

AUSTRALIAN ABORIGINAL MUSICAL INSTRUMENTS: THE DIDJERIDU, THE BULLROARER AND THE GUMLEAF

Neville H. Fletcher
neville.fletcher@anu.edu.au

Abstract

The Australian Aboriginal people developed three musical instruments – the didjeridu, the bullroarer, and the gum-leaf. Most well known is the didjeridu, a simple wooden tube blown with the lips like a trumpet, which gains its sonic flexibility from controllable resonances of the player's vocal tract. The bull-roarer is a simple wooden slat whirled in a circle on the end of a cord so that it rotates about its axis and produces a pulsating low-pitched roar. The gum-leaf, as the name suggests, is a tree leaf, held against the lips and blown so as to act as a vibrating valve. Originally intended to imitate bird-calls, the gum-leaf can also be used to play tunes.

I. Introduction

THE Australian Aboriginal people have lived in this country for more than 40,000 years with almost no contact with the outside world until the arrival of Europeans in 1788. There are more than 200 tribes, all with different languages. During their history they have developed sophisticated tools such as the woomera spear-thrower and the returning boomerang. They also developed three musical instruments, the best known being the didjeridu, often spelt "didgeridoo" and actually called a yidaki or yiraki in the Aboriginal language of the Yolngu people where it originated – there are more than 200 such languages. The other two instruments are the bull-roarer, and the gumleaf.

The didjeridu is a simple wooden tube blown with the lips like a trumpet, which gains its sonic flexibility from controllable resonances of the player's vocal tract. The bull-roarer, called by other names in Aboriginal languages, is a simple wooden slat whirled in a circle on the end of a cord so that it rotates about its axis and produces a pulsating low-pitched roar. The gum-leaf, as the name suggests, is a leaf from a Eucalypt tree, held against the lips and blown so as to act as a vibrating valve. The sounding pitch is controlled by vocal tract resonances and is typically about an octave above the female singing voice. Originally intended to imitate bird-calls, the gum-leaf can also be used to play tunes. This paper will briefly describe each of these instruments.

I. The Didjeridu

The didjeridu originated in Arnhem Land on the northern coastline of central Australia, and has some similarity to bamboo trumpets and even bronze horns developed in other cultures, though it pre-dates most of these by many millennia. The reason for its origin lies in the absence of tubular plants such as bamboo and the presence of termites ("white ants") in much of Northern Australia. The characteristic feature is that the didjeridu, which is a slightly flaring wooden tube about 1.2 to 1.5 metres in length, is simply hollowed out by natural termites from the trunk of one of the small Eucalypt trees of the region. After cutting down the tree, the maker cleans out the tube of the instrument with a stick, smooths the outside by removing the bark and scraping with a sharp stone, and then in many cases paints traditional tribal designs on it using pigments made from soil and ash mixed with resinous tree gum, giving white, red-brown and black colours. The blowing end is generally smoothed by adding a rim of beeswax. Two typical instruments are shown in Fig. 1.

The predominant sound of the didjeridu is a low-pitched drone with frequency near 70 Hz, but depending significantly upon the length of the instrument and the flare of its bore. The second mode



Figure 1. Engineering student Ben Lange, playing a didgeridu among the Eucalypt trees from which such instruments are made. Another didgeridu of different shape leans against a tree. Ben has an Aboriginal heritage.

of the tube, with frequency a little less than 1.5 times that of the fundamental because of the tube flare, is used sparingly as an accent to the sound, and the main sound variation comes from production of emphasised formant bands, the frequencies of which can be adjusted by the player over a range from about 1 kHz to 3 kHz, as shown in Fig. 2. In traditional use, the didgeridu, with clap-sticks for emphasis, accompanies songs or illustrates traditional stories about ancestors and animals [1]. Recently, however, its use has spread into the popular music domain and it has had world-wide influence [2].

The acoustics of the didgeridu tube is simple. Because of the irregular shape and general slight flare, the upper resonances (impedance maxima at the lips) are not well aligned with odd harmonics of the fundamental, and the main determinant of drone quality is the smoothness of the walls, on a sub-millimetre scale, and

the absence of cavities. The diameter of the blowing end, typically about 30–40 mm, is also important, as will be examined later.

Didjeridu players use a technique called “circular breathing” to enable them to maintain the sound without pause for a period of minutes. In this technique, once the sound has been started and the lungs are partly emptied, the player inflates his cheeks to provide air to maintain the drone and then closes his soft palate and inhales rapidly to refill his lungs. This repeated process gives an approximate rhythm to the sound with a period of several seconds, since only a plain drone can be maintained while the air supply is coming from the inflated cheeks, while for the rest of the time the player can use his tongue position and other techniques we are about to discuss to vary the sound.

The real acoustic interest comes from the techniques by which unusual sounds are made [4–8]. The prime technique is one involving adjustment of the impedance maxima of the vocal tract, as judged from the vibrating lip valve, by raising or lowering the tongue towards the hard palate while the vocal folds are partially closed to isolate the upper vocal tract from the lungs. This technique changes the shape and volume of the mouth cavity and upper vocal tract and so adjusts its resonance frequencies, the relevant ones of which lie in the range 500 to 3000 Hz. If this vocal impedance is high, then it inhibits air flow through the lips into the didjeridu tube near the resonance frequency and so reduces the intensity of radiated sound. It is then the sound components in the uninhibited bands between these impedance maxima that are prominent. Highly skilled players can add further resonances, perhaps from the nasal passages as in the “harmonic” or “xoomij” singing of Mongolia, to emphasise single harmonics of the sound.

The acoustics underlying these performance techniques has been examined using a novel acoustic impedance probe that injects a calibrated flow signal consisting of about 500 sinusoidal components

into the player's mouth during actual performance and simultaneously measures the acoustic pressure in the mouth, thus giving the impedance [7].

The main reason that these techniques are so effective in the didjeridu, compared with other lip-driven instruments, is that the diameter of the instrument bore near the lips is large compared to that of the upper vocal tract, and there is no intervening mouthpiece cup and constriction to isolate one from the other. The vocal tract resonances therefore exert a controlling influence on the sound.

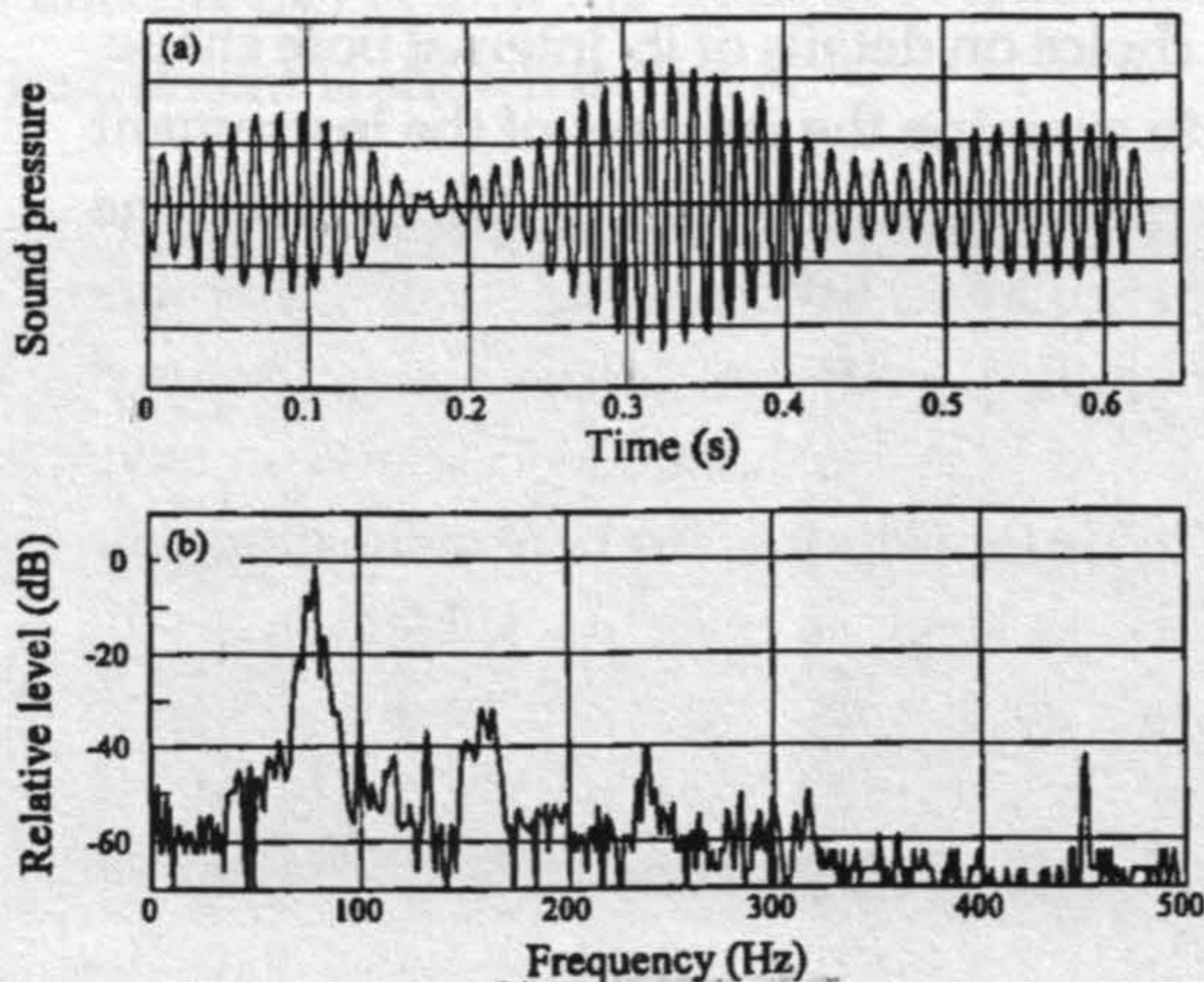


Fig. 2. Spectra of didjeridu sound. (a) an uninflected drone, and (b) a drone with two prominent formant bands near 2.5 and 3.7 kHz (From [4]). The vocal tract impedance maxima, which reduce the radiated sound, occur near 1.4 kHz, 2.2 kHz and 3.2 kHz in this case.

The other impressive contribution to didjeridu sound comes from a technique in which vocalisation occurs simultaneously with normal lip-generated drone. There are then two pressure-operated valves, the lips vibrating at frequency f_1 and the vocal folds vibrating at frequency f_2 , acting in series upon the air flow so that their modulating effects are multiplied rather than added. Because the operation of

each valve is nonlinear, since the air flow is essentially governed by a Bernoulli equation, this combines with the multiplication effect to generate multiple sum and difference frequencies $nf_1 \pm mf_2$ in the sound output [3,8]. If the player sings a note a musical tenth above the drone, so that $f_2 = (5/2)f_1$, then the sub-octave $f_1/2$ is generated, along with all its harmonics, giving a deep “growl”. In addition, the player may insert many other transient sounds to mimic the cries of native dogs or birds, with marked dramatic effect.

While a didgeridu maker can choose the tree from which the instrument is made and determine its length and location relative to the tree roots, he has little choice on details of its internal bore shape. It is therefore interesting to examine the features of the instrument that determine its quality in the view of the player [9]. Study of the opinions of a group of expert players testing a variety of didgeridus established that a major quality criterion is the acoustic input impedance, which should be very low so that the vocal tract can have as large an effect as possible. This means that the bore of the didgeridu at the mouth end should be as large as possible, subject to it still being a good fit to the player’s mouth. The generally preferred mouth diameter was about 50 mm. Players also preferred a slightly flaring shape with the open-end diameter being about 80 mm, or about 1.6 times the input diameter. The larger open end not only aids in acoustic radiation but also shifts the pipe resonances away from harmonic relationship, so that the basic drone has relatively weak upper partials, which allows the tonal variations to be more prominent. Tube length, and thus drone pitch, was not a major consideration. Perhaps surprisingly, a simple PVC pipe of appropriate diameter does not score too badly in this comparison!

I. The Bullroarer

Since there are no bull-like animals in Australia, this is a misnomer for the Aboriginal instrument, but the actual word used is “secret-sacred” and not shared with non-Aboriginal people. In addition, of

course, it varies from tribe to tribe because of their diverse languages. The instrument itself consists of a simple wooden slat, 30 to 40 cm in length and 5 to 7 cm wide that is whirled around in a circle on the end of a length of cord. The slat rotates under the influence of aerodynamic forces and generates a pulsating sound with a frequency typically around 80 Hz. This sound is an important feature of Aboriginal initiation ceremonies.

The instrument itself is by no means unique to Australia, and similar sound generators have been used by populations as diverse as those of ancient Egypt and the Inuit of Northern Canada. An Australian instrument is shown in Fig. 3.

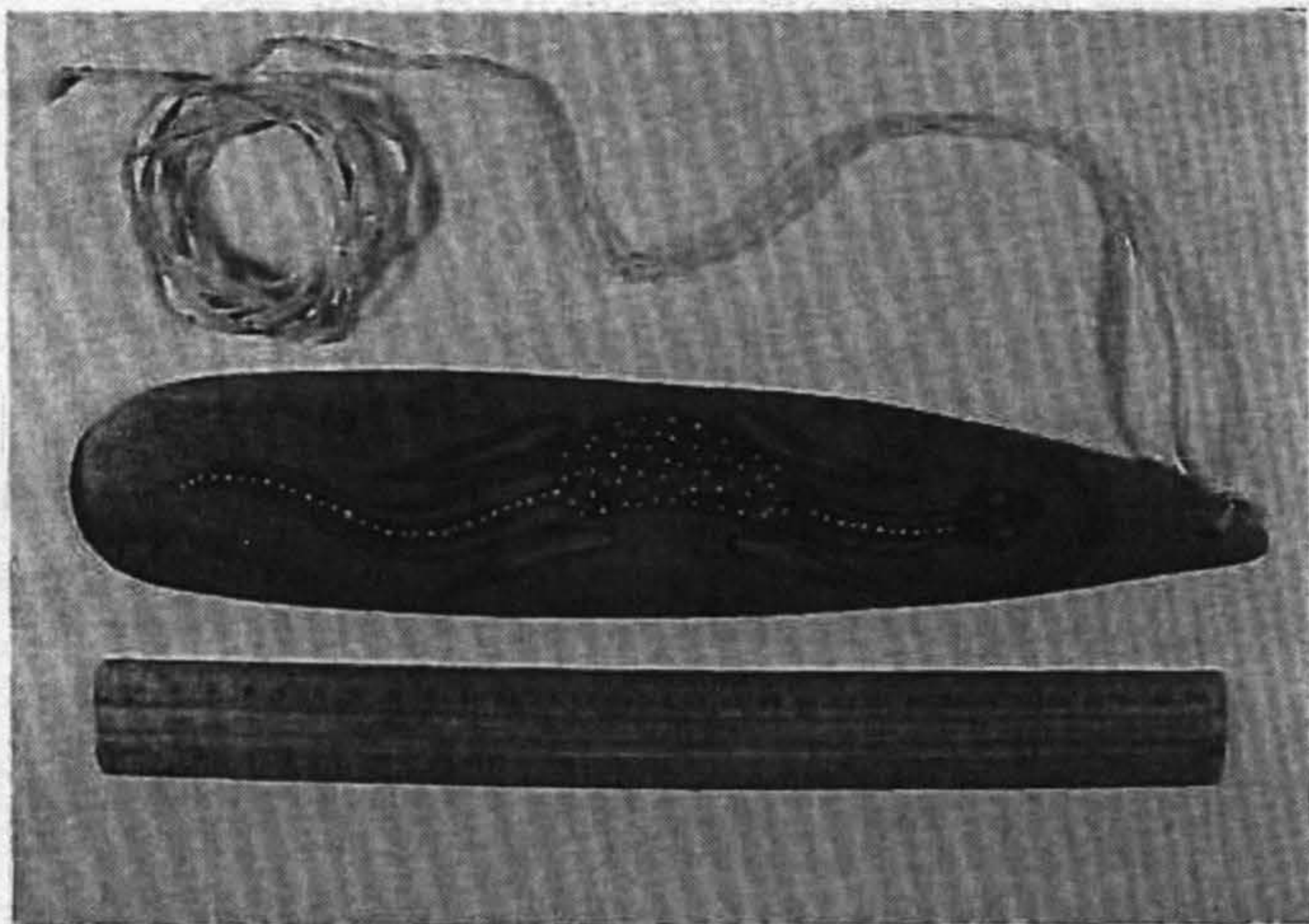


Figure 3. An Australian bullroarer. Note the decorations, which show the totemic symbol of the tribe of the maker. A 30 cm ruler is shown for comparison. (From [10])

The aerodynamics of sound generation in the bullroarer has been described in detail elsewhere [10], and only an outline will be given here. Since the quasi-static aerodynamic forces and torques on the slat balance out over a single period of its revolution, the aerodynamic

torque driving its rotation depends upon the rate of rotation itself. There is one rotation-inducing torque term that is linear in slat rotation speed, and also a drag term proportional to the square of the rotation speed. These lead to a threshold rotation rate that must be exceeded to begin the process, and then to an upper limit to the rotation rate. From experiment, the steady axial rotation frequency f of a rectangular slat of width W swung through the air on a string of length L with arm rotation frequency F can be shown to be approximately

$$f \approx 1.1 LF / W - 5.$$

Each rotation of the slat creates an oscillating flow dipole and, from considerations of symmetry, the dipole oscillation frequency, and thus the radiated sound frequency, is $2f$. The radiated acoustic power P is approximately

$$P \approx 3 (p/c^3) H^2 V^6$$

where H is the length of the slat, p is the density of air, c is the speed of sound in air, and $V=2\pi LF$ is the speed of the slat through the air. From these two equations we see that wide slats produce sound of lower frequency but that the radiated power is independent of slat width. Sound frequency is, however, proportional to airspeed and thus to arm rotation rate, and the radiated power is a strong function of this arm rate. For typical conditions, the radiated power is about a milliwatt for a slat length of 30–50 cm, a string length of about 1 m and an arm rotation rate of 120 r.p.m. ($F = 2$ Hz), which is about as fast as can normally be achieved. Sound radiation is nearly omnidirectional.

Because the output power is a strong function of airspeed V , and the arm rotation is normally faster on the down-sweep than on the up, the sound pulsates with a frequency typically between 1 and 2

Hz. There is an additional slower pulsation with a period of several seconds that derives from the fact that the slat rotation gradually twists the cord, providing a contrary torque which eventually stops the rotation and re-launches it in the opposite sense.

Analysis of the sound, as in Fig. 4, shows little harmonic development, the second-harmonic peak being about -30 dB relative to the fundamental. The peaks are, however, somewhat broadened because of the variable rotational speed of a human arm.

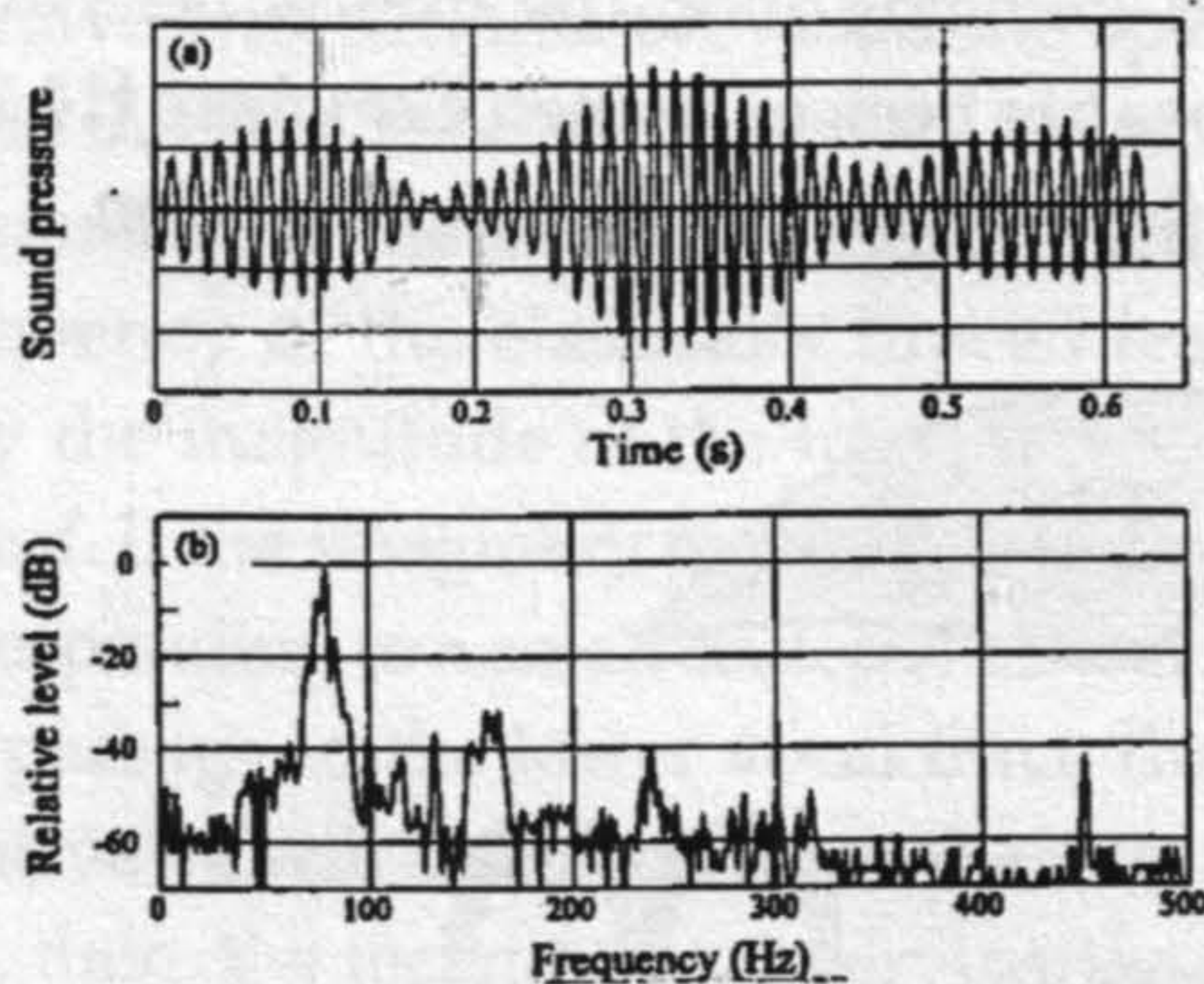


Figure 4. (a) The pressure waveform of sound from a bullroarer, showing typical pulsations. (b) Frequency analysis of this sound, showing low harmonic development. (From [10])

II. The Gumleaf

The gumleaf is altogether more primitive as a musical instrument, since it consists simply of a leaf, the shape of which is illustrated in Fig. 5(a), from one of the various species of Eucalypt trees growing throughout Australia, held against the lips using the fingers of both hands. It does, however, have a long tradition and culture [11], and has interesting aerodynamic and acoustic properties [12].

In the normal playing configuration, shown in Fig. 5(b), the leaf is held tightly against the lower lip and, in a bent shape, lightly

against the upper lip [13]. It is stretched rather tightly between the two hands. When air pressure is applied through the mouth, it tends to lift the top of the leaf away from upper lip and allow air to escape, so in this sense the valve can be described as an “outward-swinging door”, which is given the symbol (+,-), indicating the effect on the flow of applying pressure from the supply side (+) and that from the exhaust side (-). Its configuration is thus similar to that of the valve constituted by the lips of a brass-instrument player, although these are sometimes (+,+) as in a sliding door, and the opposite of the reed of a clarinet, which is (-,+), as in an inward-swinging door. The acoustic behaviour of valves of each of these types has been examined elsewhere [14,15], and this treatment provides the basis for the present discussion.

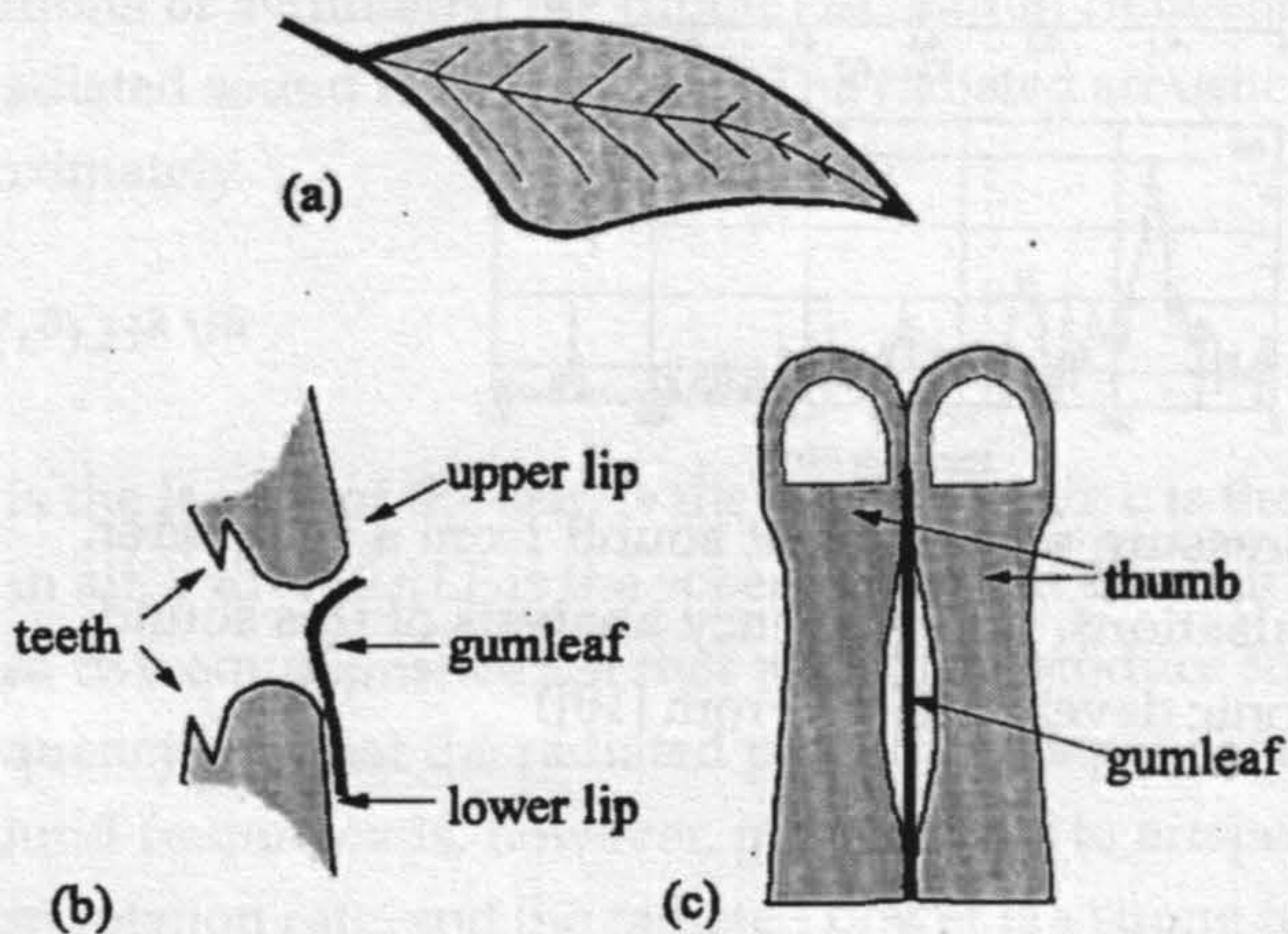


Figure 5. (a) The shape of a typical gumleaf from a Eucalypt tree. (b) In normal playing, the leaf is held firmly against the lower lip and rested lightly against the upper lip, and it is the upper edge of the leaf that vibrates. (c) A variant way of holding the leaf that results in a raucous quasi-chaotic sound.

Although it takes a good deal of trial and error for a beginner to even produce a sound from a gumleaf held as indicated in Fig. 5(b) above, a skilled player can control the pitch with good accuracy over

a range of more than an octave and play simple tunes with ease, the pitch range being typically from about 500 to 1000 Hz. Interest therefore centres on exactly how this is done.

Theory [14] and experiment [15] agree that for a valve with configuration (+,-) to oscillate, the sum of the up-stream and down-stream acoustic impedances must have a negative imaginary component. Since the downstream impedance is essentially zero in this case, this implies that the mouth and vocal tract must present a compliant (capacitive) impedance at the lips. When this condition is satisfied, the valve will oscillate provided the applied air pressure exceeds a certain threshold and the losses are not too great. The actual oscillation frequency is necessarily higher than the mechanical resonance frequency of the elastically braced leaf, and is further determined by the magnitude of the impedance presented by the mouth to the leaf. If the imaginary part of this impedance is negative and large, corresponding to a small enclosed air volume in the mouth and a narrow passage to the lower vocal tract, then the oscillation frequency of the valve will be much higher than its natural frequency. In many ways, then, the technique for varying the mouth and vocal tract when playing the gumleaf is similar to that used in whistling.

As the gumleaf valve opens and closes, so the pressure in the mouth falls and rises, with an appropriate phase delay of nearly 90° . Because the airflow through the valve is in turn proportional to its opening area and to the square root of the driving pressure, this nonlinear relationship generates harmonics of the fundamental frequency, and the sound is rich in upper partials and has an incisive quality.

There is one other way of playing the gumleaf that is also worthy of mention. In the simplest case the leaf is held horizontally so that it is simply lying parallel to the slot between the lips. As a variant, the leaf is sometimes held vertically between the sides of two opposed thumbs, as in Fig. 5(c), which are then pressed against the lips to create essentially the same configuration. The aerodynamic behaviour

is now very different, and laboratory investigations suggest that the leaf, which is essentially flat, moves backwards and forwards in the slot and, at the same time, twists about its longitudinal axis. This motion repeatedly narrows and widens the flow channel at a frequency equal to twice the mechanical oscillation frequency of the leaf and so has a similar effect on the air flow and thus on the emitted sound. In a larger-scale laboratory experiment the motion could be made simple and regular, but in most playing situations the leaf makes irregular contact with the lips or the thumbs and this upsets the motion. The resulting sound, while having a predominant pitch, is rough and quasi-chaotic. It is useful for special effects, such as imitating the cry of the native sulphur-crested cockatoo [16], but has no obvious musical value.

III. Clapsticks

As in most cultures, the Aborigines also use percussive instruments in their ceremonies. They do not appear to have developed any form of drum but they did make specially shaped sticks for this purpose. Because the wood used is a fine-grained hardwood, the clapsticks are physically durable and produce a sharp and well defined sound.

In their usual form, these sticks are about 200 mm in length and 20 mm in diameter and are shaped to a long point at each end. One stick is held in each hand by the singer and they are struck together at about the mid-point of each. The pointed ends ensure that the fundamental transverse vibration has a high frequency, so that the percussive effect stands out well against the drone of the didjeridu.

In many performances, however, special clapsticks are not used, but instead a male dancer carries two boomerangs which are clapped together to produce a rather different sound. Because of the large size of the boomerangs – 30 to 50 cm in length – they also stand out well visually in the dance.

IV. Conclusions

Ethnomusicology is a very interesting field, and it is made even more interesting when allied with a study of the acoustics of the musical instruments that were developed by the society under study. The musical instruments of the Australian Aboriginal people have come into world prominence because of the popularity of the didgeridu, both as a tourist item and as a musical instrument. It is only recently that we have begun to have an appreciation of the acoustical subtleties associated with performance on this and other ancient instruments.

Acknowledgment

The original version of this paper was presented at the Stockholm Music Acoustics Conference SMAC03 in August 2003 and subsequently published in *Acoustics Australia* 31, 51–54 (2003). The present paper has been up-dated to include more recent research. I am particularly indebted to Joe Wolfe, John Smith, and Alex Tarnopolsky from the University of New South Wales and to Lloyd Hollenberg from Melbourne University for their major contributions to our joint work on the didgeridu, which was supported by a grant from the Australian Research Council.

References

- [1] Jones, T.A., "The didgeridu" *Studies in Music* (University of Western Australia) 1, 23–55 (1967).
- [2] Neuenfeld, K. (ed.) *The Didgeridu: From Arnhem Land to Internet* (John Libbey & Co, Sydney, 1997).
- [3] Fletcher, N.H. "The didgeridu (didgeridoo)" *Acoustics Australia*, 24, 1–11 (1996).
- [4] Fletcher, N., Hollenberg, L., Smith, J., and Wolfe, J. "The didgeridu and the vocal tract" *Musical Sounds from Past Millennia, Proc. ISMA-2001, Perugia*, ed. D. Bonsi, D. Gonzales and D. Stanzial, 1 87–90, (2001).

- [5] Wolfe, J., Tarnopolsky, A.Z., Fletcher, N.H., Hollenberg, L.C.L. and Smith, J., "Some effects of the player's vocal tract and tongue on wind instrument sound" Proc. Stockholm Music Acoustics Conference, SMAC03 (KTH, Stockholm 2003).
- [6] Tarnopolsky, A., Fletcher, N., Hollenberg, L., Lange, B., Smith, J. and Wolfe, J., "The vocal tract and the sound of a didgeridoo" *Nature*, 436, 39 (2005).
- [7] Tarnopolsky, A.Z., Fletcher, N.H., Hollenberg, L.C.L., Lange, B., Smith, J. and Wolfe, J., "Vocal tract resonances and the sound of the Australian didgeridu (yidaki): I. Experiment" *J. Acoust. Soc. Am.*, 119, 1194–1204 (2006)
- [8] Fletcher, N.H., Hollenberg, L.C.L, Smith, J., Tarnopolsky, A.Z. and Wolfe, J., "Vocal tract resonances and the sound of the Australian didgeridu (yidaki): II. Theory" *J. Acoust. Soc. Am.*, 119, 1205–1213 (2006)
- [9] Smith, J., Rey, G., Dickens, P., Fletcher, N., Hollenberg, L., and Wolfe, J., "Vocal tract resonances and the sound of the Australian didgeridu (yidaki): III. Determinants of playing quality" *J. Acoust. Soc. Am.*, 121, 547–558 (2007).
- [10] Fletcher, N.H., Tarnopolsky, A.Z. and Lai, J.C.S., "Rotational aerophones" *J. Acoust. Soc. Am.*, 111, 1189–1196 (2002).
- [11] Ryan, R., 'A Spiritual Sound, A Lonely Sound': Leaf Music of Southeastern Aboriginal Australians, 1890s–1990s. PhD thesis, Monash University, Clayton, Australia, 1999.
- [12] Fletcher, N.H. and Tarnopolsky, A.Z., "The leaf-reed: the simplest woodwind instrument?" Proc. International Symposium on Musical Acoustics ISMA2004, Nara, Japan pp.116–119 (CD-ROM item 2-S1-9) ISBN 4-9980602-4-4 (2004)

- [13] Patten, H. How to Play the Gumleaf, booklet and CD (Currency Press, Strawberry Hills, NSW, Australia 1999).
- [14] Fletcher, N.H., "Autonomous vibration of simple pressure-controlled valves in gas flows" *J. Acoust. Soc. Am.*, 93, 2172–2180 (1993).
- [15] Tarnopolsky, A.Z., Fletcher, N.H. and Lai, J.C.S., "Oscillating reed valves — An experimental study" *J. Acoust. Soc. Am.*, 108, 400–406 (2000).
- [16] Fletcher, N.H., "A class of chaotic bird calls?" *J. Acoust. Soc. Am.*, 108, 821–826 (2000).