5aMUa2.  An acoustic study of ceramic traditional whistles

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Ceramic whistles are very common all along the old European traditions. Gifts, decoys or simple decorative objects these whistles may have extremely various shapes: animals, tea-pots and sometimes flutes. Even with this extremely variability, their interior shapes are very similar: a channel where to blow, an edge and a small cavity. Some of them produce a single sound when others present one or more tone holes, the later corresponding mainly to flute shaped whistles. Their acoustic behaviour appears to be very simple: Helmholtz resonators or flutes driven by the common non linear excitation system. Nevertheless some are known as water whistles and sometimes as "nightingales". The acoustic study presented will first verify that the simplest whistles are really working as Helmholtz resonator with the noticeable exception of the flute shaped ones that remain whistles for the organologist but are a different object for the acoustician. Then a particular attention will be given to the "nightingales" ones. Their sound production will be related to the level of water they contain and the modulation of the acoustic signal analyzed in terms of coupling between the oscillation of the water and the Helmholtz acoustic resonance.
INTRODUCTION

Terra cotta whistles [1] are very common all along history of civilizations as well as in ethnic traditions in Europe and may be everywhere. They may be used as bird calls, or to give audible alert signals, but these objects of various sizes can also appear as decorative humoristic objects sometimes part of a ceremonial. In eastern Europe, there are many testimonies relative to the use of the whistle within the framework of a "loving dialogue", premises of marriage. Far from these whistles, Peruvian antic whistling bottles [2] present, with a greater outside volume but a comparable whistle size, a shape that is similar to that of the whistle we are studying. To our knowledge and with the important exception of this later work [2] it appears that acoustic studies has never been realized on a real and wide corpus of whistles. On the other hand, from an acoustic point of view, information can be found on studies that concerns “theoretical” whistles as in references [3,4]. The aim of the present work is to put in light, on an ethnographic sample of whistles, the main principles of their acoustical behaviors. In the following the samples will be briefly described, their acoustic principles roughly written and some of the “musical” signals they are producing analyzed.

A SHORT DESCRIPTION OF THE WHISTLES

Flute Whistles

Among the wide corpus (27 samples) of terra cotta whistles we could observe, a particular set is given by those that are only rough copies of flutes. These instruments present a cylindrical part with a few holes and can be used to play very simple tunes. They appear as flutes and despite their ethnologic interest do not have any particular acoustic characteristics. From an organologic point of view they are surprisingly considered of the same category than ocarina types as both exhibits finger holes. The excitation system is as on all whistles a jet-edge system [3,4].

Ocarina and normal Whistles

With shapes less complicated than the previous ones, some whistles appears as ocarinas. Small resonant volumes drilled in the terra cotta before heating, are hidden in the whole volume of a decorative zoomorphic or utilitarian object. Only a small part of this object corresponds to the whistle. The resonant volume is separated from the massive body, that can be massive or an empty cavity. This characteristic, of a great volume object with a small volume whistle is common on all these instruments. It is also the case on the corpus of Peruvian bottle whistles of reference [2] where the bottle is of normal volume but connected with the whistle excitation system. The ocarina whistles may be considered as normal whistles with a few holes. They sometimes exhibits a single hole that allows the production of sounds imitating some animals, mainly birds.
Nightingale Whistles

A common use of whistles is to imitate birds and they are often bird calls. Among this category a special kind of whistles show a larger cavity and are impossible to play without a certain amount of water filled inside the cavity. When the cavity is partially filled of water the normal blowing of the whistle sounds as it was a modulated nightingale song. The Peruvian bottle whistles of reference [2] where the bottle is connected with the whistle excitation system may belong to this category.

THE ACOUSTICS OF THE WHISTLES

Flute Whistles

As flute whistles look like flute, it is easy to verify that they are working as flutes. Their sounds correspond roughly to the resonances (c/2L) of a flute with c the speed of sound and L the acoustic length of the flute. As the excitation system is of poor design it is quite difficult (even impossible) to play higher registers. The instrument is only playable on its first mode. These objects are essentially flutes.

Ocarina Whistles

These whistles belong to the wide family of jet-edge-resonator whistles [4]. They comprise terra cotta small objects possessing a cavity and sometimes one or two finger holes as on an ocarina. Their main characteristics are the huge difference that exists between the size of the object and the small size of the hidden resonant cavity. One or sometimes two or three tones are possible with a strong influence of the blowing pressure. Basically, their acoustic characteristic correspond to a Helmholtz resonant cavity excited by a jet edge system. The basic frequency that can be produced is of frequency \( \frac{1}{2\pi} \sqrt{\frac{S/l}{V}} \), where \( V \) is the volume of the cavity, when \( S \) and \( l \) are directly related to the jet edge system. \( S \) is the surface of the mouth of the excitation system while \( l \) refers to the Rayleigh correcting length and is approximately equal at 0.6 \( R \) with \( R \) the equivalent radius of the mouth. If the determination of the surface and by consequence of the correcting length is easy to do, it is not the case for the estimation of the volume of the resonant cavity. X ray images have been realized [1] that give an approximate value of the cavity volume for some of the whistles under study but it is often impossible to determine this volume with precision. Another way to determine it precisely should be its indirect determination through the resonance frequency of the blown whistles.

Nightingale Whistles

The song of the nightingale is often perceived as a strongly and rapidly modulated unique tone. To produce this “charming” effect, these whistles are using a partially water filled cavity. The air is blown into the cavity and the volume of water has to be sufficient to allow both the oscillation of the water inside the cavity and the excitation of the whistle through its jet edge system. The oscillation modulates the blowing pressure that excite the high frequency whistle.

THE SOUND OF THE WHISTLES

Flute and Ocarina Whistles

The sound produced by a whistle can be analyzed through spectrograms. The following one (figure 2) corresponds to a four second sound while the frequency resolution is of 10 Hz. This fine band analysis shows, upon an important level of noise, the harmonic structure of the self sustained jet edge system associated with the resonant Helmholtz cavity. The frequency of the fundamental (around 500 Hz) is coherent with the visible dimensions of the cavity obtained by radiography [1]. The high level of noise as it increases with the blowing pressure is an obvious consequence of the approximate design of the mouth of the whistle and the frequency of the fundamental is in a “normal musical range”.
FIGURE 2. This sound produced by a simple zoomorphic whistle show an increase then decrease blowing pressure. The fundamental frequency normally increase when the harmonic contents is increasing.

**Nightingale Whistles**

FIGURE 3. The strong modulation of this “nightingale” sound is produced by the oscillation of the mass of water contained in the resonant cavity: more the blowing is strong more the oscillation is important.
The behavior of these last kind of whistles appears very different of that of ocarina type ones. First the family of “nightingale” whistles has to be blown with a certain amount of water inside. Secondly the main frequency is quite high (around 3000 Hz in the example presented on figure 3 where the analysis resolution is 10 Hz). This is confirmed when blowing the whistle empty of water. And finally its main acoustic characteristic is the strong and fast modulation of the sounding frequency. This modulation has a period around $1/8$th second. It is excited by the continuous blowing pressure on the mass of fluid contained in the whistle.

(1)

CONCLUSION

Even if the sound that is produced by whistles appears as simple as that produced by a Helmholtz resonator excited by a jet-edge system, the variability of their design, from flutes to ocarina offers a wide field of study. This interdisciplinary field cross acoustics organology and ethnology. It also crosses the field of ancient history. For this last point of view, it can be thought that the Peruvian corpus [2] may be of the “nightingale whistles” family. First as the size of the resonant cavity alone is small and sounds at high frequency as it is the case in our corpus. Secondly, because the volume of liquid contained in the bottle can easily be put in oscillation when blown through the channel visible on the left of figure 4 of reference [2]. For simple whistles organologically speaking they are of ocarina type and their sounding frequency can give an indication of the real Helmholtz resonance volume, but for the flute type whistle, even if they appear as whistle, their resonances correspond more to a flute principle than to a whistle one.

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REFERENCES