THE DIDJERIDU AND THE VOCAL TRACT

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Abstract: The Australian didjeridu is a deceptively simple instrument acoustically but, because it is closely coupled to the player's vocal tract without an intervening mouthpiece, a skilled player can produce a wide variety of striking musical effects. Measurements and supporting theory elucidate the roles of passive instrument acoustics, lip motion, controllable vocal tract resonances, and active vocalisation.

INTRODUCTION

The Australian didjeridu, commonly spelt 'didgeridoo' in popular writing and actually called a yidaki in the Yonglu language of the local Aboriginal people of Arnhem Land in Northern Australia where it originated, has been part of the Aboriginal culture for thousands of years. It has now penetrated modern popular culture and is widely known around the world [1] though only a little has been written about its acoustics [2]. The instrument itself consists for a wooden tube, between 1.2 and 1.5m long, made by the boring action of termites in the thin trunk of one of a variety of Eucalypt trees. After cutting and scraping, the mouth end of the tube is coated with beeswax for playing comfort and the instrument is sometimes decorated with designs reflecting the tradition or 'dreaming' of the tribe to which the maker belongs. Because of their natural origins, didjeridus have no standard bore dimensions, but the blowing end generally has an interior diameter of about 30mm and the tube at the open end about 50mm, although some instruments flare to more than 100mm diameter.

The didjeridu is played much like a Western brass instrument, except that there is no mouthpiece cup and the lips are very relaxed because of the low drone frequency, typically around 70Hz. The player uses a 'circular breathing' technique in which the mouth cavity is filled with air and closed at the soft palate to sustain the sound while a quick breath is taken in through the nose. In this way the drone sound can be sustained almost indefinitely. The breathing action adds a pulsation to the drone, and this is then enhanced by rhythmic variations in blowing pressure and vocal tract configuration.

In addition to this basic drone sound and its rhythmic pulsation, the player can sound several higher modes of the tube for occasional emphasis, can manipulate vocal tract resonances to give striking changes in sound quality, and can also add sounds with the vocal folds to imitate birds and animals or otherwise illustrate a musical story.

INSTRUMENT ACOUSTICS

Little needs to be said about the passive acoustics of the instrument itself. The bore has approximately the shape of a truncated cone, for which the input impedance is readily calculated. Because the truncation is large, the mode frequencies follow a pattern almost like 1, 3, 5, ..., except that the lowest mode, particularly, is significantly raised in frequency. The second mode therefore sounds appreciably below the pitch of the expected musical twelfth. Instruments vary from one to another, not only in the frequency pattern of higher modes but also in the damping, which is influenced primarily by the smoothness of the tube walls. The steady sound is, however, precisely harmonic [3], though transients may be influenced by the mode frequencies.

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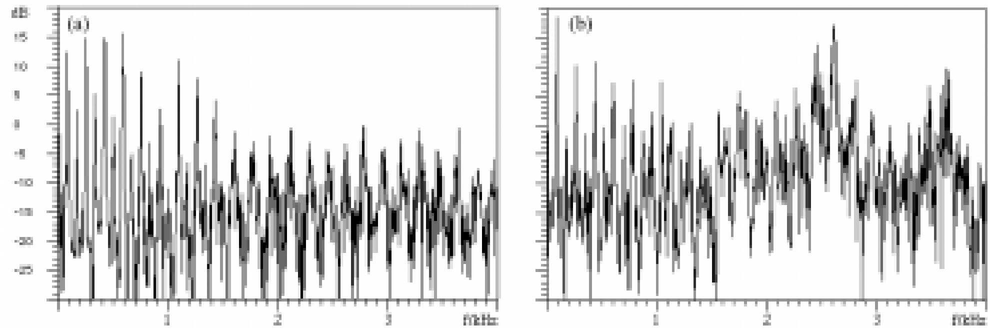

Figure 1. Spectrum of typical didjeridu drone sounds (a) the uninflected drone; (b) a nasal drone produced by raising the tongue to constrict the airway.

The other significant point to note is that the characteristic impedance of the tube, about $\rho c/S$ where ρ is the density of air, c the speed of sound, and S the area of the tube, is significantly less than that of the human vocal tract, which has a rather smaller cross-section. Since the acoustic volume flow must be continuous from mouth to instrument, this means that changes in the vocal tract configuration can have a significant influence upon the sound.

LIP MOTION AND SOUND GENERATION

While the mechanism of sound generation in the didjeridu is similar to that in ordinary brass instruments, there are significant differences. In all cases the lip motion is probably complex, and the scope of the 3-dimensional bio-modelling and aerodynamic problems involved suggests an initial approach based on simple models of lip motion. Such models use just one geometrical parameter and characterise the lips as acting like either 'outward swinging doors' or else 'sliding doors' under the combined influence of blowing pressure and acoustic pressure oscillations in the instrument tube and player's mouth.

Observations of a didjeridu player's lip motion using stroboscopy show that the lips normally spend an appreciable fraction of each cycle in a completely closed configuration. This contrasts with the behaviour of a trumpet player's lips which normally have a nearly sinusoidal motion and just touch for a very small fraction of each cycle. These observations are supported by theoretical modelling of the situation [4] which also suggests that the principal mode of motion is of the 'outward-swinging door' type. Since the pitch of the didjeridu drone is very low, this finding agrees with earlier work on the variation of lip motion across the playing range in the case of trumpeters [5].

Lip motion is significant in two ways. The natural resonance frequency of the lip vibrations must be adjusted by the player to approximate the frequency of the tube resonance being excited, but the frequencies are not exactly the same and the sounding frequency is slightly different again and depends upon the mode of lip motion [6]. More importantly in the present case, the fact that the player's lips are closed for part of each cycle enhances the harmonic content of the flow waveform and thus of the radiated sound. This enhancement, which is very much what happens with the human vocal folds in speech, allows formants in the spectral envelope to produce clearly audible effects.

VOCAL TRACT CONFIGURATION

A skilled didjeridu player can produce a wide variety of sounds from the instrument. Of particular interest are the tonal effects produced by constricting the vocal tract. An example is shown in Fig. 1, which shows first of all the sound spectrum of an uninflected drone and then the result produced by constricting the vocal tract by raising the tongue. In the second case there are pronounced 'formants' or peaks in the spectral envelope that are closely analogous to the formant peaks associated with vowel sounds in human speech. A skilled player can vary the frequencies of his vocal tract resonances over a quite wide frequency range so as to manipulate this formant structure, and can even emphasis individual harmonics of the drone after the fashion of Xoomij or 'harmonic' singing.

While a didjeridu player is keenly aware of the modifications made to the vocal tract to produce particular effects, it is not easy to decide exactly what is happening. To examine this, a skilled didjeridu player (LH) played steady sounds on the instrument using various formant effects, while being simultaneously scanned by medical magnetic resonance imaging (MRI) equipment [7]. Fig. 2(a) shows a profile image for playing with a simple uninflected drone. It can be seen that the vocal tract is 'open' and of approximately uniform width from the lips down to the vocal folds. In contrast, Fig. 2(b) shows a similar scan when the tongue position is changed to give the sound a high 'nasal' quality. In this case, the tongue has been raised to constrict the vocal tract between the lips and the soft palate, after which it resumes its normal width in the trachea. These images form the basis of an initial investigation of the effects of vocal-tract impedance and vocal tract resonances on sound quality.

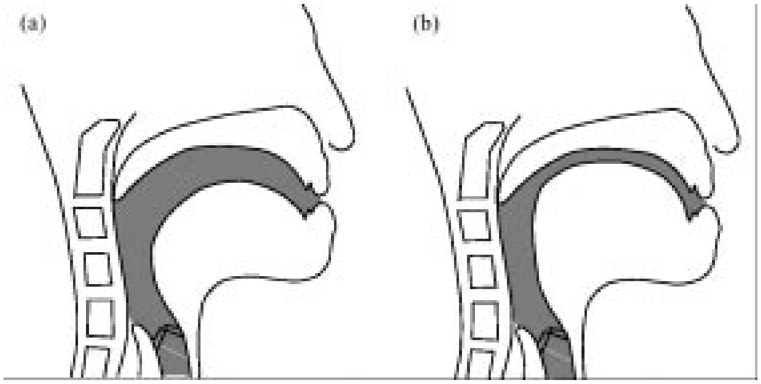

Figure 2. Sketch of vocal tract configurations during playing, as revealed by MRI imaging. (a) while playing a simple uninflected drone; (b) while producing a sound with a pronounced 'nasal' quality.

In parallel with these imaging studies, measurements were carried out of the vocal tract acoustic input impedance, as measured at the player's lips, for various playing configurations. To achieve this, a computerised system developed by two of the authors [8] was used to measure input impedance in real time by injecting a specially tailored probe signal at the player's lips. This could be done either in a simulated playing configuration, with the impedance probe blocking the lip opening or, using a similar probe inserted into the mouth near the lips, directly during the intervals in which the lips were closed during playing. Two impedance spectra, corresponding approximately to the two configurations shown in Fig. 2 are shown in Fig. 3. It can be seen that there are pronounced maxima in the vocal tract impedance, and that these maxima are in the range 1.5−2.5kHz for the constricted sound (b). They clearly have a close association with the formant structure of the sound illustrated in Fig. 1.

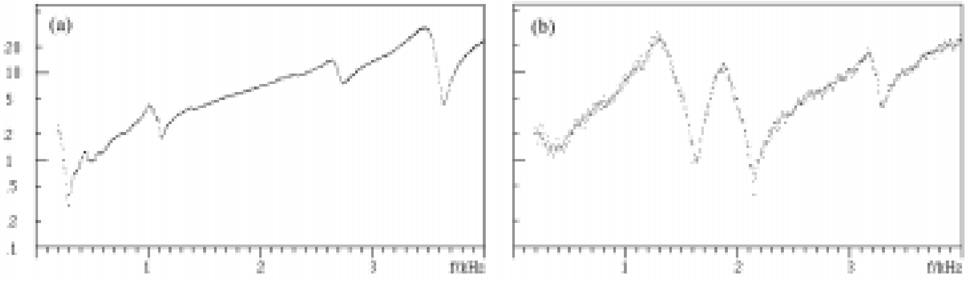

Figure 3. Input impedance of the vocal tract at the player's lips as measured (a) while playing a simple uninflected drone; (b) while producing a sound with a pronounced 'nasal' quality. The impedance units are MPa s m^{-3}.

A fully integrated theoretical model of the didjeridu system, including vocal tract and player's lips, is still under development. The measured vocal tract impedances can be explained on the basis of a model in which there is a constriction at the position of the vocal folds and a completely absorbing termination in the lungs at the end of the bronchi. The geometry of the vocal tract between these two terminations is described by the three-dimensional MRI images.

Details of the coupling between vocal tract and didjeridu air column depend upon the model adopted for lip motion, since there are phase shifts involved here. In general terms, however, theory suggests that formant resonances in the sound are associated with impedance maxima in the vocal tract impedance measured at the lips. The study is still in its early stages.

VOICED SOUNDS

In another important performance technique, the player produces voiced sounds, using vibrating vocal folds, while producing a continuous drone sound. The air flow through the glottis is thus modulated at the vocal-fold frequency f_1, and then additionally modulated at the generally lower frequency f_2 of the vibrating lips. Because the effect on the air flow is multiplicative rather than additive, this produces flow components at frequencies $f_1 \pm f_2$. Each modulation is non-sinusoidal, however, so harmonics of each fundamental are present at quite large amplitude, and the resultant sound therefore contains overtones of frequencies $mf_1 \pm nf_2$ where m and n are integers.

This technique can be used to produce a subharmonic of the normal drone at $f_2/2$, for example by singing a note a fifth $f_1 = 3f_2/2$ or a tenth $f_1 = 5f_2/2$ above the drone fundamental. More usually, rapidly changing vocal utterances are used to simulate the sounds of animals.

CONCLUSIONS

The didjeridu is a simple instrument with an astonishing range of acoustic possibilities. We are at present engaged in a project aimed at understanding some of these remarkable playing techniques.

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