An investigation on "tonal" and "playability" qualities of eight didgeridoos, perceived by players.

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Abstract

As for many instrumentalists, didgeridoo players seem to rate the quality of the instrument according to the *tonal* qualities and the *playing* properties. Our study is carried out in a preliminary and prospective way on a serie of eight instruments chosen by the players, in a corpus of around fifty instruments, for their diversity of qualities and geometries.
The study includes an experimental procedure (tests with two players, joint authors of this study) and a geometrical and physical analysis of the instruments and emitted sounds.
Some first correlations between the geometrical and physical properties of the same instrument, the nature of the emitted sound and the quality perceived by the players will be presented or proposed.

1. Introduction

The quality we are interested in is the result of the perceptive process not from the listener but from the player – for example the process that occurs during the buy of an instrument. Sensed by different organs, the subjective expression of that quality varies according to the prefered style, the technical ability and the musical background of the instrumentalist.
The quality is usually separated into two fields.
The first one is related to the *tonal* properties whereas the second is referred to the given technical availabilities of the instrument in terms of *playability*.
The first aspect is also judged by the listener, although the signal he perceives is not identical to that of the player, notably because of different spatial position.
For the didgeridoo, tonal quality is linked to the spectrum structure of the emitted notes and the traditionally used terms to characterize them range from *muffled* up to *bright*.
The instrument capability to underline some harmonic spectrum components, which favors a more analytic than synthetic listening, is an other factor included in the judgement. That equally holds for the *spatialization* character of the emitted sounds which one can associate sometimes the semantic attribute of sound *volume*, or sound *width* or *largeness* (impression that the sound comes from everywhere).
The *playability* is linked to the sound *efficiency*, the sound *dynamics*, the *air column resistance*, the *ease of playing* but also to various aptitudes of the instrumentalist.
Among these, one finds the aptitude for *over blowing*, for raising or lowering the note (on and under pressure), for *modulations* obtained in modifying the position of the tongue, for *rythmic* effects, for *vocalization*, *cries*, etc.
We can already notice that this quality is multidimensional and that the definition of these numerous dimensions or degrees of freedom, is complex and difficult, even problematic for some of them. It is a challenge to study this subject with the player's help. Fortunately, already some articles have been written on the subject (see [1], [2] and [3]).

2. Geometrical data of instruments

The eight selected *very good* didgeridoos from a corpus of around fifty instruments, are shown together in Fig. 1 with a reference PVC tube.

Figure 1: The selected instruments.

The pitches of these instruments start from $A_1^{\#}$ + 50 cents (60 Hz) to F_2 + 15 cents (88 Hz). The pitch is not a simple function of the length as is usually the case and it can happen that for two instruments, the lowest in pitch is not the longest.

Basic geometrical characteristics :

- Lengths : from 1.1 m to 1.633 m.
- Input diameters : 28 mm to 30 mm. They are rather constant, as a rim of beewax is added by the player for confort in blowing.

- Output diameters : between 60 mm and 178 mm.
- Unlike a western wind instrument, such as the trombone for example, the internal bore varies irregularly, very often without any direct connection with the external shape.
- The internal volume varies from 1.6 litres up to 5.2 litres.

2.1. Comparisons

Internal dimensions of the bore of three didgeridoos are shown in Fig. 2. Two, numbered 3 and 8, being situated at the extreme of the range and an another one, numbered 5, in a middle distance.

2.2. Interpretation

The bore of the didgeridoo is highly irregular unlike western wind instruments, which are well described by simple forms such as conical, cylindrical or cylindro-conic. We must point out that over and above the irregularities of the wall thickness, these are sometimes numerous slight leakages of air that can be observed and felt by hand.
It is difficult to describe the didgeridoo as a single instrument, as we can do for the trombone, because the geometrical differences are so large. Therefore, we will rather talk of a family.

3. Acoustical measurements

These considerable variabilities of geometrical data can only accentuate the quality differences, that is to mean it could help us in this study.
These geometrical differences are affecting acoustical parameters, such as the resonances, the instrument's directivities or the air column resistance for example.

3.1. Input impedance measurements

In a didgeridoo, the resonance peaks are not in a harmonic relationship, unlike in a trombone. To visualize this property, it is possible to plot for each instrument, f_n / m , a sort of reduced frequency, where n represents the rank of the mode and m is an integer.
A satisfactory brass instrument must have by design a set of resonances whose frequencies are close to a complete harmonic serie. In this case, m can take the values : [1, 2, 3, 4, …] as an ideal complete cone.
For an ideal cylindrical tube, the serie would be : [1, 3, 5, 7,…].
For the didgeridoos, the nearest serie in order to obtain a good alignment varies a lot between the instruments.
For the didgeridoo 6, we find [1, 3, 4, 6, 8, 9, 11, …], while for the 2, [1, 2, 3, 4, 5, 6, 7, 9,…].
The figures 3 & 4 show the amplitudes of the input impedance peaks (linear scale). The bandwidth (quality factor) and the playing frequency are superposed.

This measure gives us as well useful informations about the *easiness* and *stability* of the drone sound (*fundamental*) but also about the easiness to obtain the overblowing *régimes*.
For didgeridoo number 6, the amplitudes of the forth through the seventh partials are too weak to reinforce the oscillations of the lips.

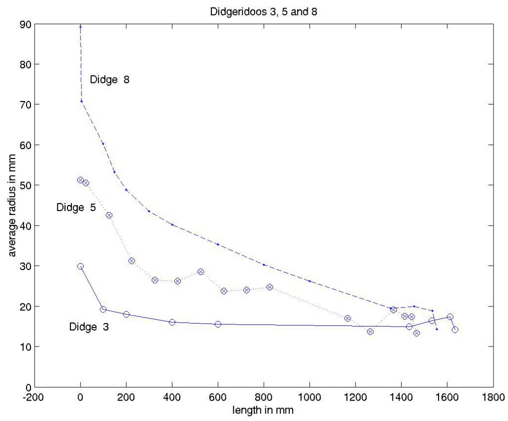


Figure 2 : Average internal radius of three didgeridoos.

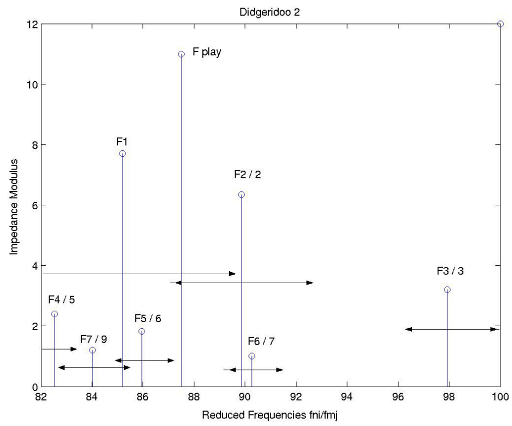


Figure 3 : Inharmonicity of didgeridoo 2.

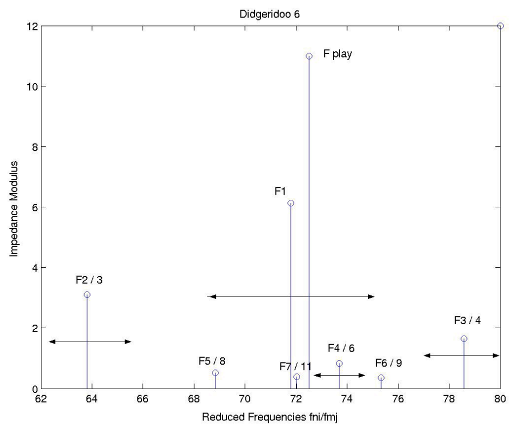


Figure 4: Inharmonicity of didgeridoo 6.

3.2. Directivity

We have already mentioned the differences of output diameters, ranging from one to threefold. This can lead, between didgeridoos *3* and *8* to a *k.a* of 0.066 and of 0.27 for the *fundamentals* (k.a is the Helmholtz number). Didgeridoo 8 will be more directive, above the tenth component for example, than that number 3. A perceptual difference will be present and will affect perhaps the spatialisation character.

3.3. Efficiency

The conversion between the pneumatic power input and the acoustical power output is different from one instrument to the other.
One first estimation of the differences made by one of the player has shown consistency in the results.
Measured at the output bell, in the axis at a distance of 30 cm, the sound levels vary between 88 dB_{lin} for the *3*, 102 dB_{lin} for the *8*, and 95 dB_{lin} for the *5*, considering a steady excitation at the inlet.

4. Tonal Quality

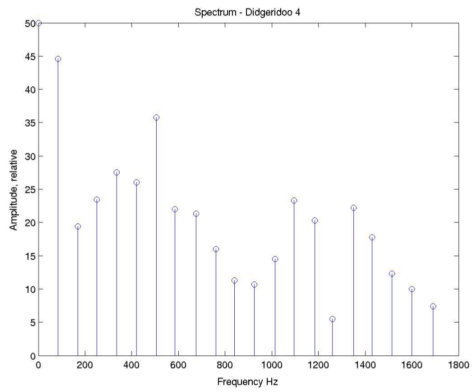
Tonal quality is linked to the spectral composition of the emitted notes as mentioned in the introduction.
We know from previous studies [3] that for the didgeridoo, the player can have influence on it by using his vocal tract in a way which is more distinctive than what can be done with the trombone for example. However, the instrument sets the limits of this influence. In this part of the study, we are merely pointing out the spectral differences linked to the possibility shared by some didgeridoos in emphasizing some spectral components, qualified by the players as quality criteria. So, in the following figures, Fig.5 and Fig.6, one can find the spectrum of the drone sound for two instruments which allow this effect (4 and 6) and two others, which do not (1 and 3). The two instruments allowing this effect have input impedances much weaker than the two others, permitting a greater influence from the vocal tract.

5. Air column resistance (RCA)

This quality is linked to the possibility of playing the drone sound. One instrument with a high RCA allows to maintain for a long time this note without any new breathing. For example, the didgeridoo *2* has a RCA judged high and been noted 7/10 during the tests. The drone sound can be played 21 seconds with a single breath, whereas the didgeridoo *3* noted 4/10, can last only 16 seconds. One of the consequences of a high RCA for the instrumentalists is the possibility to shriek for musical ornamentations without perturbing the basic vibration.

5.1. Emitted sounds quality of spatialization

This subjective criteria is actually the one whose definition given by the instrumentalists during the evaluation tests is not accurate enough. That tonal sensation appears to possess a *volumic* character (*apparent size* or *largeness*), which has been studied in the past. [4]. More recently, a study has shown that for the trumpet, *largeness* was correlated with the directivity of the instrument [5]. This criteria can be strongly affected by the room where the tests are carried. Its investigation needs a thorough study with a under control or measured acoustical space.



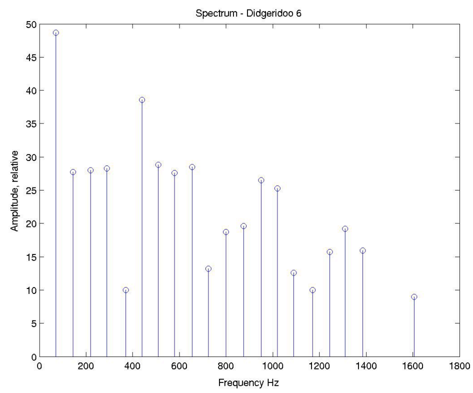


Fig. 5 : Spectrum of drone sound for didgeridoos 4 and 6.

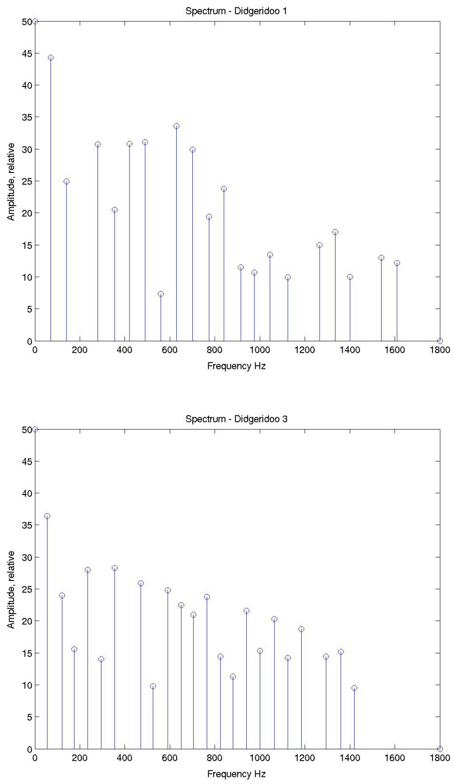


Fig. 6 : Spectrum of drone sound for didgeridoos 1 and 3.

6. Discussion – Perspectives

The first part of the study has allowed us to have a better understanding of the meaning of terms used by the instrumentalists when assessing the quality of didgeridoos.
We can establish similarities between the subjective valuation pattern used by these players and those used by the western brass players, notwithstanding the fact that there are specific ways of playing the digeridoo (circular breathing and the practice of manipulation of the vocal tract resonances), which are less or not used when playing western wind instruments. This study has also made possible to identify correlations between the subjective and objective data, allowing the explanation of the perceptual criteria with physical parameters (obtained by measurements) and to find back some previous results obtained for the trumpet [6].
In the future, we will have to confirm these correlations by setting up subjective tests and using also free verbalization methods. Multidimensional scaling techniques will allow the treatment of the data and to build a perceptive space even if when the stimuli are not any more considered as sound but as instruments played by the instrumentalist, the study becomes more difficult.
Input impedance curves (amplitudes, quality factors, frequencies and their relation) are directly connected to several quality criteria, e.g.:

- playability facility related to the drone tone.
- stability of the drone.
- aptitude for overblowing
- playing dynamics (not yet mentionned in our paper)

The helping of one air column mode at least or of a set of air column modes, to collaborate with the nonlinear excitation mechanism to maintain a steady oscillation (*régime*), will have of course an effect on the tonal quality of the emitted sound. This timbral effect is similar to that achieved by putting a mute into a trombone bell which significantly modifies the modes of the air column.
Our aim is to better understand the description of the sound emitted by the didgeridoo. It will be necessary to conduct psychoacoustical experiments in order to determine the perceptual attributes that the players use for discriminating between different didgeridoos tones.
With the purpose of studying the properties of some instruments to emphasize some spectral components of the drone, instead of restricting ourselves to the lips/didgeridoo mutual interaction, we should rather consider the whole system: the instrument, the vocal tract and the lips.
The use of an artificial mouth and vocal tract is considered for the next part of our study, which will make possible a better control by separating certain parameters (lips or vocal tract parameters).
Work is now ongoing to address a precise measurement of sound *efficiency* and *directivity*. These two qualities, with the addition of *timbral* quality are related to the notion of *largeness*, which we will study in a nearby future.

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