forty four note pairs played in a random order over a pair of AKG K240 MK II headphones. It took the form of a triangular test. For each of the forty four note pairs, each subject was presented with the pair of notes and with a benchmark sound (which was a replication of one of the notes in the pair). They were then asked to identify which note the benchmark sound corresponded to. In the situation where a subject was unable to decide which note corresponded to the benchmark sound, they were instructed to select a sound randomly. The volume was adjusted to give a comfortable listening level and, for a given note pair, the sounds could be listened to as many times as wished and in the order desired.

2.3 Results and discussion

2.3.1 Artificial mouth consistency

It is important to be sure that any differences perceived by subjects during the listening tests were due to variations between the instruments rather than any inconsistency with which the artificial mouth produced the notes. To ensure that this was the case, control pairs were included in the listening test for each of the four note pitches investigated.

Assuming the artificial mouth had behaved in a consistent manner during the recording of the notes, a listener should have been unable to identify which of the notes of a control pair corresponded to the benchmark sound. That is, a correct identification should have only occurred by chance. To test this hypothesis, the responses of the 40 listeners to each of the four control pairs are compared with the binomial probability distribution. According to this distribution, for a given trial in the listening test, the probability of at least 26 subjects answering correctly by chance is 4.03%. This provides strong evidence that, if there are 26 or more successes in a control pair trial, the notes making up that control pair have discernibly different sounds; i.e. the artificial mouth did not behave consistently when playing those notes. This was the case for both the E4 and G4 note pitches (26 and 30 correct answers respectively). However, for the A4 and C5 note pitches (23 and 25 correct answers), the listening test results indicate that, at the 5% significance level, the artificial mouth did behave consistently when producing the notes.

Further evidence regarding the artificial mouth's behaviour can be seen in Figure 2, which shows frequency spectra for the four control pairs of notes. Figures 2(a) and 2(b) show frequency spectra for the E4 and G4 control pairs respectively. It is clear that, although the envelopes of the two notes that make up each pair are very similar, there are small differences. These differences are put in context by observing Figures 2(c) and 2(d) which show frequency spectra for the A4 and C5 control pairs. In these figures, the envelopes of the two notes that make up each pair are virtually identical. These observations are confirmed by Figure 3, which plots the magnitude of the differences between the spectral envelopes of the two notes for each of the four control pairs. It is clear that the differences are much greater for the E4 and G4 control pairs (with maximum values of 2.1 dB and 3.8 dB respectively) than for the A4 and C5 control pairs (with maximum values of 0.7 dB and 0.5 dB respectively). It should be noted that a gap has been left in the envelopes plotted in Figure 2(a) to reflect the fact that the partials drop below the background noise level in this frequency range (as a consequence, there is also a gap in Figure 3(a) over this range).

Both the listening test results and the frequency spectra for the control pairs indicate that the artificial mouth did not behave consistently when producing the E4 and G4 note pitches. As a consequence, in the analysis given in the following sections, only the listening test results for A4 and C5 are considered. As C5 is played with no valves pressed down while A4 is played with valve three pressed down, the situation where the resonance properties of the two trumpets differ significantly and the situation where the resonance characteristics are in close agreement are still both represented.

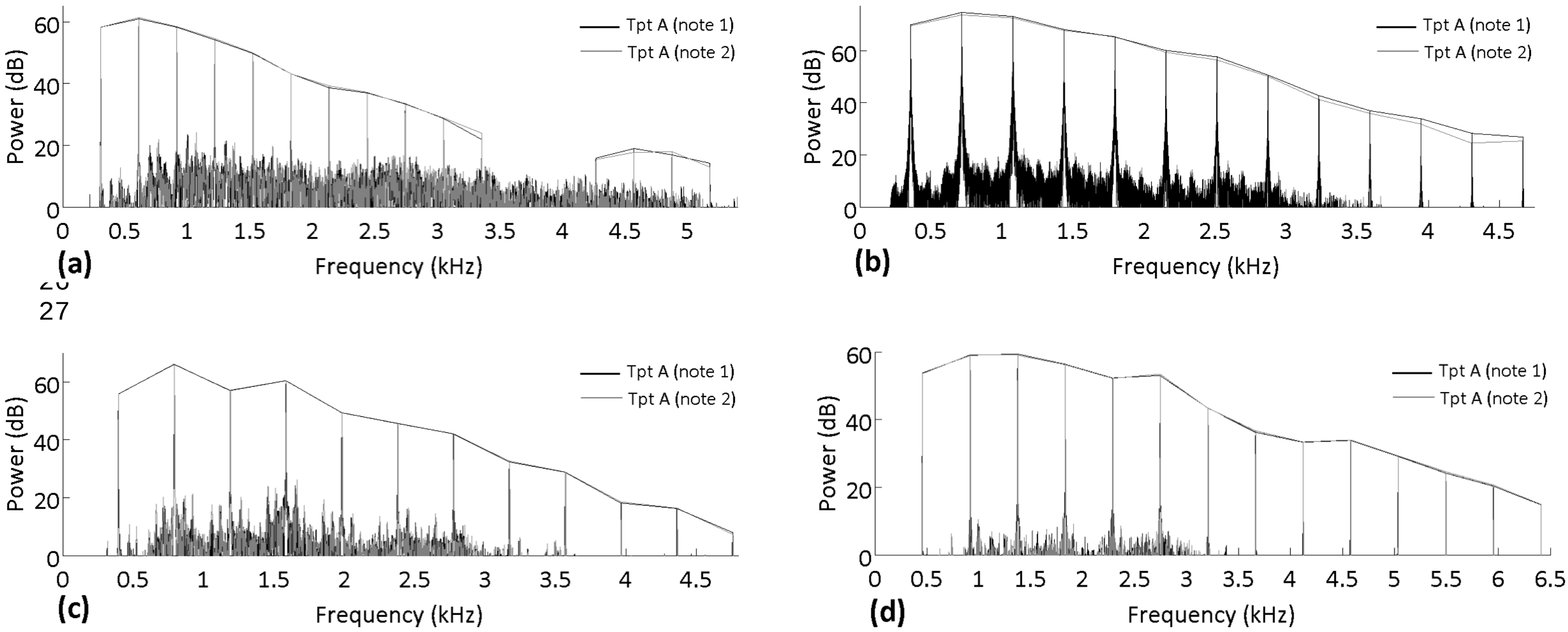

Figure 2: Frequency spectra of control pairs of notes at pitches (a) E4, (b) G4, (c) A4 and (d) C5

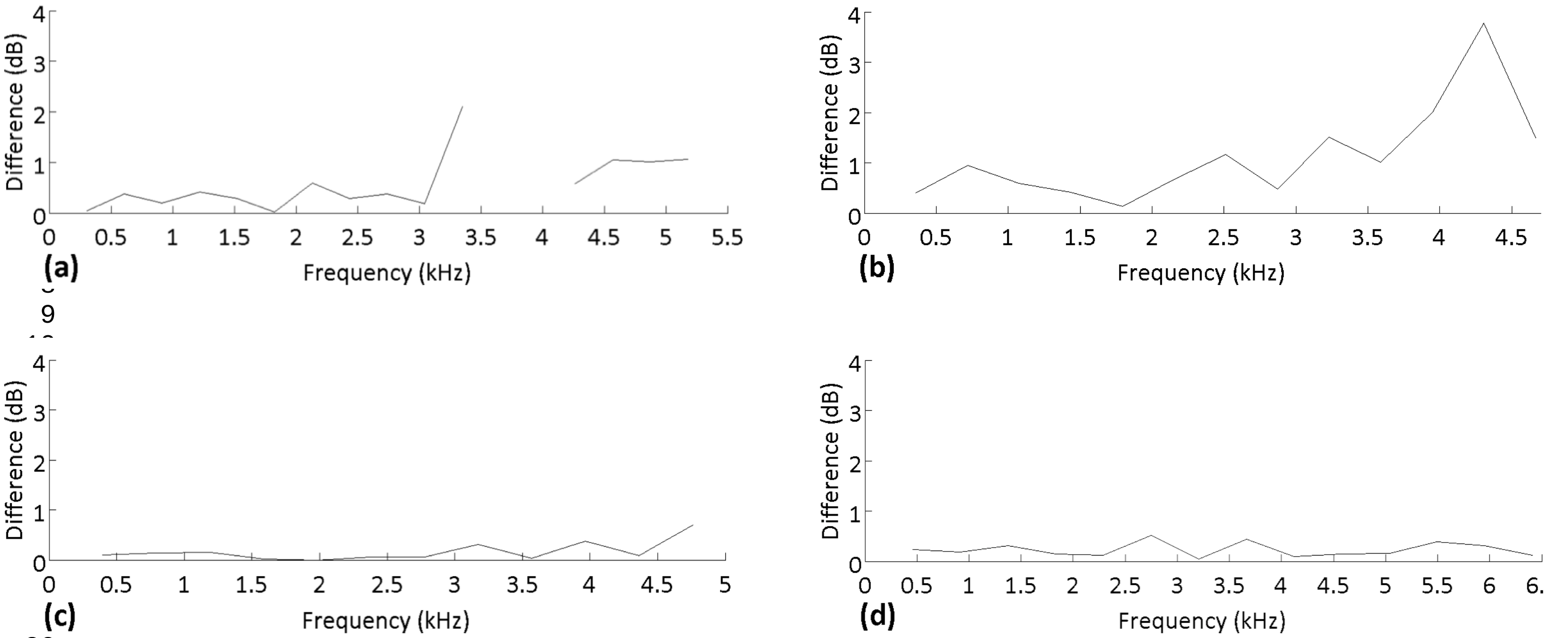

Figure 3: Magnitude of differences between the spectral envelopes of the two notes for the control pairs at pitches (a) E4, (b) G4, (c) A4 and (d) C5

2.3.2 Analysis of results

In the listening test, each subject was played 10 repetitions of the comparison pair for each of the four pitches under investigation. For two of these pitches (E4 and G4), there were doubts over whether the artificial mouth had been behaving consistently. However, for the other two pitches (A4 and C5) the artificial mouth was deemed to have produced the notes in a consistent manner. Therefore, at these pitches, any differences perceived by the listeners must have been due to differences between the two trumpets.

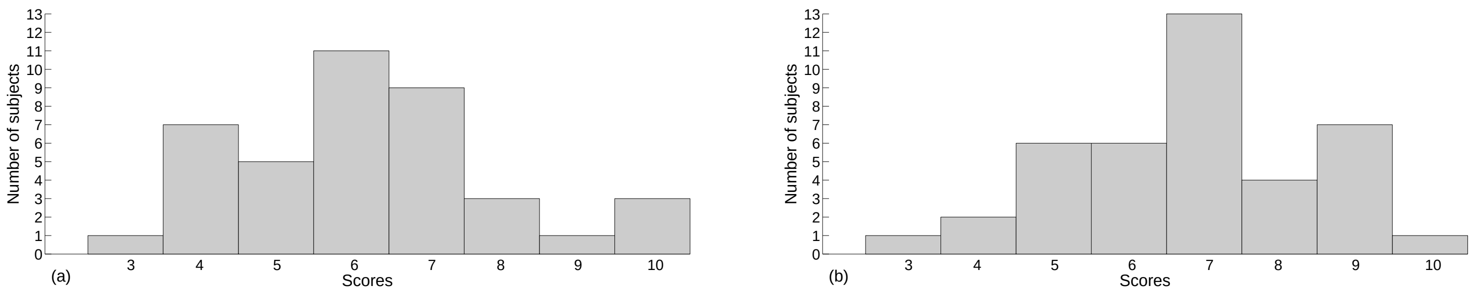

Figure 4: Histograms of the listening test scores achieved by the 40 participants for (a) the A4 comparison pair and (b) the C5 comparison pair

According to the binomial probability distribution, the probability of an individual achieving at least 9 correct answers by chance over the 10 trials is only 1.07%. It can therefore be concluded that, at a significance level of just over 1%, a subject is able to discriminate the sounds if they get 9 or 10 successes for a given note pitch.

Figure 4 provides histograms of the scores achieved by the 40 listeners for the A4 and C5 comparison pairs. Examining the figure reveals that 8 of the 40 subjects (including 2 trumpet players) were able to discriminate the two notes that made up the C5 comparison pair (i.e. they correctly identified the sound corresponding to the benchmark sound at least 9 times out of the 10 repetitions). For the A4 comparison pair, only 4 subjects (none of whom were trumpet players) were able to discriminate the two notes. Although only a small number of individuals were able to discriminate the sounds produced by the two trumpets at either of the pitches, twice as many individuals were able to discriminate the sounds of the C5 comparison pair. This reflects the fact that C5 is played with no valves pressed down. In this valve configuration the leak is present in the bore of the trumpet B, affecting its resonance properties and causing them to differ significantly from those of trumpet A.

Further evidence that the listeners found it easier to discriminate the sounds produced by the two trumpets at a pitch of C5 rather than at A4 can be found by looking across the group of 40 subjects. For the C5 comparison pair the average number of successes out of 10 was 6.83 whereas for the A4 comparison pair the average number of successes was 6.20.

It might be anticipated that a trumpeter would be more able to discriminate sounds produced by the different trumpets than a non-trumpet playing musician would. However, analysing the listening test data in more detail reveals that the average scores achieved by the trumpeters (5.47 for A4 and 6.53 for C5) were actually less than those achieved by the non-trumpet playing musicians (6.64 for A4 and 7.00 for C5). That said, the numbers of subjects in the two samples are in reality too small to enable any firm conclusions to be drawn from these values.

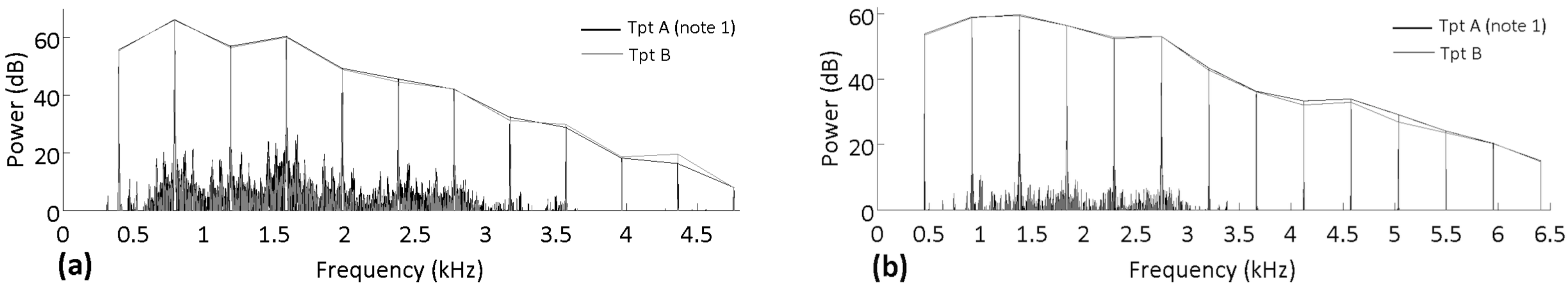

Figure 5: Frequency spectra of comparison pairs of notes at pitches (a) A4 and (b) C5

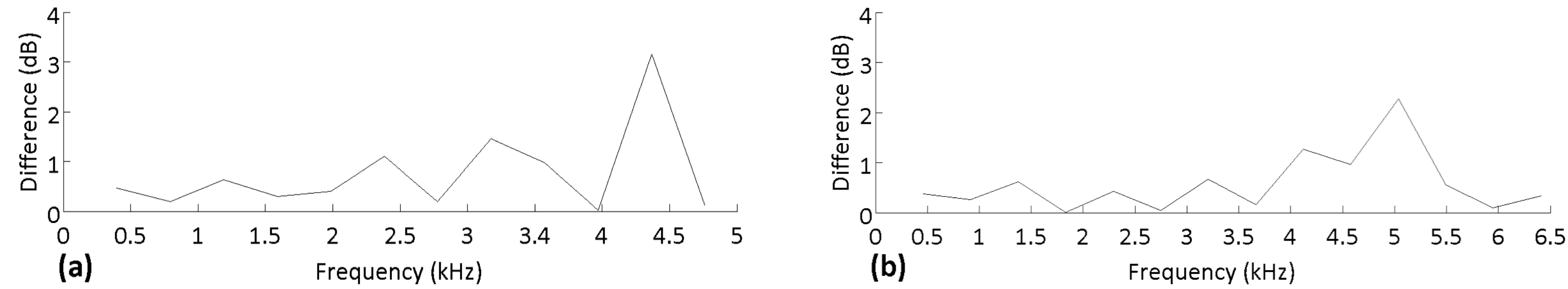

Figure 6: Magnitude of differences between the spectral envelopes of the two notes for the comparison pairs at pitches (a) A4 and (b) C5

For reference, Figures 5(a) and 5(b) show frequency spectra for the A4 and C5 comparison pairs respectively. At both pitches, small differences between the envelopes of the frequency spectra of the two notes of the comparison pair can be observed. The magnitudes of these differences are plotted in Figures 6(a) and 6(b). Although small (with maximum values of 3.2 dB and 2.3 dB respectively), they are clearly greater than any differences in the corresponding control pairs (see

Figures 3(c) and 3(d)) and are the most likely reason that some listening test participants were able to consistently discriminate the sounds.

3 Playing tests

Playing tests are generally used to collect musicians' opinions on the playing characteristics and tonal qualities of instruments. The aim of such tests is usually to relate the subjective judgements of the players to the physical or acoustical properties of the instruments. For example, [2] carried out playing tests to investigate the vocabulary that musicians used when making judgements on a variety of different trumpets and then attempted to correlate the terms they used with acoustical properties. Similarly, [5] attempted to relate the perceptions of bassoonists regarding the playing properties of different crooks to differences in their geometries. Meanwhile, [9] implemented playing tests on a French horn with different mouthpieces and then tried to correlate the musicians' preferences with acoustical and geometrical properties. In all of these studies, playing tests were employed either to compare instruments (or components of instruments) produced by different makers or to compare different models of instrument (or component) produced by the same maker.

In this section, playing tests designed to compare the two Pearl River trumpets are described. These instruments are produced by the same manufacturer and are of the same model type.

3.1 Method

3.1.1 Participants

The playing tests were carried out by the fifteen trumpet players who participated in the listening tests. These trumpeters differed in their levels of expertise and experience. Two were professional players, six were students attending the trumpet performance section of the Conservatoire National Supérieur de Musique et de Danse de Paris (CNSMDP), and seven were amateur players (students attending other sections of the CNSMDP).

3.1.2 Procedure

The first stage of the tests involved evaluating the extent to which the trumpet players were able to perceive differences between the playing properties of the two Pearl River trumpets. In order to do this, each player undertook a 2-alternative forced choice (2-AFC) test [7, 4] with warm-up. The test procedure is as follows. At the start of the test, the musician is given five minutes to play the two trumpets and become familiar with them. Following this, five warm-up trials are carried out in which the trumpets are presented in a random order. By playing them both, the player attempts to determine which instrument is trumpet A and which is trumpet B. After each warm-up trial, the player is informed whether they answered correctly or not. Finally, the pair of trumpets is presented twenty further times in random order and each time the musician is again asked to judge which instrument is which. Again, after each trial, the player is informed whether their answer was correct or not. To ensure the experience is as comfortable as possible, each musician plays the two trumpets using their own mouthpiece.

In order to minimise the possibility of a player identifying the trumpets from slight variations in their appearance or small differences in the mechanical operation of their valves, each test was carried out in a darkened room and the subject was required to play the trumpets without pressing any of the valves. Apart from this restriction, at all stages of the test the musician was free to play whatever notes, and at whatever dynamic level, they chose. In fact, the requirement that the trumpets be played with no valves pressed down was beneficial as this is one of the valve configurations which maximises the acoustical differences between the instruments (as the leak is only present in the bore of trumpet B when valve three remains unpressed).

According to the binomial probability distribution, the probability of an individual achieving 16 or more correct answers by chance over the 20 trials is only 0.59%. It can therefore be concluded that, at the 1% significance level, a musician is able to consistently tell the two instruments apart if they exhibit at least 16 successes in the 2-AFC test. Those players who were able to consistently distinguish between the instruments proceeded to the second stage of the tests where their judgements on the relative qualities of the instruments were gathered. This involved each subject detailing the strategy that they used to discriminate the instruments and then filling out a closed questionnaire which uses explicit criteria to compare the trumpets with respect to their sound quality and playability. Finally, each subject was asked to state the price that they would be prepared to pay for each trumpet.

3.2 Results and discussion

3.2.1 Subjects' scores

Figure 7 shows a histogram of the scores achieved by the subjects at the first stage of the playing tests. Five subjects demonstrated the ability to discriminate the two trumpets at the 1% significance level (indeed they all correctly identified the instruments at least 19 times out of the 20 trials). One of these five players was primarily a clarinettist and had only been learning the trumpet for 6 months. However, the remaining four players were students in the trumpet performance department of the CNSMDP. It might be hypothesised, therefore, that musicians currently undergoing studies in trumpet performance are more able to discriminate between the two instruments than those that aren't currently receiving musical training. This hypothesis can be investigated by applying Fisher's exact test to the playing test data (Fisher's exact test is equivalent to the Chi-Square test but is applicable to small sample sizes). The calculated one-tail p value of 0.047 indicates that, for the fifteen players that participated in the playing test, there is a correlation at the 5% level between being able to discriminate the two instruments and being a trumpet student at the CNSMDP.

It is interesting to note that the two professional trumpeters were amongst the 10 players that were unable to discriminate the trumpets at the 1% significance level. However, they did both correctly identify the instruments correctly 14 times out of the 20 trials. They were, therefore, able to distinguish differences between the instruments at the 5% significance level.

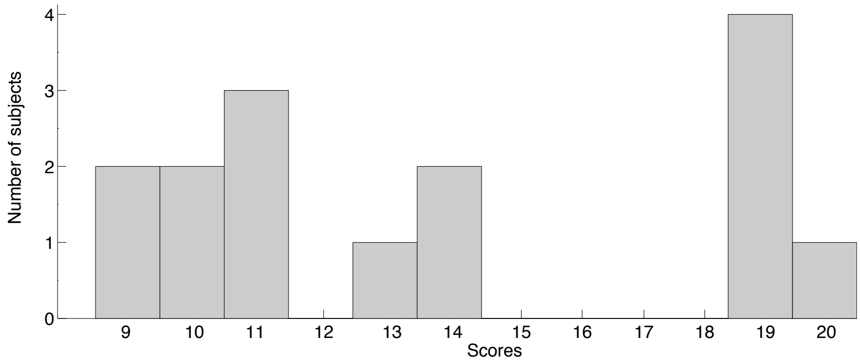

Figure 7: Histogram of the playing test scores achieved by the fifteen trumpeters

3.2.2 Quality assessment

Table 2 shows judgements on the relative playing qualities of the two trumpets made by the five players who demonstrated the ability to discriminate between the instruments. The criteria which the five trumpeters were asked to judge the instruments against were taken from the work of [10], in which the terminology used by a group of players talking freely about the musical qualities of the trumpet was studied. The criteria relate both to the playability of the instruments and the quality of the sound produced by them. For example, in terms of playability, the criteria cover how easy each instrument is to play (ease of playing), how much sound is produced for a given player input (efficiency), how easy it is to change the pitch and timbre of notes through embouchure adjustment (flexibility), how quickly each instrument responds to a change in player input (responsiveness), and how accurately each instrument produces the sound that the player wishes it to (touch). Meanwhile, in terms of sound quality, the criteria consider how well tuned each instrument is (tuning), the brightness of the timbre produced (timbre brightness), the richness of the timbre produced (timbre richness), how uniform the timbre is over the pitch range (timbre uniformity), and the fullness of the sound produced (fullness of sound). The criteria also cover the level of tactile feedback each instrument provides to the lips (centring) and how pleasant each instrument is to play (pleasant to play).

For each of the categories, the table shows whether a subject felt trumpet A fulfilled the criterion best, whether trumpet B fulfilled it best, or whether they found no difference between the two trumpets. Where a subject was unable to decide between these three choices, they are recorded as having made no judgement.

Criteria	Trumpet A	Identical	Trumpet B	No judgement
Justesse *(tuning)*	2		1,3,4,5	
Homogénéité du timbre *(timbre uniformity)*	2,3	5	1,4	
Brillance du timbre *(timbre brightness)*			1,2,3,4,5	
Richesse du timbre *(timbre richness)*	5	1	2,4	3
Rendement *(efficiency)*	3	5	1,4	2
Facilité de jeu *(ease of playing)*	2	5	1,3,4	
Toucher *(touch)*	2	1	3,4,5	
Temps de réponse *(responsiveness)*		1	2,3,4,5	
Largeur de son *(fullness of sound)*	2,3,5		1,4	
Centrage *(centring)*	5	2	1,3,4	
Flexibilité *(flexibility)*	2	5	1,3	4
Confortable à jouer *(pleasant to play)*	2	5	1,3,4	

Table 2: Subjective comparison between trumpet A and B

Examination of Table 2 reveals that, for ten of the twelve categories, the majority of the players felt that trumpet B fulfilled the criteria better than trumpet A. The views of the players were equally split for the "timbre uniformity" category and it was only with regard to the fullness of sound produced by the instrument that more players perceived trumpet A as satisfying the criterion better. It is worth noting that the views of the five players for the "ease of playing" criterion were exactly the same as their views for the "pleasant to play" criterion, suggesting a possible redundancy between these two criteria.

Looking in more detail at the judgements of the individual players, subjects 1 and 4 both felt that trumpet A did not satisfy a single criterion better than trumpet B did, while subjects 3 and 5 each thought that trumpet A only fulfilled three criteria better than trumpet B did. Somewhat at odds with these views, subject 2 thought trumpet A fulfilled seven criteria better than trumpet B did. Interestingly, subjects 1,3,4 and 5 were the CNSMDP trumpet students while subject 2 was the student whose main instrument was the clarinet and who had only been studying the trumpet for six months.

Figure 8 represents visually the subjective judgements recorded in Table 2. For each of the twelve categories of interest, it indicates the number of players that felt trumpet A better satisfied the criterion and the number that felt trumpet B did.

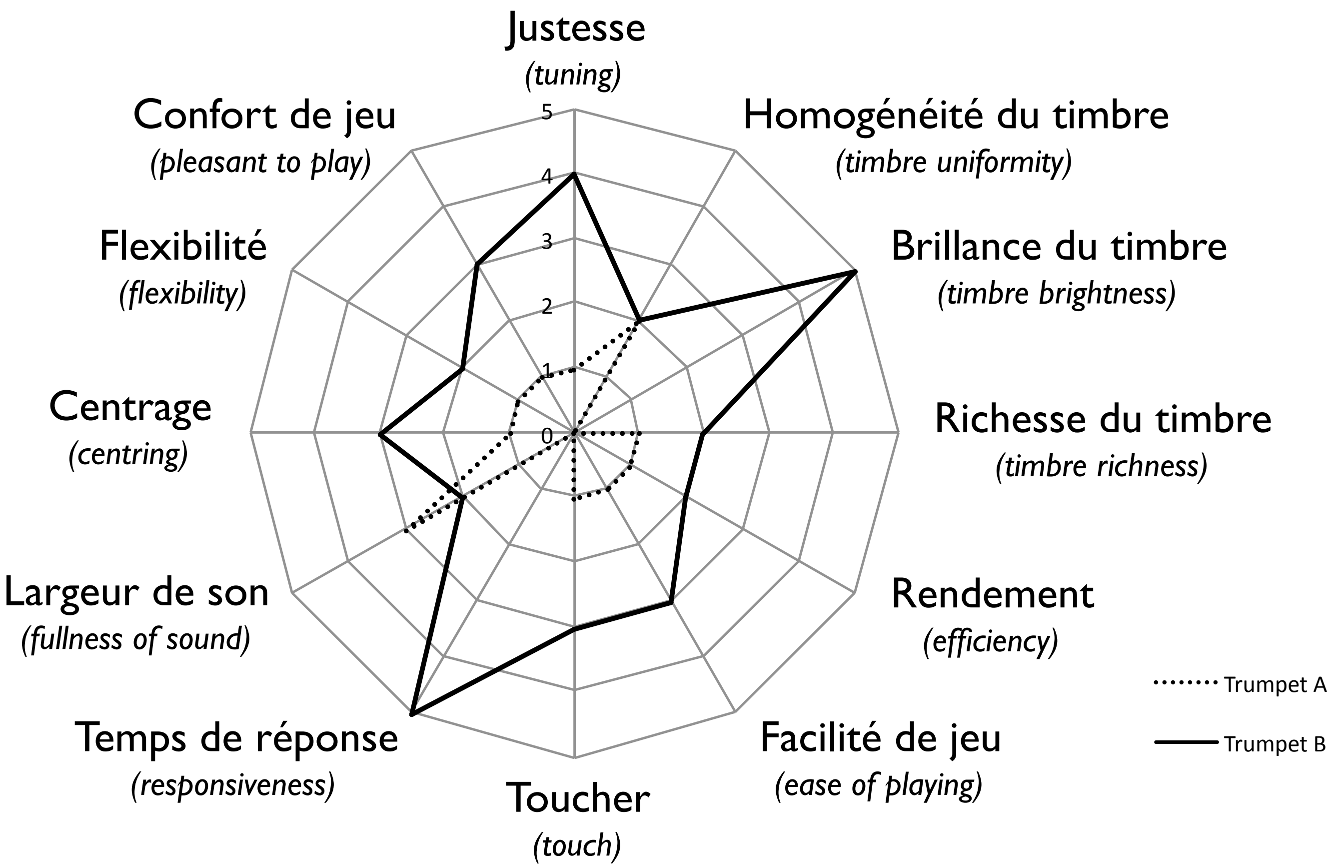

Figure 8: Multicriteria comparison of the trumpets

From the subjective judgements displayed in both Table 2 and Figure 8, it appears that the majority of the players generally preferred the playing properties of trumpet B to those of trumpet A. This is worthy of note, and is possibly somewhat surprising, given that trumpet B is the instrument which contains a leak in its bore as a result of a problem during manufacturing.

3.2.3 Willingness to pay

Table 3 reports the prices that the five subjects stated they were willing to pay for the two trumpets. These values should be considered in a relative manner as the players did not always have a good knowledge of the general cost of trumpets (notably, subject 3 said he used 1000 euros as a benchmark because he had no idea of the absolute price).

	Proposed price / euros	
Subject	Trumpet A	Trumpet B
1	300-400	500-600
2	300	240
3	800	1000
4	50	70
5	80	90

Table 3: Willingness to pay for the two trumpets

From the table, it can be seen that four of the five players indicated that they would pay more for trumpet B than for trumpet A. Only subject 2 put a higher price on trumpet B, reflecting the quality judgements displayed in Table 2 where subject 2 generally gave opposite views to the other players. Again, the fact that the majority of the players were prepared to pay more for trumpet B than for trumpet A is a little counterintuitive, given that it is trumpet B that contains the leak.

4 Conclusion

The two trumpets that were employed in this study are low-cost, mass-produced instruments of the same model type. One of the trumpets contains a leak in the lower channel of its third valve and, consequently, the resonance properties of the two instruments differ significantly under certain valve configurations. Despite the physical disparity between the trumpets, the listening and playing tests reported in this paper show that most subjects were unable to perceive differences between the two instruments, either in terms of the sounds they generate or their playability.

There were, however, a small number of individuals who were able to discriminate between the sounds of the two trumpets in the listening tests. This ability was greater for those notes produced with no valves pressed down than for those produced with valve three pressed down, reflecting the fact that the resonance properties of the two trumpets differ significantly for all fingerings where the third valve is not pressed down.

There were also some trumpet players who were able to consistently distinguish between the instruments in the playing tests. Interestingly, the trumpeters who were able to discern differences in the playing properties of the two instruments did not generally achieve good scores in the listening tests. The absence of a relationship between the outcomes of the listening and the playing tests is not necessarily surprising as different perceptive mechanisms are involved in each instance. It is also worth restating that those players who were able to differentiate between the two trumpets generally preferred the playing properties of trumpet B (and were prepared to pay more for it than trumpet A) even though this is the instrument that contains the manufacturing flaw.

From the point of view of manufacturing consistency, it is worth considering that only a third of the trumpeters who participated in the playing tests were able to consistently distinguish between the two instruments, despite the fact that one contains a leak part way along its bore. This defect therefore appears not to have been an issue for the majority of the players. Moreover, as only one amateur player was able to perceive a difference between the instruments, it could be argued that an adequate level of manufacturing consistency was achieved during the production of the trumpets, given that low-cost instruments of this type are generally aimed at beginner players rather than at professionals.

5 Acknowledgments

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