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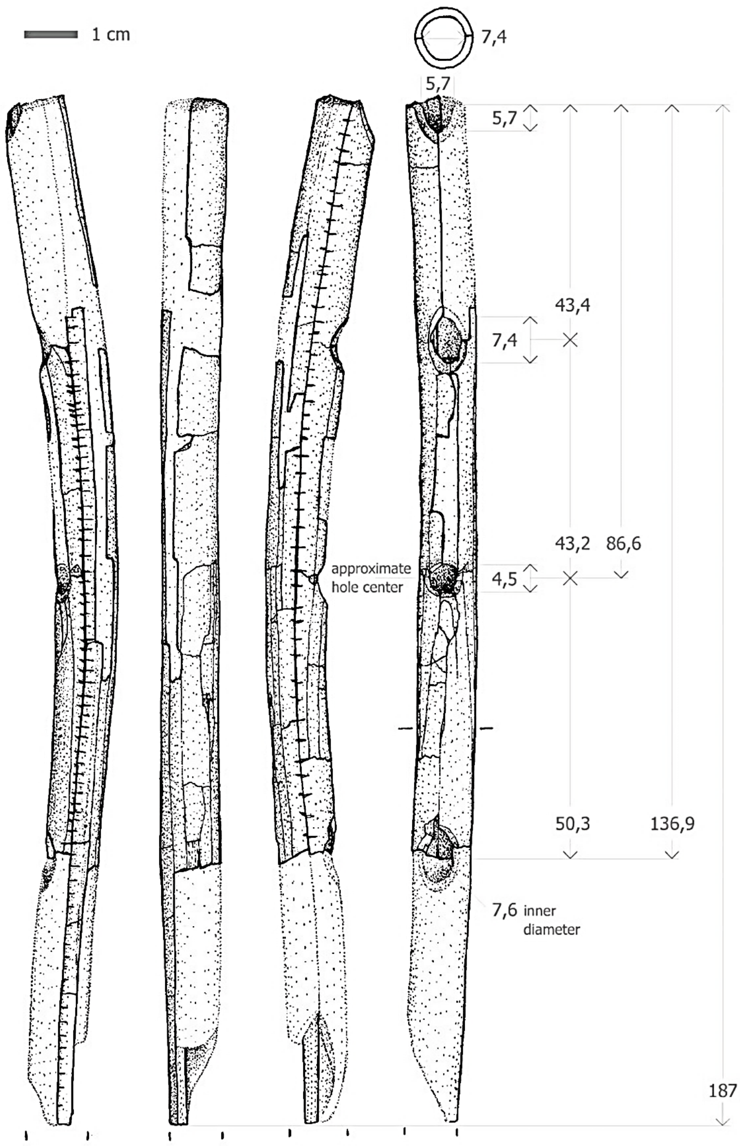

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Editorial

It is with great excitement that we present the first issue of the newly founded *Journal of Music Archaeology*, as an overture, we hope, to numerous follow-up issues. We intend these to appear annually from now on.

In launching this new journal we aim to continue the tradition of *Studien zur Musikarchäologie*, of which twelve volumes in all were edited under the supervision of Ellen Hickmann, Ricardo Eichmann, and other notable music archaeologists between 2000 and 2021. However, the *Journal of Music Archaeology* also strives to take the journey further, foremost to boost the visibility of our burgeoning field by publishing the articles on an openly and easily accessible online platform, hosted at the *Austrian Academy of Sciences*. We hope that the prospect of timely open-access publication will be particularly attractive for younger colleagues.

To this same end, we are also aiming at a level of inclusivity that goes beyond that of the *International Study Group on Music Archaeology* (ISGMA) and its biennial symposia. We wish to reach out to all researchers, musicians, or instrument makers concerned with music-archaeological questions and, as the editors, warmly invitate all those active in these fields to submit research results whenever these are concerned with the archaeology of sounds and musics of past cultures all over the globe – with music being understood in the broadest sense as including not only all sorts of intentional, regulated sound production beyond linguistics, but also all kinds of rhythmical expression.

The process of moving on from congress proceedings to a peer-reviewed journal took our team into uncharted territory, for example, with regard to content requirements, questions of format and layout, and above all issues of quality and quantity. We were happy to take on these various challenges and resolve them to the best of our abilities over the course of many hours of discussion. We extend our heartfelt thanks to our ‘first authors’ for their patience and cooperation while unintentionally acting as test subjects for this first issue.

With the eleventh ISGMA Symposium, organised at the Humboldt Forum in Berlin in 2021, as its point of departure, this volume includes several articles on Palaeolithic wind instruments – reflecting workshops held at the conference. The remaining two thirds of the articles cover a wide geographical range from Central and South America through Europe to East and South-East Asia. Similarly, the contributions cover the broadest possible time span, from the Palaeolithic up to modern times, which provide comparative ethnographic data that help in interpreting past evidence. New questions and methodologies sit easily beside the results of ongoing and new projects. Reflecting the traditional material focus of the ISGMA, most articles deal with instruments in some

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way or other, in terms of original finds, iconography, or philological investigations. Their authors represent the healthy mix of scholarly generations that has proven so fruitful in the music-archaeological research community which we have been so happy to be part of.

Enormous thanks are due to our many anonymous peer reviewers for their careful and helpful suggestions, as well as to Simon Wyatt and Sarah Burgin for their rapid and efficient English editing. Special thanks go to the staff of the *Austrian Academy of Sciences Press* for their support in making this music-archaeological journal a reality.

November 2023

Dahlia Shehata
Florian Leitmeir
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Experimental Restoration and Reconstruction in Music Archaeology

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Abstract

Restoration attempts to recover the original shape of excavated musical artifacts that have been damaged. Reconstruction is primarily focused on unearthed musical instruments or those depicted in images, and aims either at creating reproductions of playable replicas and imitations, or at simulative manufacturing and model reconstruction. Restoration, on the other hand, can be carried out in tangible or intangible ways. Tangible restoration can be perceived visually, while intangible restoration is instead sonic, and therefore aurally perceptible. Restoration not only recovers the integrity of fragmentary instruments, but also, if possible, reconstructs the sound of the original instrument based on pitch measurement and analysis. Restoration can also be applied to musical iconographic sources and musical textual symbols, such as musical notations and surviving classical texts. The restoration of musical notation is not the same as transcription of musical score. The restoration of epigraphic texts aims mainly to restore blurry and otherwise unclear or missing characters. Reconstruction, on the other hand, is a kind of simulation experiment that uses physical or virtual manufacturing to copy, imitate, and reproduce musical remains, for the purpose of exploring ancient musical practices. Based on excavated objects, musical instruments can be copied or imitated, while simulative experiments based on iconography are necessarily limited to speculation.

Keywords

Restoration – Reconstruction

1 Introduction

Known as research methodologies, restoration and reconstruction are lab-based experimentation in music archaeology. Restoration tries to recover the original shape of excavated musical artifacts that have suffered little damage. Theoretically, restoration involves all types of musical remains including musical instruments, iconographic representations, epigraphic texts, ancient notations, and sometimes sites and ancient venues for music performance, such as theaters, stages, concert halls, and other buildings for performing arts. Historically, restoration attempts were mainly limited to musical instruments, since other remains, especially ancient notations and theatrical buildings, are more difficult to restore.

Borrowed from experimental archaeology, reconstruction primarily focuses on unearthed musical instruments or those depicted in images, in order to create playable reproductions (replicas) and imitations. In addition, through 3D printing or VR technology it is also possible to create simulative manufacturing and model reconstruction.

This paper will examine the various methods used in restoration and reconstruction, and will compare the similarities and differences of both types of experimentation.

2 Restoration

Restoration can be carried out in both tangible and intangible ways. Tangible restoration is visible; it may be, for instance, the recovery of an instrument's shape. Intangible restoration is invisible, as it is sonic and therefore perceived aurally, for example, the retrieval of tone series and scales of musical bells and chime stones discovered by Chinese archaeology.

Restoration of musical instruments mainly focuses on incomplete finds, such as damaged or fragmentary specimens, which can be recovered through restoration techniques. The broken or damaged parts may be repaired by professional technicians, and in the case of some instruments it is even possible to recover the ways in which they were assembled.

With regard to incomplete instruments, the restoration is possible only when certain preconditions are met:

1) the broken parts of instruments are not missing or lost.
2) the broken parts of instruments can be glued or otherwise joined, or
3) although the broken parts are missing or lost, there is only one way to reconstruct their original shape.

It must be noted, however, that the recovery holds some uncertainties if there is more than one possibility for restoration, in which case the restoration cannot be considered definitive in terms of music archaeology.

Some clay ocarinas, for instance, are not well-preserved when excavated; but although the blow hole has been damaged, it is possible to restore it based on the shape of the mouthpiece. Like fragmentary Chinese chime stones with a standard pentagonal shape, it depends on different factors. They may be restored if the missing part is merely an angle of the chime stone; otherwise, it is not easy to estimate the sizes of the missing parts on both sides, so restoration in these cases must necessarily involve some imagination and hypothesizing. Sometimes unearthed bamboo or bone flutes are in a similar condition to clay ocarinas and lithophones – the broken and missing parts of the pipes cannot be exactly reconstructed; thus, it is impossible to estimate the shape and size of the instrument, which makes its recovery and restoration very difficult.

Technologically, archaeological restoration not only recovers the integrity of a broken instrument, but also, if possible, reconstructs the tone series or scale of the original instrument through pitch measurement and analysis. Two case studies may serve as a point of reference. One of them has been carried out on the late Western Zhou (877–771 BCE) chime stones *biānqìng* (编磬) unearthed from tomb M27 in Hancheng Liangdaicun (Shaanxi) in 2005–2007, and comprising ten stones in a set, five of which are incomplete, although their broken parts were found when it was excavated.[1] Before taking pitch measurements, I discussed the possibility of repairing the fragmentary pieces with the chief excavator Sun Bingjun. We let technicians glue the pieces together and thus restore all five broken stones, which produced better tones after restoration, except for one with poor intonation and sound quality. In this way the idea of restoring the scale structure of this set of chime stones has been realized.[2]

Another example is a set of 107 chime stones uncovered in pit 14 of the Western Han tomb in Zhangqiu Luozhuang (Shandong), dating to approximately 186 BCE. Some of its stones are broken into two or three, or even more pieces.[3] In the past, in most cases, such broken stones either were not analyzed with regard to the pitches they were intended to produce, or only more complete specimens were studied. Cui Dayong, the excavation leader of Luozhuang Han dynasty's tomb, proposed gluing all the broken stones in order to recover their original shape. Once the process of restoration was accomplished, the vast majority of chime stones began to emit correct sound and produce their relative pitches in the original arrangement, which enabled the recovery of the scale that was once played on them.[4]

Aforementioned studies have proved that some restored chime stones can produce sound and, indeed, can be played, while the relative pitches in the original set of some other stones will not be greatly affected, even though the timbre has more or less changed. Under these circumstances, it is possible to deduce the overall tone series and scale structure of chime stones. Nevertheless, it is not possible to recover the sound or pitch of all broken chime stones, not least due to differences between various chime sets and specimens, and the nature of these differences. So far the reason for this has been unclear, and it needs to be researched comprehensively from the perspective of petrology, archaeoacoustics, and archaeological restoration technology.

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[1] Shaanxi Sheng Kaogu Yanjiuyuan 2007.

[2] Fang 2019a.

[3] Jinan Shi Kaogu Yanjiusuo 2004.

[4] Fang 2010.

It should be noted that sound or pitch restoration is not equally possible for all musical instruments, and there are considerable differences between individual finds. Some instruments become dull or even lose their sound after repairs. Although some broken musical bells *biānzhōng* (编钟), for instance, have been glued together by technical means, and their shape has been restored to the original form, they are not playable and they do not produce real sound. The fragmentary wind instruments, such as bone or bamboo flutes, are usually soundless after restoration.

Strictly speaking, due to various factors the original acoustic properties cannot be recovered in full once the instruments have been buried. In fact, sound restoration mainly aims to reconstruct the relative pitch, especially the tone series or scale structure of the percussion instruments with fixed pitch, such as ancient Chinese chime bells and chime stones, rather than their absolute pitch and timbre.

Some individual finds from sets of fixed-pitch percussion instruments, which have lost their original sound due to damage, require comparisons with the data from pitch measurement based on intact instruments of the same kind. Such measurements generally result from quantitative analysis and have certain common characteristics and rules, which can, by analogy, be used to reconstruct the pitch of the damaged, dumb instruments in the sets.

Ancient Chinese two-tone musical bells and chime stones with the same pitch arrangement, as well as others found in different sites but with the same number of pieces in a set and dated to similar periods, exhibit common tonal features, which can serve as the basis of comparison for some complete sets of damaged bells and stones that have lost their original sound. This could enable the reconstruction of their relative pitch and tone series or scale structure. For example, a set of nine Ju Gongsunzhaozi chime bells dating to the mid-Warring States period (c. 350–300 BCE) were found in a tomb in Zhucheng Zangjiazhuang (Shandong) in 1970, two of which were damaged and had lost their sound.[5] The data of pitch measurement is shown in Table 1.[6]

Chime bells with nine pieces in a set frequently occurred in China's central plain area during the Eastern Zhou times (770–256 BCE); for example, nine bells recovered from tomb M1 of Chu state in Henan Xichuan Xiasi may form a pentatonic scale with *zhǐ* (sol) mode when their first tones are played:[7]

zhǐ – yǔ – gōng – shāng – jué – yǔ – shāng – jué – yǔ
sol – la – do – re – mi – la – re – mi – la

Through comparison, we may conclude that the Ju Gongsunzhaozi chime bells formed the same scale structure (question marks indicate soundless bells):

zhǐ – yǔ – ? – shāng – jué – yǔ – shāng –? – yǔ

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[5] Shandong Zhucheng Xian Bowuguan 1987.

[6] Weng 1992; Fang 2006: 243–45.

[7] Zhao 1996: 319. Chinese pentatonic scale steps take the following names: 徵 (*zhǐ*), 羽 (*yǔ*), 宫 (*gōng*), 商 (*shāng*), 角 (*jué*), which is equivalent to sol, la, do, re, mi.

Except for the third and eighth bell, the scale produced by the remaining bells is apparently identical to the scale of the nine chime bells from the Eastern Zhou period. Therefore, it can be inferred that the two missing first tones of Ju Gongsunzhaozi chime bells are respectively *gōng* (do) and *jué* (mi), and their scale structure is the same as that of the Eastern Zhou nine-piece chime bells from the central plain area of China.

No.	First tone	Second tone
1	G♯$_4$ −32	A♯$_4$ −21
2	A♯$_4$ −24	C$_5$ +4
3	soundless	soundless
4	D♯$_5$ −3	F$_5$ −23
5	F$_5$ −10	G♯$_5$ +35
6	A♯$_5$ −7	C♯$_6$ +22
7	D♯$_6$ +23	F♯$_6$ +20
8	soundless	soundless
9	A♯$_6$ −26	C♯$_7$ +5

Table 1: Data of pitch measurement of Ju Gongsunzhaozi chime bells

The pitch measurement data of grouped instruments can also be applied to the reconstruction of tone series or scales of incomplete sets of instruments. The late Western Zhou Lái (逨) bells are a good example. After excavation of a bronze vessel hoard in Meixian Yangjiacun (Shaanxi) in 1985, a set of nine bells was first stolen and later partially retrieved; unfortunately, five bells are still missing. Four bells with inscriptions are at present stored at the Meixian County Museum (Shaanxi) in China; three of them (no. I, II and III) are larger, and each is inscribed with 117 characters, while the smallest one (no. IV) has only the last 17 characters of the entire inscription, suggesting that the other 100 words are likely inscribed on the missing bells.[8]

One Lai bell with 117 inscribed characters, like the three larger Lai bells housed in China, is displayed in the collections of Cleveland Art Museum in the US.[9] So far, the pitch of four bells in China have been measured, the data of which is presented in Table 2.[10]

No.	Specimen no.	First tone	Second tone
1	II	A♯$_3$ +34	D$_4$ −14
2	I	D$_4$ −3	F$_4$ +37
3	III	G$_4$ −13	A♯$_4$ +35
4	IV	G♯$_6$ −4	B$_6$ +33

Table 2: Data of tone measurement of late Western Zhou Lai bells

In Central Plain area, mid- to late Western Zhou chime bells often occurred in sets of eight pieces that formed a four-note-scale in *yǔ* (la) mode,[11] which has become a common practice in chime bells' tradition (words in square brackets refer to the second tones):

yǔ – gōng – ju [zhǐ] – yǔ [gōng] – jué [zhǐ] – yǔ [gōng] – jué [zhǐ] – yǔ [gōng]
la – do – mi [sol] – la [do] – mi [sol] – la [do] – mi [sol] – la [do]

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[8] Liu 1987.

[9] Fang 2011: 127–32.

[10] Fang 1996.

[11] The ancient Chinese regarded *gōng, shāng, jué, zhǐ* and *yǔ* as the five positive tones (*wǔzhèngshēng* 五正声), and the fourth and seventh as the two changes (*èrbiàn* 二变) that were not orthodox notes. According to the records of *Zhou li* (the ritual system of the Zhou, about 3rd century BCE), the court music of the Western Zhou Dynasty used *gōng, jué, zhǐ* and *yǔ* in four notes which have been proved in the scale structure of chime bells discovered by Chinese archaeology, even though it seems they correspond to re, fa, la, and do. See Fang 2011: 159–65.

Returning to the Lai bells, a set of four bells preserved in mainland China missing four other bells may form a similar scale structure (underlined characters indicate the pitch names of missing bells, the symbol '↑' indicates higher pitch with inaccurate intonation):

yǔ – *gōng* – *jué* [*zhǐ*] – *yǔ* [*gōng*] – *jué* [*zhǐ*] – *yǔ* [*gōng*] – *jué* [*zhǐ*] – ↑*yǔ* [*gōng*]
la – do – mi [sol] – la [do] – mi [sol] – la [do] – mi [sol] – ↑la [do]

The comparison of the Western Zhou chime bells with an eight-piece set suggests that the four Lai bells in China should be the second, third, fourth, and eighth piece of the set, while the first, fifth, sixth, and seventh bell are still missing. Obviously, the Lai bell from Cleveland should be the first one of the set, with its first tone *yǔ* in the complete assemblage of eight bells.

In addition, another Lai bell was reported in George Fan's private collections in New York.[12] With 25 characters inscribed, and judging by the content of inscriptions, this bell should be the seventh piece in a set of eight, and connected to the subsequent eighth bell (the last one). Moreover, this bell produces D_6 (first tone) and $F\sharp_6$ (second tone), which corresponds to the pitch of the seventh bell in the set, in which two bells (the fifth and sixth) are absent from the complete set of eight bells. Hopefully, all eight bells will be reunited in the future.

Restoration research can also be applied to iconographic sources of music. Some three-dimensional musical images, such as the ancient terracotta figures of musicians, can be restored by reattaching the broken-off fragments; for instance, the musical instrument models held by the figures, which have fallen off and been separated from the hands, or broken musical instrument models, can be glued back together to restore the integrity of the musical image, so as to show the overall gesture, motion and musical instruments held by the terracotta figures. However, other pictorial representations, such as partly damaged mural paintings or fragments of frescoes and statuettes, can be restored, but it is sometimes difficult to precisely estimate their original appearance and therefore restoration is impossible.

Also, restoration research can be applied to musical textual symbols, such as musical notations and unearthed classical texts referring to musical activities. Unearthed fragments of writing with musical notation are usually incomplete, but it is possible to recover some symbols or deduce the missing parts from the remnants. It should be noted that musical notation restoration is not the same as the transcription of musical score. Although the transcription of ancient musical scores aims to recover ancient music to a certain extent, the transcription result does not usually produce the authentic form of the ancient music itself, due to the subjective approach of translators, as well as the unknown aspects of rhythm, meter, tuning of string instruments and so forth. According to current interpretation, Dunhuang pipa tablature (敦煌琵琶谱), for example, consists only of the symbols that represent fingering positions on the pipa lute of the Tang dynasty (618–907 CE), so different translations vary with regard to melody and rhythm. Because of the different understanding of the pipa tuning, the translated music also differs in pitch and melody. The notation

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[12] Shouyangzhai 2008: 121–23.

restoration is therefore the basis of notation interpretation, but the notation interpretation does not restore music in its original form.

The restoration of epigraphic texts aims mainly to restore blurry or unclear characters, or texts where just a few characters are missing. Some of them can be restored by visual observation, and some need to be restored by means of scientific and technological methods, such as infrared photography, for example, which is currently applied to the restoration of ancient Chinese bamboo slips.

As for the restoration of missing characters in surviving classical texts, some can be deduced from the context, while others can be supplemented by transferring the general rules observed in the existing unearthed musical documents. The inscriptions on the Western Zhou chime bells, for example, are intrinsically connected in terms of content. Sometimes one chime bell has an independent complete inscription; sometimes several chime bells are jointly inscribed with a complete inscription. Therefore, the restoration of characters and passages supports the study of unearthed musical documents, and once this restoration is successful, it can in turn serve in the musical restoration of unearthed chime bells.

3 Reconstruction

In music archaeology, reconstruction is a kind of simulation experiment that borrows from the methodology of experimental archaeology, and uses physical or virtual means to copy, imitate, and reproduce the musical remains, so as to explore the music practices of ancient people. The design and implementation of simulation experiments in music archaeology is normally accomplished by close collaboration between music archaeologists, instrument makers, and instrumentalists.

Theoretically, experimental reconstruction in music archaeology may concern all music-related remains. However, due to the characteristics of the research objects and the limitations of experimental conditions, research has so far primarily focused on material objects and pictorial representations of musical instruments.

The reconstruction of musical instruments comprises instrument making and playing, through which it is possible to study the design, manufacture, craftsmanship, and sound properties of the instrument, and thereby verify some conclusions or hypotheses. Although the process of experimentation is considerably suppositive, it concerns, after all, the actual production practice of musical artifacts, which cannot be replaced by reasoning and imagination. Actually, in ancient times, craftsmen who produced musical instruments may have relied on measurements and procedures[13] which are difficult for us to simulate one by one in our reconstruction of musical instruments. Therefore, parameters need to be varied across simulation experiments.

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[13] According to classical texts, *Kaogongji*, the ancient Chinese chime stones, were made to a certain size ratio, and there were specific grinding and tuning parts. For details, see Fang 2006.

It is almost impossible to discover the whole manufacturing process and how the instruments were played and performed. The damaged instruments that could not be properly restored and played for the sake of further study on their pitch, and the instruments that survive only in images but not as archaeological finds, can also be reconstructed to explore the possible playing methods and sound properties.

Finds of ancient musical instruments are usually individual, partial, and sometimes even fragmentary; meanwhile the reconstruction is expected to discover a relatively complete manufacturing process of ancient musical instruments, and to explore the possible musical practices in ancient society.

There are two main methods of experimental reconstruction, which are worthy of exploration: copying and imitating musical remains. It must be pointed out that the reproduction and imitation of musical remains cannot be equivalent to, or substitute for, the original. They all belong to the category of a simulation experiment, not restoration. Based on excavated objects in an archaeological context, musical instruments can be copied or imitated, while in the case of iconographic evidence, the reconstruction of musical instruments is necessarily limited to imitation.

Reconstruction can aim at either a copy or an imitation. 'Copies' and 'replicas' are strict replications from original musical remains and are different from imitations. The reproduction of unearthed musical instruments is required to be highly consistent with the originals in terms of manufacturing materials, craft skills, dimensions, weight and sound (if well-preserved). Therefore, the material and technical conditions for musical instrument replication are higher than those for imitation, and it often requires interdisciplinary study and multi-professional cooperation.

When discussing the experimental reconstruction of unearthed musical instruments, Ricardo Eichmann proposes "historical reproduction",[14] emphasizing that the ancient principles of design and production methods should be explored and applied to the reconstruction of musical instruments. He points out that ancient manufacturing tools were different from modern ones; thus the timbre of musical instruments made by ancient methods may have considerably differed from those made by modern techniques. Obviously, ancient methods should be examined and adopted for musical instrument reproduction. Undoubtedly, it is better to use ancient manufacturing tools, rather than the modern mechanical types of equipment and techniques. Nevertheless, while some ancient methods and tools might be discovered through study, others may not. This is a subject that needs to be continuously explored through simulation experimentation.

When replicating chime bells from the tomb of Marquis Yi of Zeng, the manufacturing materials and substances had to be the same as the originals. The alloy composition used to replicate the chime bells needed to be obtained through scientific testing so that the replicas could be consistent with the unearthed originals. In terms of the manufacturing method of chime bells, Chinese scholars have conducted research on the design, casting, technology, and tuning of the chime bells

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[14] Eichmann 2004.

from the tomb of the Marquis Yi of Zeng.[15] In appearance, the duplicated chime bells should have been identical in color to the originals, and should have looked the same as the originals so as to give the effect of 'copy from the real'. More importantly, the pitch and scale structure of the replicas needed to be the same as the ones of the original bells.

Scholars have also done simulation experiments on musical instruments found in Europe, and explored their materials, manufacturing techniques, and methods. When reconstructing the European bronze Lurs, Peter Holmes and Nik Stanbury studied whether ancient people had used the lost-wax process.[16] Anders Lindahl made reproductions of a pottery drum from the middle Neolithic Age and another one from the late Bronze Age excavated in Skåne, Sweden. He explored the ceramic materials and firing methods of the pottery drum, and analyzed the possible manufacturing methods in the prehistoric period.[17] Lena Alebo speculates that seal skins could probably be used as the drum head.[18]

The playable replica of a musical instrument is not only required to 'look like' the original, but also to 'sound like' it. Of course, the shape and structure of a musical instrument are important, but considering its musical function, it is more crucial to reproduce the sound, i.e. the pitch and intonation of the copied instrument should be consistent with the original. However, it should be noted that it is very difficult to reproduce the timbre of an instrument in accordance with the original, thus we would call the sound of a replica 'sonic similarity' rather than 'sonic equality'.

Unlike replication, the imitation of musical instruments has no strict requirements for materials, sizes, sound, manufacturing methods, and techniques. They may differ from unearthed instruments to some extent, sometimes only having a similar shape in common. However, musical instrument imitation could also be more similar to the original, what is in Chinese called *gāofǎng* (高仿, 'higher imitation'), but even so, it is still an imitation. Some instrument imitations are toys or souvenirs, and musical archaeology is certainly not concerned with them. Thus, we can see that the musical instrument replication belongs to a higher level of simulation experiment, while musical instrument imitation represents a lower level.

As stated above, imitation of musical instruments can be divided into two types: imitation based on physical objects and imitation based on images, and there are certainly many differences between them.

The reference point for imitations of musical instruments are three-dimensional physical objects, but the iconographic sources, such as mural paintings, are two-dimensional and lack important information: for instance, the size and internal structure of the depicted musical instruments. As for figurines of musicians with musical instruments, although three-dimensional, they differ significantly from reality. Therefore, the academic value of imitated musical instruments based on iconographic sources is lower than that based on unearthed musical instruments.

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[15] Hubei Sheng Bowuguan 1992.

[16] Holmes and Nik 1986.

[17] Lindahl 1986.

[18] Alebo 1986.

Chinese scholars have carried out simulation experiments on the ancient musical instruments depicted in the Dunhuang murals in Gansu, imitating most of the instruments shown in the paintings and making them suitable for music performance.[19] However, the reproduction based on music iconography must necessarily be limited to the imitation level, and its authenticity is naturally weaker than the imitation or duplication based on the actual musical instrument. As Graeme Lawson states, making an instrument based solely on an image cannot be regarded as copying, because copying a picture can only result in another picture.[20] Ricardo Eichmann cautions that in order to rebuild ancient instruments based on musical images, one must have a knowledge of art history, musical acoustics, and archaeology; otherwise misinterpretations and mistakes will inevitably occur when imitating ancient instruments.[21] All these conclusions show the limitations of musical instrument reconstruction based on images.

In order to explore the playing methods and sound properties of instruments, 3D printing technology is currently applied to simulate their manufacture, which has become a new approach to the study of reconstructing surviving organological finds. More accurate data can be obtained by using CT tomography to measure the dimensions of unearthed instruments. On this basis, the shape of imitated instruments is more accurate and thus more suitable for 3D printing. However, materials used by 3D printing methods are only substitutes for original materials and substances, and they cannot equal the original, thus this kind of study belongs in the category of imitation.

In 1988, I made reconstructional experiments on several flutes found in China, such as Neolithic (c. 5000 BCE) bone flutes and whistles from the site of Yuyao Hemudu (Zhejiang), early Warring States (433 BCE) bamboo flutes from Zenghouyi's tomb, Western Han (202 BCE–8 CE) bamboo flutes from tomb no. 3 in Changsha Mawangdui (Hunan) and the Western Han bamboo flute from a tomb in Guixian Luobowan (Guangxi).[22] In the experimentation, plastic tubes were used as materials, and their inner diameters were different from those found in bone and naturally growing bamboo, because plastic tubes are of constant diameter, which is not true for the originals. Imitation experiments, however, help in understanding the playing method and possible tone series or scale structure of ancient Chinese flutes.[23]

In 1935, a stone-made ocarina *xue* (埙) was recovered from the M1550 tomb in Anyang Yinxu Xibeigang (Henan), dating to the first phase of Yinxu archaeological culture (1260–1235 BCE). The ocarina's top part, including a mouthpiece and some finger holes, is broken and incomplete, and its bottom is unsealed.[24] Judging by the internal traces in its empty body, this ocarina was hollowed out from bottom towards its middle part, and polished in a longitudinal reciprocating motion,

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[19] Dunhuang Yanjiuyuan Yinyue Wudao Yanjiushi 1992.

[20] Lawson 2010.

[21] Eichmann 2000.

[22] Fang 2006: 3–10.

[23] Due to the limitations of the technology available at the time, my imitation experiments did not involve reproductions made of bone, nor did they use 3D printing techniques. For details, see Fang 2006.

[24] Liang and Gao 1976; Zhuang 1972.

while the inner circumference of the bottom hole was polished in a transverse rotational movement. Li Chunyi proposed that the inner cavity of the bottomless ocarina was easier to hollow out, but it remains unknown whether or not there was a plug in the bottom. If there was not, the instrument could be played in an upper octave; the timbre would be brighter and louder, like an open pipe.[25] If imitation experiments had been carried out on the stone-made ocarina, it would have been possible to test whether it could be blown like an open pipe or whether a piston to plug the bottom hole could be used.

Another example is the mouth organ *shēng* (笙) made of gourd and bamboo discovered in the tomb of Marquis Yi of Zeng. According to the excavation report, a blowing tube mold of the mouth organ may have been used to enclose the young gourd that later made it grow into a long tube for blowing.[26] In order to test the application of this method in the making of the original mouth organ, one might want to test this hypothesis by the simulation of gourd growth.

Imitation experiments also include the reconstruction of ancient musical remains such as soundscape sites – for instance, stages and theaters. The process of turning them into either physical objects or computer models involves experimentations and archaeo-acoustic research on the sites. Jens Holger Rindel's computer model, 3D virtual production and sound simulation experiments on an ancient Roman theatre are meaningful attempts at a respective reconstruction.[27] However, such experiments have so far been rarely conducted in comparison to the many reconstructions of excavated instruments.

Additionally, in the case of some sites of ancient architecture related to musical events, from which only foundations survive, it is possible to design models or schematic diagrams of buildings above ground through the research of archaeological data, which of course involve a considerable number of speculative parameters. For example, at the site of the important music institution Líyuán (梨园) of the Tang dynasty, which has been excavated at Huaqinggong in Lintong (Shaanxi), only the foundations of the houses remain. The point of reference for its imitation is the foundation that may provide certain evidence in terms of building area and space division.[28] However, since the above-ground buildings had been destroyed, the architectural pattern, style and construction can only be inferred from the foundation and other relevant remains, which may also require a good deal of conjecture and imagination.

Along with the continuous development of science and technology, computer-aided research has been increasingly applied in the field of experimental archaeology in order to conduct simulation experiments on archaeological finds. In the case of music-archaeological simulation experiments, the application possibilities of new technologies are quite broad. Virtual simulation and virtual reality technology may become a new developmental trend in constructing computer mathematical models of music archaeological finds. For example, computer generated models can

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[25] Li 1996: 401.
[26] Hubei Sheng Bowuguan 1989: 174–75.
[27] Rindel 2008.
[28] Fang 2019b: 186–92.

be used to simulate the acoustic effects of ancient stage and theatre, and VR technology can be used to integrate the visual, auditory and even somatosensory aspects of various music-archaeological remains, so that the audience can feel and experience the realistic existence of ancient musical life as if they were part of it.

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Reflections on Archaeomusicological Practice in South America

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Abstract

This paper aims to describe some problems and issues that have emerged from the practice of archaeomusicology in South America, especially in the Andean region. Some methodological approaches emerge from the specific problems of organological studies of pre-Hispanic objects, related to the evidence about sound use and the interpretation of sound by local cultures. This article presents four features of Andean music that illustrate some of the main methodological approaches that must be utilized when studying pre-Hispanic music in the Andes; the tone quality, the organological expansion from a singular object to multiple objects; the physical movement of musician and hearer as part of the sound properties, and musical performance as part of a social exchange between musicians and listeners. Each of these features offers a new perspective on archaeo-musicological studies, as well as on the contributions of the field to a greater understanding of new discussions in present society.

The focus of this article will be to understand the 'sound object' as an acoustic object, as one or more objects, as related to the surrounding ambient, as a moving object, and as a modifier of the player's or listener's experience.

Keywords

Andean methodological tools – Sound design – Sound movement – Sound and society

1 Introduction

This paper aims to highlight some tendencies in archaeomusicology that have emerged in South America, as identified by myself and some of my colleagues from Ecuador, Peru, Bolivia, Argentina, and Chile. I will focus on some methodological approaches linked to organology, which is the main source of data for our studies of pre-Hispanic sound cultures. Frequently the instruments and "sound objects" under study lack any contextual data whatsoever regarding their provenance, or indeed regarding any other aspect, and this means that we must rely only on organological analysis to interpret them. This poses a fundamental problem of analysis, as our methodological tools to define a musical instrument, to understand how it was used, and what relation it had to the

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society that produced it, come mainly from Europe. We have a large bibliography on pre-Hispanic Andean instruments, however, this is not the place to refer to it, except for those authors who have attempted to understand local instruments through the interpretation of local cultural clues, as is the case with the study of Sinu flutes of Colombia (Olsen 1988), and Nazca flutes from Peru (Gruszczyńska-Ziółkowska 2014), among others.

Since the colonization process in South, Central, and parts of North America consisted in erasing all remains of the pre-European past, we had been taught that all "musical" traces from past centuries were definitely lost (see, for example, Martínez 2004). Since the second half of the 20th century, however, this idea has been questioned, and in recent years indigenous voices have become part of the process. Decolonization has become a new position in the debate (Rivera 2010; Castro-Gómez and Grosfoguel 2007). Through this process, we have the opportunity to revise our concepts of 'music', 'sound object', and other concepts akin to these topics in the Andean region.

In this article I will present some of the findings that I have been discussing with other scholars from Chile, Argentina, Bolivia, Peru, and Ecuador.[1] I have divided them into four topics that can be used as hypotheses and methodological tools when studying ancient sounds in the Andes. They refer to the tone quality, the organological inclusion from a singular to multiple objects; the physical movement of musician and listener as part of sound properties, and the playing of music as a social dynamic.

2 Tone quality: the expression of sound

This hypothesis is based on many current Amerindian practices in which the concept of 'timbre' or 'tone quality', as the spectral composition of sound, has a central importance for their music. This applies to single instruments as well as consorts of many instruments. After describing several examples, I will assess this concept as a tool for interpreting archaeological instruments.

Many Andean panpipes (*sikus, antaras, surisiku*) have a second row of tubes attached to the main tubes, whose purpose is to enhance their timbre. I will refer to these tubes as *palq'a*, one of its Aymara names.[2] There are many types of *palq'a*; while the ratio between the main tube and the *palq'a* can vary, it is often 1:1 (the same length), 1:2, or 3:4. *Palq'a* tubes can be open or closed at the distal end. By combining varying length ratios with an open or closed end, a different harmonic response is obtained, enriching the timbre with diverse spectral structures (Gérard 1999; 2008), whereby a single instrument as well as an orchestra composed of many instruments use only one

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[1] I am indebted to many scholars, such as Arnaud Gérard from Bolivia, Carlos Sánchez and Carlos Mansilla from Peru, Estelina Quinatoa from Ecuador, Esteban Valdivia from Argentina, among many others. All of them have helped and contributed to this investigation for over 40 years, for which I am very grateful.

[2] Its nomenclature is extensive, and it sometimes very precisely identifies a particular kind of *palq'a*. Some of them are *palq'a, phallqa, pallqa, sanq'a, shallka, chala, q'asa, kaéharisqa, china, compañía, sirinu, serena, siruni, sirena, haylli, ch'usa, orko, iiojo, falso, falsa, falsete, falsos, carga, resonador, marimacho, alto y bajo.* For its use, place of use, references and analysis, see Pérez de Arce 2021: 92.

Figure 1: *Baile chino.* Kilimarí (central Chile) 2010. Photo by the author.

type of *palq'a*. This is applied to the entire ensemble of flutes, thus giving it its characteristic sound quality.

In order to enrich the timbre of many flutes in highland Bolivia (*tarkas, jantarkis*) and Chile (*flautas de chino),* their internal tube is perforated in such a way as to produce two different diameters along its length. When blown with considerable strength, this renders a multiphonic effect (i.e., two tones are heard) with a pulsating quality. Flutes in general tend to be blown with a technique producing multiphonics and harmonics (Cepeda 2011: 8; Prudencio 2015: personal communication; Gérard 1997; 2015: 11, 52; Sánchez 2016: 67; 2018b: 241; Pérez de Arce 2018). Local musicians can distinguish subtle differences in these characteristics, showing preferences for specific flutes (Gérard 1997: 41–42; Cepeda 2011: 89; Stobart 1996; 2018: 217). There is a preference for dense, complex sounds, with distinct dissonances. The so called *bailes chinos*, in central Chile, take this notion to the extreme, as their orchestras avoid any consonance, all flutes are in a dissonant relation, and there is no melody or rhythm, only one continuous pulse (Figure 1). The sound complexity is so great that it almost defies description, not only because it is ever changing, but also because it changes with the location of the listener. There is a sort of equilibrium between the precise local control of sound aesthetics in the creation of each flute, in each musician, in each group, and with the presence of random situations that occur during the performance. Chaos seems to be as important as controlled situations (Pérez de Arce 1996).

If we look at the pre-Hispanic record of flutes in the Andes, this hypothesis about the importance of tone quality as the main subject of study changes our understanding of pre-Hispanic 'music'. First, we must pay attention to hundreds of double flutes found elsewhere – from Chile to Colombia, but mainly in Ecuador and Peru (Gérard 2015; cf. Figure 2). They consist of two globular flutes with a common airduct which, when played together, produce strong *battimento* (a beating

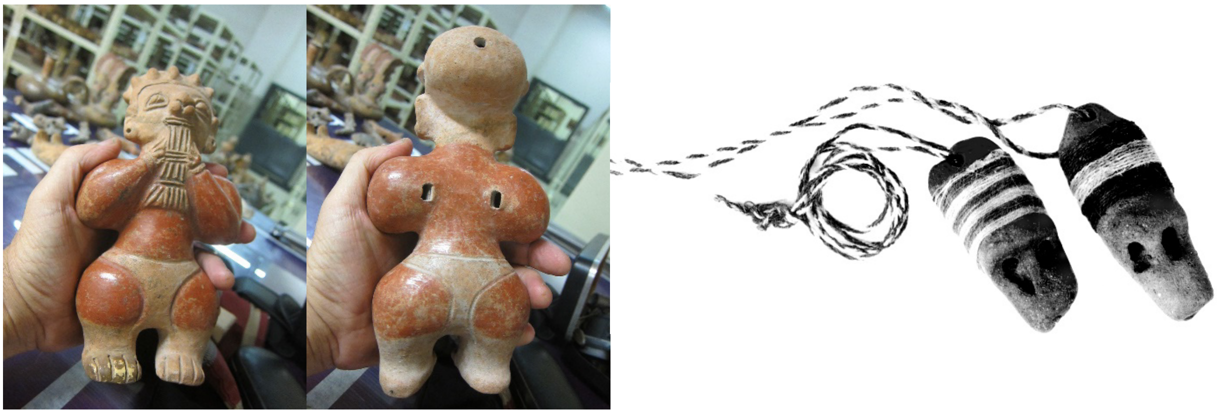

Figure 2: Prehispanic double flutes. Left: La Tolita, (500BC–500CE, Ecuador). Museo de Antropología y Arte Contemporáneo de Guayaquil, Ecuador. The hole at the top is for blowing, the two holes at the shoulder of the figure correspond to the airduct openings. Right: Faldas del Moro (900–500BC, Chile). Museo Chileno de Arte Precolombino, Chile. Two similar flutes, each one with two slightly different tones. Photos by the author.

effect when two slightly different frequencies interfere). Almost all of them lack fingerholes, which has left them out of most descriptions (although well known, see Brohée 2019). Many seem to have been important instruments, built with outstanding craftsmanship (Figure 3). We find the same search for *battimento* in different flute types, such as 'ocarinas' (duct globular flutes), 'whistling bottles' (that are sounded by the movement of water, without human breathing), and also 'antaras', a kind of panpipe that comes in pairs, which, when played together, give a delicate *battimento* throughout (Gruszczyńska-Ziółkowska 2009).

This changes our understanding of the importance of a musical instrument, in which pitch production and tuning possibilities are only one of its properties, and sometimes the least important one. There is an Andean aesthetic paradigm of *poco varía* ('little varies', Borras 1998) that allows us to consider the great amount of fine variations between similar artifacts as a value. For example, the little variation on the small vibration of sound we find in hundreds of double flutes can be seen as part of the aesthetic quest of these communities.

Figure 3: Cabinet with dozens of one-note clay flutes from different cultures from Ecuador. Museo Centro Cultural de Manta, Ecuador. Photo by the author.

Another example of the rich timbre expression of flutes as an intentional characteristic of the instruments is demonstrated by the blowing of flutes with a strong, energetic, intense breath in search of a complex timbre response, as is generally done in flute playing in the region. When played with a gentle stream of air, these flutes respond with a 'European' tone quality, that is to say, with pure tones. When overblown, or when blown with a higher pressure of air, they respond in an 'Andean way', so to speak, expanding the horizon of our interpretation of sound towards an expression of complex timbre.

Figure 4: Two sikuris playing a melody by alternating their notes. Jaiña (Northern Chile) 2014. Photo by the author

3 Instruments as single or multiple sound objects played in pairs or in ensembles

This paradigm is used in almost all traditional flute playing in consorts in the highlands of Bolivia and Peru. The *siku*, a type of panpipe, is a flute made of two separate objects, played in alternation by two musicians. Each player has a set of notes that the other lacks, which, when intertwined, form a scale (Figure 4). Thus, to play a melody they must *trenzar* (intertwine) their sounds (Valencia 1982; Bellenger 2007; Ávila and Padilla 2002; Stobart 2002; Ibarra 2011; Barragán 2013; Castelblanco 2016). The result of this performance is a sound that seems to be played by a single flutist who does not breathe between notes, rather than being perceived as played by two persons. The same intertwining technique is common to many other flutes and trumpets in northern South America (Colombia, Venezuela, Surinam, Guayana), Amazonia (Brazil, Colombia, Venezuela, Ecuador, Peru), Chaco (Paraguay, Argentina, Bolivia), the highlands (Peru, Bolivia, Chile, Argentina), the central and southern Chile and Argentina.[3] This indicates that the concept of playing two instruments as one is a common practice among vernacular music throughout the continent.

Pre-Hispanic evidence of paired flutes includes references to double Nazca 'antaras' (Gruszczyńska-Ziółkowska 2009), whose description mentions a single instrument consisting of two flutes played by two people. A similar interpretation may be applied to pre-Hispanic flutes linked with the present-day *siku* (Sánchez 2018), *baile chino* flutes (Pérez de Arce 2018) and *pifilka* (Pérez de Arce 2007; cf. Figure 5). It seldom occurs that we find clues about pre-Hispanic pairs of

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[3] To understand this practice, I have searched the following list of ethnic groups where this practice can be found in many publications: Kuna, Motilon, Wayana Apinajé, Nahuquá, Sicuani, Sucre, Ipure, Kolomoto, Cumaribo, Guahibo, Baniwa, Ye'kuana, Makiritare, Desana, Verékushi, Kalina, Desana, Waura, Kogi, Ijca, Sanká, Reribakue, Witoto, Murui, Waunaná, Wanano, Piapoco, Ware-kena, Puinave, Siriano, Weó, Tukano, Pedubá, Cubeo, Epera, Amuesha, Yánesha, Guarayo, Ioresox, Cuña Pirúi, Chipaya, Aymara, Quechua, Mapuche. Today it is present in many mestizo societies, and in large urban cosmopolitan ones as well (González Bravo 1949; Borrás 1985; Baumann 1996; Gérard 1999; Rios 2012; Sánchez 1996; Barragán 2013).

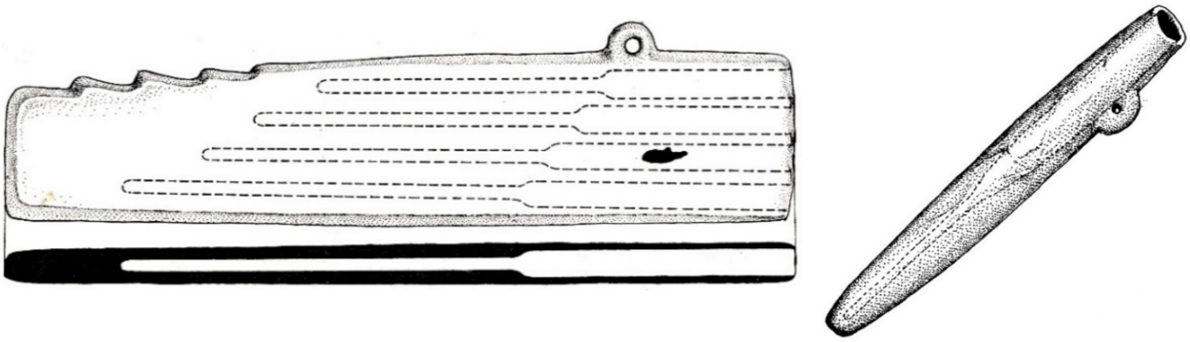

Figure 5: Prehispanic stone flutes, Aconcagua (900-1500 CE, Chile). This acoustic design shows direct connection to the present day *baile chino* tradition. Drawing by the author.

flutes that can be interpreted as having been played in pairs, but iconographic evidence attests to such a practice (Valencia 1982; 1987; 1989a; 1989b; 2016; Gruszczyńska-Ziółkowska 2004: personal communication; Ponce 2007: 162; Uribe 2007: 285; Sánchez 2016: 72, 83–84; La Chioma 2018). This alters our approach to the study of a flute, as we have to consider whether an instrument played in pairs is a flute or half a flute. Based on this consideration, we must redefine our concept of "musical instrument" or "sound object", and, consequently, our approach to organology as focused on single instruments.

The present Amerindian concept of "musical instrument" extends beyond two flutes played in alternation. Almost all flutes (*siku, tarka, pinkillo, kena, flauta de chino* among others) in the southern Andes are played in consorts in which all flutes share the same organological characteristics (typology, number of holes, sound producing mechanism, etc.), meaning that all have a similar timbre and share a similar playing technique. They are always played in unison; thus their individual sounds merge into the whole, giving the impression of an enormous single instrument played by many musicians (Figure 6; cf. Pérez de Arce 2018). There is strong evidence for the existence of this practice in some pre-Hispanic cultures, such as Moche and Nazca (D'Harcourt and D'Harcourt 1925; Jiménez Borja 1951; Pollard 1979; Valencia 1982; 1987; 1989a; 1989b; 2016; Gruszczyńska-Ziółkowska 2004: personal communication; 2009; La Chioma 2013).

Thus, our concept of a single "musical instrument" or "sound object" must extend to a group of objects. The usual way we understand "ensemble" in urban music, as a group of different instruments (piano, bass, drums, etc.) in which they can be substituted if circumstances require it (guitar, bass, drums), does not correspond to the Andean concept of "ensemble", in which a single flute –

Figure 6: Sikuriada (panpipe ensemble). Puno, 2008. Photo by the author.


Figure 7: Part of a large collection of similar clay flutes in the form of human figures. Museo de Antropología y Arte Contemporáneo de Guayaquil, Ecuador. Photo by the author.

with all its organological characteristics – defines the whole ensemble due to its specificity. For instance, the sound of ensembles in two villages may be perceived as different, if the flutes played in these ensembles slightly differ (they may have a different *palq'a* modificator of the tone quality, for example). If we consider the possibility of interpreting a pre-Hispanic flute as part of a more complex multiple instrument (Figure 7), a single instrument may no longer emerge as simple and crude, but as part of a complex sound system. If we extend the role of organology from the analysis of single objects to paired objects or multiple objects of similar characteristics, our possibilities of interpretation expand dramatically, because multiple objects can be understood as part of a single complex one. Since both practices (playing paired and multiple instruments) are found today in distant parts of the continent, this hypothesis gains weight as a methodological approach to archaeomusicological research. Using the Theory of Systems to interpret the complex multiple flute structures has proved very successful in my research, as it has permitted me to define some abstract concepts in a more comprehensive way (Pérez de Arce 2022).

4 Physical movement as part of the sound properties

The movement of the body of the performer (in dance or music) is an integral part of so-called "music" in the whole continent.[4] Instruments are usually played while dancing, walking or jumping. "Movement and music are the same" is said all over the Andes (Jiménez Borja 1951).

The musician's movement changes the concept of 'music' conceived as a pure sequence of sounds, isolated from its surroundings. The sound is influenced by the movement as it changes its relation with the listener and when it changes its position in space (Briceño 2015; Martínez 2014).

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[4] The concept of "music" is Eurocentric, as has been extensively discussed (see Nettl 2001: 125; Green 2003: 270; Szurmuk and Irwin 2009: 150–52; Castelblanco 2016: 48). This term does not exist in Amerindian languages and in great part of non-European languages (Nettl 2005: 17). However, all cultures use something we understand as "music", but its scope, its borders, and its relation with other expressions (human and non-human) varies greatly from one case to another. Even inside Eurocentric terms, definitions of music are multiple, depending on different perspectives (Cámara de Landa 2004: 128; Jiménez 2013: 131; RAE 2016), sometimes describing it as an activity (Small 1998: 2, 9, 13; Turino 2008: 1; Feld 2013: 237). In this article I use "music" as a universal system of organized sound, different from speech, used by man, and will not discuss its application to "musical instruments", whose discussion I have presented earlier (Pérez de Arce and Gili 2013).

Figure 8: A *lakita* ensemble (panpipes) entering the village of Jaiña (Northern Chile) at the beginning of the patrons-day celebration. During three days they will continuously travel through the village and its surroundings (2014). Photo by the author.

This creates a 'listening perspectivism' that can be considered a common aspect of all flute orchestras in the Andes. The sound is perceived in a different way by each of the listeners (because of their relative position to the sound sources), and the tone qualities of the sound also change constantly (because of the simultaneous movement of all sound sources; cf. Figure 8).

This concept is difficult to apply to pre-Hispanic sound objects, because we cannot remove them from museums, therefore we cannot test their sound in different locations, nor do we know in what places they were used in the past. There is little research on the acoustics of space in the Andes (Ferrari et al. 2017). But if we accept that the spectral composition of sound changed in subtle ways when these instruments were sounded along a ritual path, we broaden our understanding of sound as something that emerges from an object, but can be shaped by changing surroundings. Sound is not only something that emerges from a sound object, but is shaped by the surroundings in a dynamic, in resonance with the concept *yacha* used in northern Potosi, meaning knowledge as mutual transformation (Stobart 2002). According to the theory of perspectivism (Brabec de Mori 2022), houses, rivers, hills and other features of the landscape are not passive actors, but active participants, sharing in ritual practices with humans.

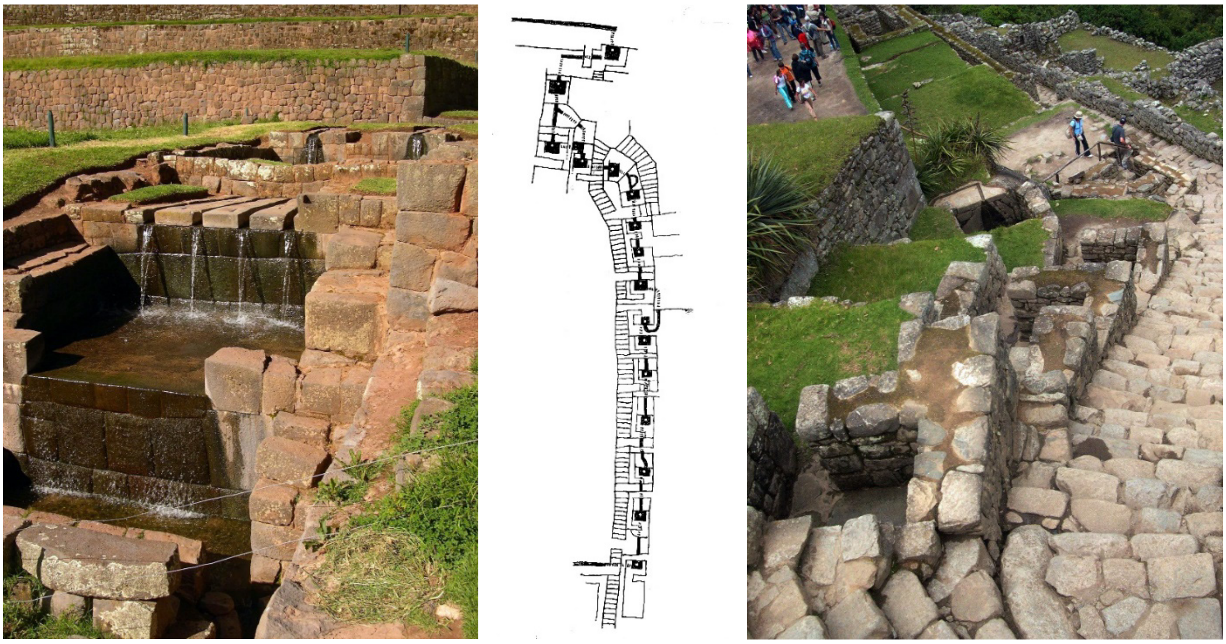

Figure 9: Inca (1200-1500 CE, Perú) waterfalls. Left: waterfall system in Tipón. Centre: plan of the great system of connected waterfalls in the main staircase in Machu Picchu, showing the connection between all waterfalls. Right: the same system, general view. Photos and drawing by the author.

This interpretation can also be applied to other kinds of sound structures. For example, in Machu Picchu (the Inca city in highland Peru) there are 16 waterfalls, each of which consists of a small water channel that transports water to a little rectangular pool about a meter below. All of these structures are carved in stone with great precision. Each pool is situated inside a small open chamber that condenses the sound of the waterfall. The whole structure is a masterpiece of precision, but it apparently had no practical use (Figure 9). However, if we think of it as a sound installation, perceived when climbing or descending the staircase, it can be interpreted as a precise sequence of sound events. This example is similar to dozens of places near Cuzco, and also as far away as Santiago, Chile and Cuenca, Ecuador, where I have seen similar waterfall structures associated with Inca culture. As waterfall sounds have a deep meaning for Andean music, in the role of the *sereno* (Diaz 2000; Mercado 2004), we can assume that these examples could have had a profound cultural meaning in the past. We can associate the interpretation of water as part of the 'musical' sphere of society with pre-Hispanic instruments that were sounded only by the movement of air through water, with no application of human breath, as it is the case with 'whistle bottles' from central and northern Andes (Pérez de Arce 2004; Valdivia 2021: personal communication).

All these examples may be interpreted as types of 'participant musical performance' (where there is no division between musician and public), different from the 'presentational musical performance' (where there is a spatial and social separation between musicians and the listeners) that is prevalent at present (Turino 2008; cf. Figure 10). Instead of thinking of Amerindian music as performed on stages, during exhibitions, competitions and urban carnivals (Mújica 2014), we need to see all our study objects as part of a vast, participative performance that includes the musician

Figure 10: Group of *mistisiku* (panpipe ensemble) walking through the streets of Puno (2008). Photo by the author.

as well as the hearer. If we consider the waterfall example as a sort of musical composition, which is activated by our movement, we can extend our field of study to include our own presence in the performative space.

5 Playing music as a form of social exchange between musicians and society

Understanding pre-Hispanic sounds and music requires perceiving many aspects that are difficult to define. If we consider the role of music in society in terms of a mutual fluid relation, we must define our understanding of 'music' as something that happens in 'time'. When we consider music as a phenomenon that 'develops in time', we are using two concepts that Amerindian languages (most of them, at least) lack: 'music' and 'time'. Many authors have discussed the term 'music' as a Eurocentric concept (Nettl 2001: 125; 2005: 17; Green 2003: 270; Szurmuk and Irvin 2009: 150–52; Castelblanco 2016: 48). Although we can find in every culture something that could be recognized as 'music', which is understood as a culturally organized sound, different from speech (Blacking 2006; Mansilla 2016), we must be careful not to apply this concept uncritically.

'Time' is another problematic concept for our study in America. According to Mendoza (2015: 182), the correct answer to the question "how is 'time' spelled in Aymara?" (*¿como se dice 'tiempo' en Aymara?*), is "it is not spelled" (*no se dice*). They have another concept, *pacha*, that we translate approximately as "space-time" (Manga 1994). This raises a fundamental question: how can we interpret 'Amerindian music' without 'music' and without 'time' concepts? We can understand it more clearly if we understand the participative performance during which music happens. The music of a fiesta ritual is not a 'concert' that occurs as a programmed sequence of sound events in time, but in a constant flux of spacetime changes (changes in space, including acoustic features, changes in the position of instruments, musicians and hearers, changes in weather conditions, changes in other sound sources at the fair, or the priests with megaphones, changes in the occurrence of simultaneous sound events, as the chanting in some ritual groups, etc.). Musicians play while moving through the streets, the graveyard, the nearby hill, the church, their sound shaped by each environment. The events, environments, the weather, and many other unplanned factors are included in the final performance. Here, the concept of 'music' is a creative and collective process that emerges from the interaction between humans and non-humans. Music creates the experience of place and time as animated, as, for example, it is conceived in northern Potosi (Stobart 2018). This conception can perhaps be applied more universally in music cultures, and if we use it in the construction of meaning of music in the past, it changes our research perspective.

'Time' is a complex matter in South American countries.[5] We have a time division in our history that separates time into 'before Columbus' – a long forgotten and unfamiliar past, studied by archaeologists – and 'after Columbus' the familiar one studied by historians, in Spanish. This shapes our understanding of 'Amerindian music' as an unfamiliar and distant reality. People in many other parts of the world perceive a continuum between their present time and history. In order to introduce a similar continuum to the Amerindian sense of time, it is necessary to decolonize our thinking, a process that has been initiated in the last decades by many scholars (Sánchez and Huarancca 2018; Pérez de Arce 2018; Quispe 2008).

These three aspects – time as a flux, as part of *pacha*, and as separated from our distant past – shape our understanding of 'pre-Hispanic music'. We should take these aspects into account when studying a sound object or an iconographic depiction of a performance, regarding it as part of a more complex unit. In this way, a simplistic and limited analysis develops into a more sophisticated understanding of interrelated factors, thus enriching the methodology of our discipline. This aspect, which has been discussed at length in ethnographic approaches since Merriam (1964), finds here a new interpretation.

Over decades of investigating 'pre-Hispanic music', I have come across many testimonies that report experiences of altered states of consciousness when playing pre-Hispanic flutes. Playing those flutes means a combination of hyperventilation and perception of strong, complex sounds,

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[5] In South America, we have a concept of "popular time" that is not necessarily akin with the "modern" one, being a sense of a relative time, in which an appointment to meet at 4:00p.m. can occur, for example, one hour later. This practice is not an exception, but a rule in less modernized regions of Chile, Bolivia and Peru, normally seen as a sign of "cultural primitivism" by politicians or businessmen. But for these regions it is an expression of a fluid time, linked with the events and rhythms of the present time, that will never be the same again. It is linked to the Andean *pacha* concept.

which can explain changes in the listener's and player's state of consciousness. As this modification happens in a subjective sphere, it is seldom shared, nor is it normally discussed as part of our work. However, since it is experienced by many researchers and musicians, neglecting it becomes a methodological problem. Once we are aware that a similar experience is common in many ritual flute orchestras (Mercado 1995–1996; Ávila 2012; Venegas 2013; Beaudet 1997), we should not hesitate to include this aspect as part of our study. The new trends in Andean and Amazonian ethnomusicology show that sound is understood to enable the communication between humans and non-humans as part of an ambiental multinaturalism (see Brabec de Mori 2022), which helps to integrate these experiences to our work.

I cannot offer any interpretation of time concept and alteration of consciousness in connection to our field of study. I think the relation of these is not merely methodological, but has to do with our role as archaeomusicologists in our society. We know our scientific duty, linked with our discipline's name. But the research we do is integrated into a greater discussion that is taking place in our society. The so-called *emergencia indígena* (Indian emergence, Bengoa 2015), including new political, social and intellectual changes, is bringing to light new questions about indigenous people. In this context, archaeomusicology has begun to serve many people, from artisans, musicians, and researchers to common people. This poses new challenges for our discipline, as there have also emerged many misconceptions, mistakes, inconsistencies that are legitimate in their own right, since they do not come from the academic environment and may thus contribute to the academic debate but they do not require this debate to provide answers. Finding my role in the face of these new social challenges has recently been of great importance to my work.

Bringing this reflection to a close, I hope this article contributes to a discussion of archaeomusicology focused on Amerindian (mainly South Andean) problems, which also are of interest in other parts of the world. In South America, we need to find local solutions to local problems, such as finding local terminology to replace European concepts. However, many problems arise from more profound differences, as is the case with concepts that are not named in indigenous languages; for instance, the 'tuning' system of flutes that for European ears sounds like a 'de-tuning' (Pérez de Arce 2021). Archaeological sciences need to invent new terminology to replace the old one that disappeared long ago. Science is also a reflection of our time. Today, our duty as archaeomusicologists is linked with society, and I feel my society, here in Chile and in the neighboring countries, is involved in certain discussions in which our findings can serve multiple purposes, with some of them being only remotely related with our field of study.

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Different Blowing Techniques for Palaeolithic Aerophones: Animal Calls, Clarinets, and Flutes

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Abstract

This article examines how individual approaches in experimental music archaeology may produce different results in reconstructing Upper Palaeolithic aerophones. The paper reveals how sound tools have been used by both prehistoric and modern hunters to imitate animal calls or to chase their prey in a specific direction. The best examples of such practices are the phalangeal whistles and a possible scraper, which have been found along with the remains of Neanderthals in Europe. A possible scraper was recently discovered in the Middle Stone Age African Border cave. Early percussion instruments like drums or different kinds of idiophones might have had multiple functions for the nomadic hunters.

From the 1990s to 2009 a number of new finds of possible Palaeolithic aerophones initiated various experimental studies. Unfortunately, many important questions could not be resolved. I intend to revive the discussions on playing techniques on one hand, and to contribute to the arguments for the non-human origin of some finds on the other.

After discussing sound production techniques of simulated animal calls and summarising the possible use of sound-producers as hunting tools, this article briefly presents two possible reconstructions with reeds and two different techniques of blowing a flute without any mouthpiece.

Keywords

Palaeolithic aerophones – Perforated mammal bones – Wing bone flutes

1 Introduction

The conclusions of my occasional experimental music performances with HF1 aerophone reconstructions in the last 11 years strengthen the hypothesis of Jean-Loup Ringot,[1] who first reconstructed this unique find as a clarinet. Since 2010, I have played with the ensemble "SteinzeitSession" and in the duo "Schtoa". We play replicas of archaeological finds of musical instruments in group performance or in a duo. The songs mostly relate to hunting scenarios or specific animals. The range of experimentation goes from Barbeque at the beach with ten to fifteen musicians and friends to duo or solo meditation music. With the clarinets and flutes, my intention was to discover which possible melodies or melodic motifs are most easily playable. It is clear that the potential to evoke very different moods, as well as a great variety of other applications resides in these sophisticated clarinets and flutes.

Individual approaches influence the reconstruction of different playing techniques for Palaeolithic aerophones. The doyen of experimental music archaeology in Germany, Friedrich Seeberger († 2011), successfully played replicas of Upper Palaeolithic aerophones found at the Swabian Alb in southwestern Germany as oblique or vertical rim-blown flutes.[2] However, his replicas are reconstructed only to the length of the fourth fingerhole. They are remarkably shorter than the Hohle-Fels find. The relation of length and diameter control optimal playability as a flute. Friederike Potengowski[3] and Simon Wyatt[4] repeatedly argue in favour of interpreting these finds as flutes. Their experiments imply that – for professional modern flautists – it is possible to play the tiny aerophones from the radius wing bones of swan or vulture as flutes. However, in my opinion, there are doubts about the accuracy of the replicas played by Friederike Potengowski, which seem to have wider internal diameters than the original find.

In 2012, two articles in *Studien zur Musikarchäologie* 8 by Jean-Loup Ringot[5] and Simon Wyatt[6] introduced me to the importance of reed instruments in Upper Palaeolithic European soundscapes. Ringot presented his interpretation of the Hohle-Fels aerophone HF1 as a clarinet with a birch bark single reed. Wyatt emphasises the convincing sound of the best preserved Isturitz aerophone played with a single reed mouthpiece ("Ersatz clarinet"[7]), which was also tested by Francesco d'Errico and Graeme Lawson,[8] and once more by Carlos García-Benito.[9] In these types of clarinet mouthpieces, the 'tongue' is cut from the wall of a tube with one closed end. The tongues can be cut from the main aerophone tube (like the Saami *Fadno* clarinet[10]), or the mouthpiece may be

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[1] Ringot 2012.
[2] Seeberger 1998; Münzel, Seeberger and Hein 2002; Conard et al. 2004.
[3] Conard et al. 2015; Münzel et al. 2016.
[4] Wyatt 2012; Wyatt 2016.
[5] Ringot 2012.
[6] Wyatt 2012.
[7] Wyatt 2012: 394, Fig. 4.
[8] D'Errico and Lawson 2002.
[9] García-Benito 2018.
[10] Emsheimer 1964.

separate, consisting of a smaller tube inserted into the main aerophone tube (like on *Launeddas* and bagpipes). Numerous clarinet-like instruments around the globe are sounded with such mouthpieces. An attachable mouthpiece, like I use for Isturitz (Figure 6), allows the playing of the same tube with or without a mouthpiece – one instrument body serves as clarinet or flute, depending on what the situation requires. However, I am so far unaware of any ethnographical parallel for such a double use. Wyatt conducted experiments with clarinet mouthpieces with a tongue split off from the tube in reconstructing the Isturitz aerophone.[11] My results further differ from Simon Wyatt's experiments regarding Isturitz and Hohle Fels: the Isturitz aerophone appears to be a multifunctional musical instrument to me. I can play a clear-sounding flute version – vertically oriented, as Barnaby Brown plays so impressively[12] – including a major third. Alternatively, I achieve a more 'windy' flute version with the oblique rim blowing technique, yielding a minor third instead of the major third. If I insert the attachable mouthpiece, a strong clarinet sound can be produced (five pitches in a range of a fifth; Table 2; Table 3; Table 4).

In 2016, Simon Wyatt tried clarinet and flute playing, and concluded that the HF1 aerophone can also be played like a flute, very beautifully, too.[13] I have not been successful in playing HF1 like a flute. I think this is due to the small diameter in relation to the length. According to Gabriele Dalferth (this volume), a relation between seventeen and twenty-four to one centimetres in length and diameter provides the optimal proportions for Irish six hole whistles. A radius wing bone of a swan or a vulture does not fall within this optimal ratio. The Hohle-Fels aerophone presumably was about twenty-six centimetres long, with 0.8 cm in maximum external diameter and around 0.4 cm in minimal internal diameter (reconstructed to former full size of a radius bone). This is relevant when comparing the differences in aerophone diameters to the differences in sound production. With the clarinet replica in a comparable size of the HF1 aerophone, I am able to play seven pitches in the range of one octave, using all fingerholes (and enhanced air-pressure for the highest pitch, Table 1).

2 Animal calls and perforated bones

Phalangeal whistles have been interpreted as hunting whistles in earlier studies.[14] In 2013, their remarkable impact on reindeer behaviour was described for two distant ethnographic contexts:[15] the animals attribute the shrill sound to alarm calls, carnivore calls, or something similar. The prey reacts by holding still when recognising such a call, standing motionless or even lying down on the ground.

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[11] Wyatt 2012: 394, Fig. 4.

[12] See the documentary "Blasts from the Past" (https://youtu.be/mF2LpQA_jtQ).

[13] Wyatt 2012; Wyatt 2016.

[14] D'Errico and Villa 1997; Holdermann 2001; Dauvois 2005; Caldwell 2009.

[15] Neal 2013; Morley 2013; see Praxmarer 2019: 77–78.

Another sound tool that may serve for hunting purposes is the so-called scraper, which imitates a warning call of red deer,[16] or bird sounds like ratchets.[17] Recently, I discovered two new possible scrapers from early archaeological contexts:[18] a raven ulna fragment with intentional notches from the Zaskalnaya VI (Kolosovskaya) site in Crimea, which archaeologists discovered in a Neanderthal context,[19] and a notched baboon fibula from Border cave that belongs to the Middle Stone Age in Africa (Homo sapiens), dated from 44 000 to 42 000 ya.[20]

To assess the possible blowing techniques for Palaeolithic aerophones, potential parallels from modern hunting whistles and animal calls have to be considered. Looking at possible hunting aerophones from Neolithic Scandinavia,[21] it becomes clear how simple tubes or hollowed out objects, with or without perforations, can fulfil helpful functions for hunters. Some of the depicted possible aerophones are reminiscent of perforated mammal bones, mostly bear bones that appear in archaeological contexts of the Aurignacian cultures of the eastern Central European region (Austria, Germany, Croatia, Slovenia). In one case – the Slovenian Divje Babe cave – such a perforated bear bone was found in a Neanderthal context, dated to around 55 000 ya.[22] The possible aerophones from bear bones and comparable mammal bones[23] show perforations that humans could have punched into the bones to craft a bone aerophone.[24] Curt Sachs was one of the first music-archaeologist researchers who postulated that the bear bone flutes represent the earliest aerophones (next to phalangeal whistles).[25] The Slovenian researchers who excavated the prominent find,[26] as well as scholars like Bob Fink,[27] and others who argue for developed cognitive abilities of Neanderthals,[28] argue for the Divje Babe find as a “Neanderthal flute”.

In contrast, other researchers point to the traces of carnivore gnawing which have been found on all potential bear bone aerophones (and other perforated mammal bones).[29]

The Slovenian researchers explain the traces of biting on the possible aerophone with the theory that the “flute” was gnawed both before and after the use as a human musical instrument. I would like to use this opportunity to assess the Slovenian researchers’ arguments for human influence on the find. Firstly, they claim to have found remains of the blowing edge.[30] This is a flat edge of 2 or 3 mm, which could easily stem from carnivore influence as well. They also claim to have

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[16] Holdermann 2001: 90.
[17] Cajsa Lund in the documentary “Blasts from the Past” (above, n. 12).
[18] Praxmarer 2023.
[19] D’Errico et al. 2017.
[20] D’Errico et al. 2017b.
[21] Lund 1988.
[22] Turk 1997.
[23] Albrecht et al. 1998.
[24] Turk et al. 2020.
[25] Sachs 1934.
[26] Turk 1997; Turk and Kunej 2000; Turk et al. 2005; Turk and Dimkaroski 2011; Turk et al. 2018; Turk et al. 2020.
[27] Fink 2002.
[28] E.g. Bedarnik 2015.
[29] Zagiba 1976; Holdermann and Serangeli 1998; Albrecht et al. 1998; D’Errico and Villa 1997; D’Errico et al. 2003.
[30] Turk and Dimkaroski 2011.

found microscopic scratches,[31] which could easily be explained by the pushing and shoving of the bone in the soil. Furthermore, the experimental attempt to punch holes into the flute does not convince me at all. There is no proof that Neanderthals ever used a multi-compositional set of a silex tool, a bone intermediate piece, and a wooden hammer[32] to perforate a bone.

I will now summarise briefly the differences in creative expressions before and after the Mousterian-Aurignacian transition in Europe. The Divje Babe find has been correlated with a Neanderthal fireplace. The material remains of these Neanderthals belong to the Mousterian culture. The Aurignacian culture is attributed to the time when modern humans first reached the central European region. Symbolic or modern behaviour like multi-component weapons, pigment and adhesive use, burial of dead and care of wounded people, proto-geometric and geometric incisions, was part of the Neanderthals' Mousterian cultures in Europe and the Near East, as well as in Homo sapiens cultures of Middle Stone Age Africa.[33]

The Aurignacian cultures that initiated the Upper Palaeolithic period in Europe in contrast have highly developed traditions of visual arts and musical instruments that surpass many other human hunter-gatherer cultural remains.[34] Aurignacian visual arts included carved statuettes and cave paintings that were rich in naturalistic and precise details, as well as advanced in their figurative composition. The wealth of different types of instruments and sound tools, the possible high-tech sound-production techniques, and intended octave intervals[35] characterise the sophisticated and elaborate musical remains of the prehistoric arts of this era. In my forthcoming doctoral thesis I postulate that the meeting of humans with very different lines of ancestry is responsible for the development of this rich culture of arts in Europe. From Africa to the Near and Far East, modern humans were contemporary and probably in contact with Neanderthals and late-erectus humans like Denisovians. That the Upper Palaeolithic diversification of cultural expression is related to cultural diversity is posited by the Melting Pot Theory (MPT). I suggest that the Upper Palaeolithic cave art would have been impossible without the multicultural setup of the societies of Late Ice Age Europe – cultural diversity leads to cultural variety.[36]

From its position directly at the interface of the two Palaeolithic cultural horizons of the Mousterian and Aurignacian, the Divje Babe possible bear bone aerophone would appear to be the missing link of music archaeology. But ultimately we do not have any evidence for intentional melodic musical aerophones of Neanderthals.

However, a replica of the bear bone with an attached membrane, which works like a modern

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[31] Turk et al. 2005.

[32] Turk et al. 2018.

[33] D'Errico et al. 2003; D'Errico and Henshilwood 2011; Wynn and Coolidge 2015; Wynn and Coolidge 2016; Půta and Soukup 2015; Praxmarer 2023.

[34] Clottes and Lewis-Williams 1997; Floss 2006; Conard et al. 2009; Blench 2007; Morley 2013; Půta and Soukup 2015; Praxmarer 2023.

[35] Praxmarer 2019; Praxmarer 2023.

[36] Praxmarer 2023.

kazoo – a voice disguiser (Figure 1.2) – demonstrates the possible function of such ecofacts as hunting tools. B.M. Blackwood and H. Balfour show the diverse use of vibrating membranes in many musical cultures in an ethnomusicological article from 1938.[37] I own a small collection of modern animal calls made for modern hunters. A small duct flute can imitate mice calls (Figure 2.1), while the technology of reed-constructions enables calling deer (Figure 2.2), ducks (Figure 2.3) or wild boars. Membranes are used to imitate the death-cry of carnivores' preferred game (Figure 2.4), thus convincing the carnivore that mortally wounded game can be found at the location of the death cry.

Another kind of sound tool with vibrating membrane ('mirliton' or 'Ansingtrommel') is a bird imitation rim-membrane construction (Figure 2.5), which is played between tongue and top of the mouth. It enables the hunter to easily play fast bird-call-like sequences by moving the tongue while blowing.

I am able to play the Divje Babe replica in Figure 1.1 like a signal hunting whistle with three pitches (blown from the notch with the lower end closed). If I turn the aerophone around I can use the attached membrane as a voice disguiser. For Palaeolithic hunters, voice disguisers enabled the imitation of animal calls. In my experiments I mostly imitate bison or deer calls. Carlos García Benito et al. (2018) used a similar membrane construction for a bird bone find from the Le Placard cave in France, where a great number of Upper Palaeolithic aerophone remains were found. Jean-Loup Ringot even uses such a mirliton to add distortion to a clarinet.[38] When the fingerhole, which is covered by a membrane, is opened, the membrane vibrates and adds a distortion effect. It is difficult to prove that hunting whistles and animal calls preceded musical aerophones. Still, finds like the early possible scrapers and the phalangeal whistles have long been interpreted in this direction. At any rate, the perforated mammal bones might equally have served as animal calls, signal whistles, or musical tools, depending on what the situation required.

Figure 1: 1. Replica of the perforated bear bone and possible aerophone from Divje Babe (Slovenia) bought in the Ljubljana National Museum. The membrane from bowel skin enables its use as voice disguiser.
2. Modern Kazoo, Voice disguiser for musical purpose

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[37] Blackwood and Balfour 1938.

[38] Ringot 2012.

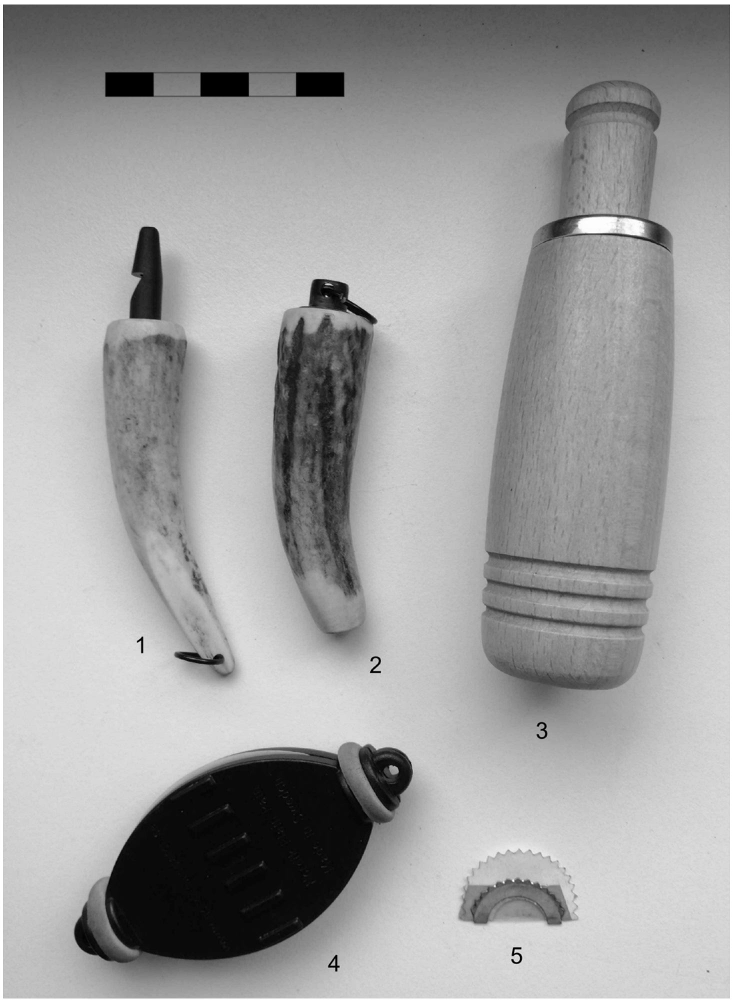

Figure 2: Modern animal calls: 1. Mouse call, duct flute; 2. Red-deer call, reed aerophone; 3. Duck call, reed aerophone; 4. Carnivore call, mirliton membrane; 5. Bird call, mirliton membrane. Scale: 5 cm.

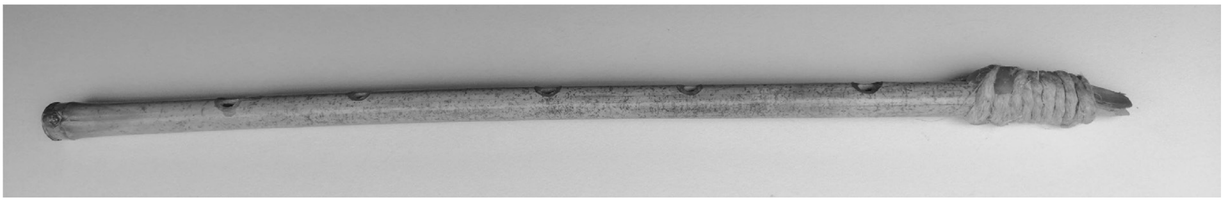

Figure 3: HF1 clarinet reconstruction from bamboo, with a birch bark single reed (clarinet, saxophone) mouthpiece.

The bones gnawed by carnivores from Divje Babe and from the Aurignacien layers in Austria, Germany, Croatia, and Slovenia are the subject of much controversy. Some researchers argue for man-made musical instruments,[39] while others hold that these bones are simply products of carnivore gnawing and are not musical instruments.[40] I suggest, even if these ecofacts have been shaped by animals, they could have been used as aerophones by prehistoric humans, in whose contexts these possible aerophones were found.

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[39] Turk 1997; Turk and Kunej 2000; Fink 2002; Turk et al. 2018; Turk et al. 2020; Bedarnik 2015.

[40] Zagiba 1976; D'Errico and Villa 1997; Holdermann and Serangeli 1998; Albrecht et al. 1998; D'Errico et al. 2003.

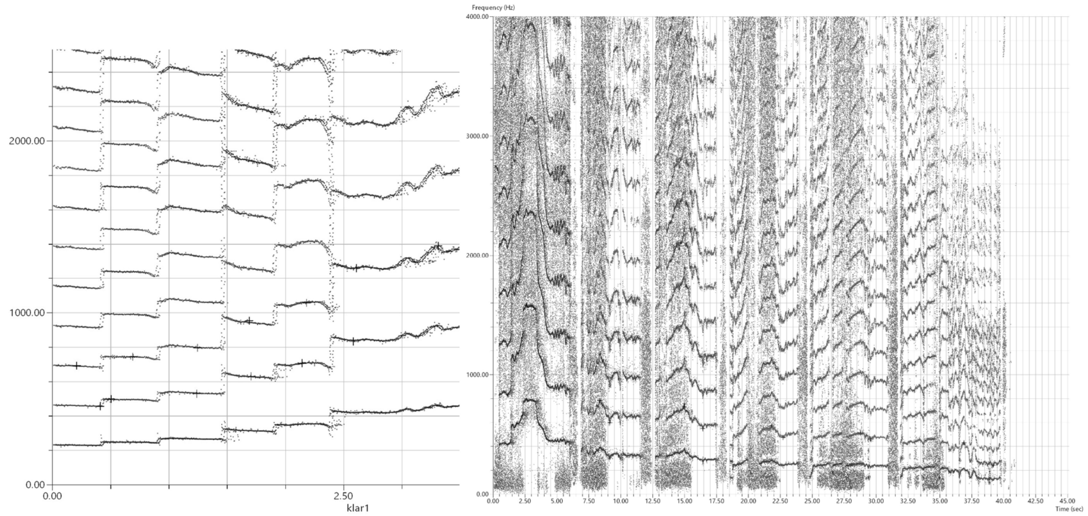
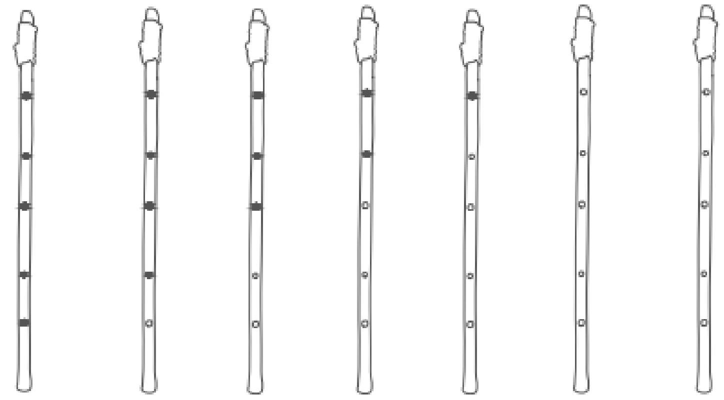


Figure 4: Frequencies played on HF1 as a clarinet: with relative stable air pressure in the left diagram; with lower and higher pressure in the right diagram (x-axis: time in s; y-axis: frequency in Hz).

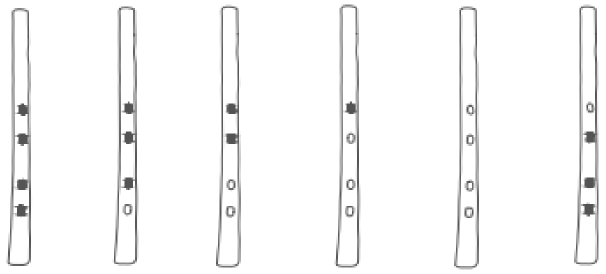


frequency (Hz)	455.94	499.22	529.51	630.49	706.94	833.89	936.31
pitch	B♭$_4$	B$_4$	C$_5$	E♭$_5$	F$_5$	A♭$_5$	B♭$_5$
Deviation (cent)	-38.38	18.60	20.58	22.76	20.90	6.82	7.38
semitone steps	-	1/2	1/2	3/2	1	3/2	1
minimum pressure	241.59	462.02	474.67	548.75	597.53	832.42	-
maximum pressure	429.53	512.61	572.24	731.23	783.63	1580.43	-
f1 : f2	1.78	1.11	1.20	1.33	1.31	1.90	-

Table 1: Pitches played on HF1 as a clarinet. The sixth finger position is the same as the fifth. The octave is easily achieved by increasing the blowing pressure in this position. This table results from the frequency analyses in Figure 4. The tonal structure might be perceived as the following steps: bass note, minor second, major second, perfect fourth, perfect fifth, minor seventh, octave.

3 Further arguments for Ringot's Hohle-Fels Aerophone (HF1) blowing technique

To show the intentionality behind the measuring of the fingerholes for the replicated aerophones HF1 (Hohle-Fels Cave, southwestern Germany) and the mostly complete Isturitz aerophone (Ist1:



frequency (Hz)	785.49	889.08	966.76	1182.56	1467.41	1536.46
pitch	G_5	A_5	B_5	D_6	$F\sharp_6$	G_6
Deviation (cent)	3.30	17.77	-37.21	11.60	-14.76	-35.15
semitone steps	-	1	1	3/2	2	1/2
minimum pressure	763.88	885.61	970.30	1203.20	1451.97	1526.07
maximum pressure	785.05	917.37	1012.65	1229.66	1483.72	1541.95
f1 : f2	1.03	1.04	1.04	1.02	1.02	1.01

Table 2: Pitches of Ist1 played as a rim-blown flute held vertically. The fifth position is overblown with the uppermost finger hole opened, and all others closed. The tonal structure might be perceived as the following steps: bass note, major second, major third, perfect fifth, major seventh, octave.

frequency (Hz)	708.35	829.36	901.97	1071.39	1240.82	1458.65	1724.88
pitch	F_5–$F\sharp_5$	$G\sharp_5$	A_5	C_6–$C\sharp_6$	$D\sharp_6$	F_6–$F\sharp_6$	A_6
Deviation (cent)	24.35	-2.60	42.69	40.69	-5.13	-25.12	-34.89
semitone steps	-	1	1/2	3/2	1	1/2	3/2
minimum pressure	651.36	760.89	837.56	1018.29	1166.15	1363.31	1648.09
maximum pressure	766.36	875.90	947.09	1111.39	1308.55	1434.51	1774.06
f1 : f2	1.18	1.15	1.13	1.09	1.12	1.05	1.08

Table 3: Pitches played on Ist1 as a rim-blown flute in oblique orientation. The second position from the right side is overblown with uppermost hole opened, and the other fingerholes closed. The last position on the right is overblown with the third finger hole – counted from the upper side – opened, and the other fingerholes closed. The tonal structure might be perceived as the following steps: bass note, major second, minor third, perfect fifth, major sixth, octave and tenth.

southwestern France, 83888(a)/75252-A3 [DB 2][41]), I undertook frequency analyses from short recordings. I played two lines for each blowing technique – one while opening finger holes one after the other and at the same time blowing a continuous breath with a relative stable air pressure; – in the second recording I blew with minimal and maximal pressure in each finger hole position and measured the maximal and minimal frequencies (to have the approximate full range at one position). I have not yet managed to produce sounds from all fingerholes on HF1 reconstructed as a flute (Figure 5). I present the frequency analyses for HF1 as a clarinet (Figure 3 and Figure 4) in Table 1.

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[41] D'Errico et al. 2003: 39–42.

Figure 5: Hohle-Fels vulture radius Aerophone HF1 reconstruction in bamboo: Notched Flute (or signal whistle?), attachable ideoglot reed mouthpiece (like Sardinian *Launeddas*). This reconstruction of Hohle Fels only works at the first two to three fingerholes when I try to play it like a flute.

With the Isturitz replica from a real vulture ulna-bone (Figure 6), which Jean-Loup Ringot gave to me as a favour, I am able to play in two different ways, vertically as well as obliquely. The sound and intervals between the pitches vary depending on whether the flute is played vertically straight down or softly sidewise over the rim, with the tube turned to an angle of about 22.5° (Table 2; Table 3).

When I put an attachable single-reed mouthpiece into the opening of the same bone aerophone corpus, the instrument becomes a loud clarinet instrument. I find the Ist1 aerophone instrument convincing in all three possible blowing techniques, while HF1 – a very tiny instrument from a radius wing-bone of a vulture – plays convincingly like a clarinet. I was able to procure the radius of a swan, which was used for a replica of the Geißenklösterle swan radius aerophone. The diameters of such radii are so small that the air column activated by flute rim-blowing techniques appears too weak to me to reach the end. When I saw the original find of HF1 in an exhibition in the Blaubeuren Museum during an excursion with a group of musicology students from Innsbruck, I was surprised by how tiny this instrument was. A swan radius in my collection (Figure 11) has a straight cut end, which shows a minimum internal diameter of 0.4 cm. To me, Ringot’s proposition absolutely makes sense for that diameter. Flute-like blowing technique might be possible as well. While I do not want to negate all the flute experiments that have been successful in former studies, I am unable to ignore the impression that the flute replicas of aerophones from the Swabian Jura played by F. Potengowski (Geißenklösterle, Vogelherd, Hohle Fels) have bigger diameters than the original finds. This makes it easier to play them like flutes. The reconstructions of the southwest German finds shown by F. Seeberger,[42] consisting of radius bird wing bones, are shorter than the circa 20 to 30 cm that would be the length of a radius aerophone from a complete bird wing bone.

The differential in air pressure between vertical and oblique flutes results in the different sounds they produce. Using the oblique technique, the pitches can easily be bent using the mouth cavity. The vertical technique has a very narrow bandwidth in comparison. The most important differences are that the Ist1 flute plays a minor versus a major third and a major sixth versus a

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[42] Seeberger 2002.

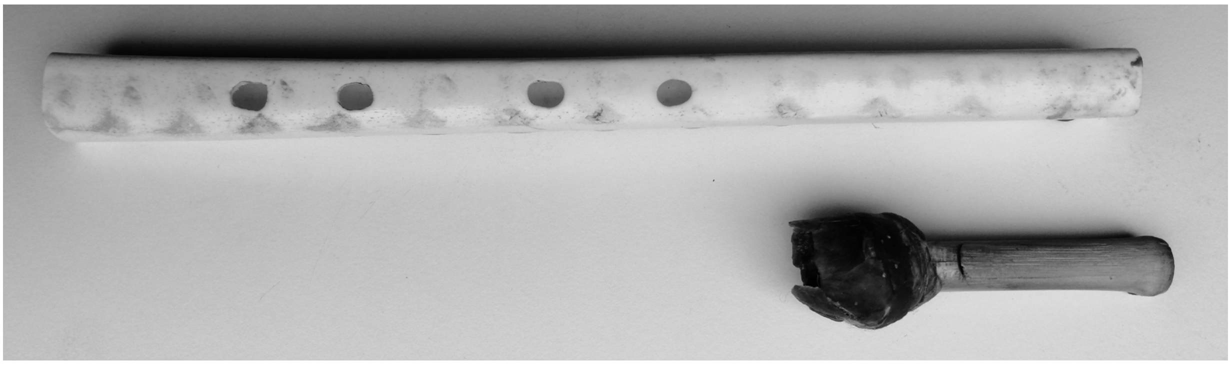


Figure 6: Vulture ulna replica of Ist1: Rim-blown flute and attachable single-reed.

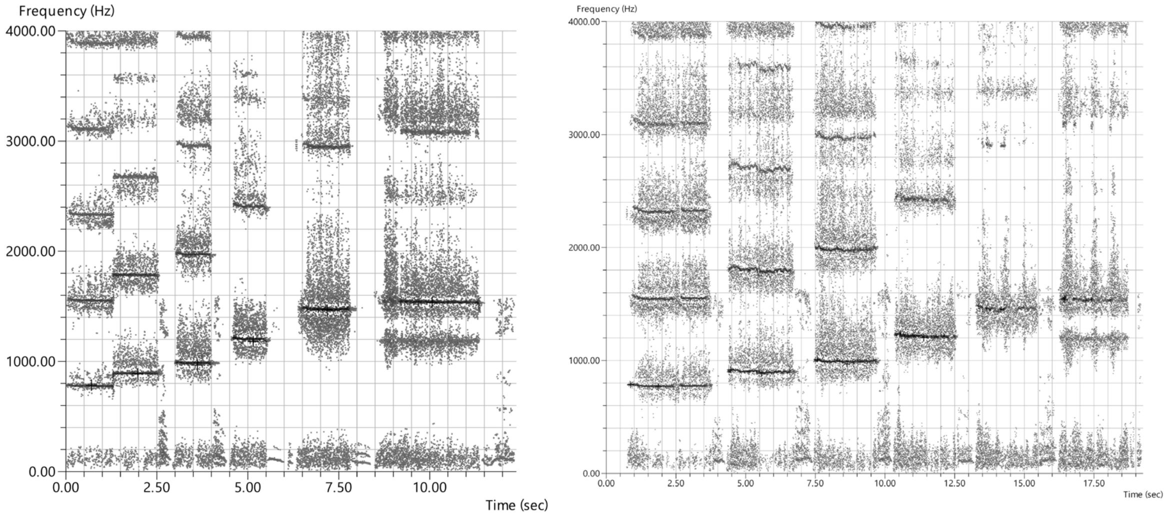


Figure 7: Frequencies played on Ist1 as a rim-blown flute held vertically: with relative stable air pressure in the left diagram; with lower and higher pressure in the right diagram. The vertically oriented version allows very limited variation of the frequencies through air pressure. For this reason, these two diagrams differ only very slightly. The highest frequencies result from overblowing with one finger hole opened (see Table 1).

major seventh, when played in oblique or vertical position, respectively. In summary, the Isturitz vertical flute produces a scale that we might perceive as bass note, major second, major third, perfect fifth, major seventh and octave (Figure 6 and Figure 7; Table 2). When I play the same flute in oblique orientation – with less blowing pressure and a softer timbre – the scale is surprisingly different: bass note, major second, minor third, perfect fifth, major sixth, octave and tenth, including two overblown pitches (Figure 6; Figure 8; Table 3).

If I attach a single-reed (7 mm internal diameter, 6 cm total length inserted by 6 mm) with a cut-out tongue into this flute reconstruction, the sound is rich in overtones and starts an octave lower than when blown as a flute. The sound and melodic character change completely. The scale would fall within the range of bass note minor second, major second, major third, perfect fifth (Figure 6; Figure 9; Table 4).

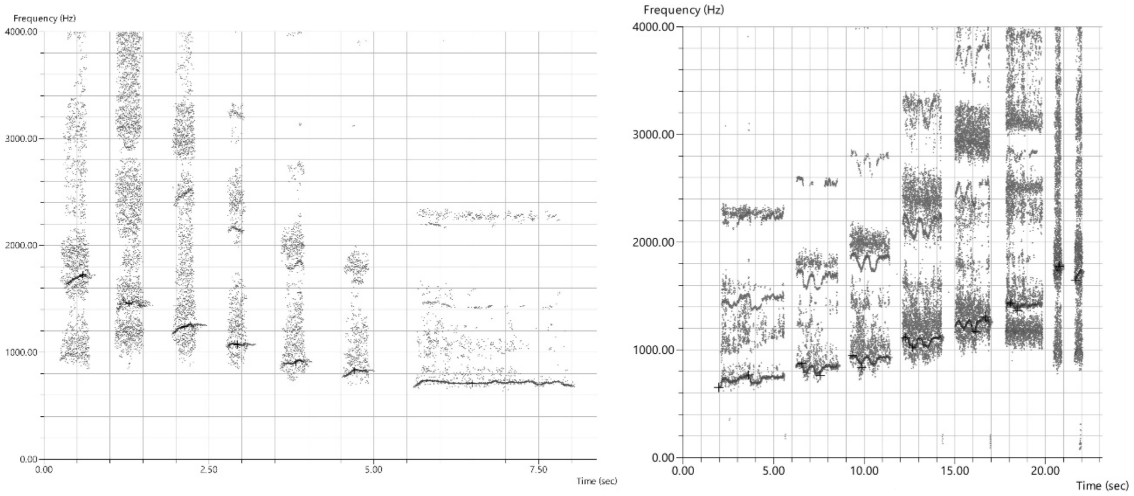


Figure 8: Frequencies of Ist1 played as a rim-blown flute in oblique orientation. Left: relative stable air pressure; right: with lower and higher pressures. The highest frequencies result from overblowing with one finger hole opened (see Table 2).

The HF1 clarinet reconstruction (Figure 3; Figure 4; Table 1) opens up sophisticated possibilities that might be described as bass note, minor second, major second, perfect fourth, perfect fifth, minor seventh, octave. When I play this reconstruction, the sound and melodic properties lead me to play an interpretation of the Pink Panther melody. This might relate to my personal expectations and the sound of the single reed and the number of fingerholes. However, it is a sophisticated instrument, and I find it much more convincing than the flute reconstructions that I have tried. Most importantly, the clarinet achieves exactly an octave range from the lowest to the uppermost finger hole (Figure 3; Figure 4; Table 1). Presumably, the generally wider finger hole distances of HF1 and other radius aerophones make more sense when equipped with a reed, while the fingerholes of the ulna flutes from Isturitz exhibit completely different systems of finger hole positioning. A worldwide comparison between the distances of the first fingerholes to the proximal end should be the subject of future research. The current state of research will be summarised in chapter 3. Finally, Ringot's experimental approach to reconstruct the bevelled (ca. 30°) end with an attached reed – like a clarinet – becomes more plausible with the results of my own experiments. Instead, the remarkably wider ulna bones, which provided the raw material for most of the Isturitz aerophone finds, absolutely make sense as flutes. My experiments therefore show that ulnae might be more suitable for flutes than radii – because of the diameters (Figure 10). Figure 11 shows a swan radius replica in my collection with a maximum external diameter of about 8 mm. The minimum internal diameter at the narrow end reaches about 4 mm (Figure 11.2).

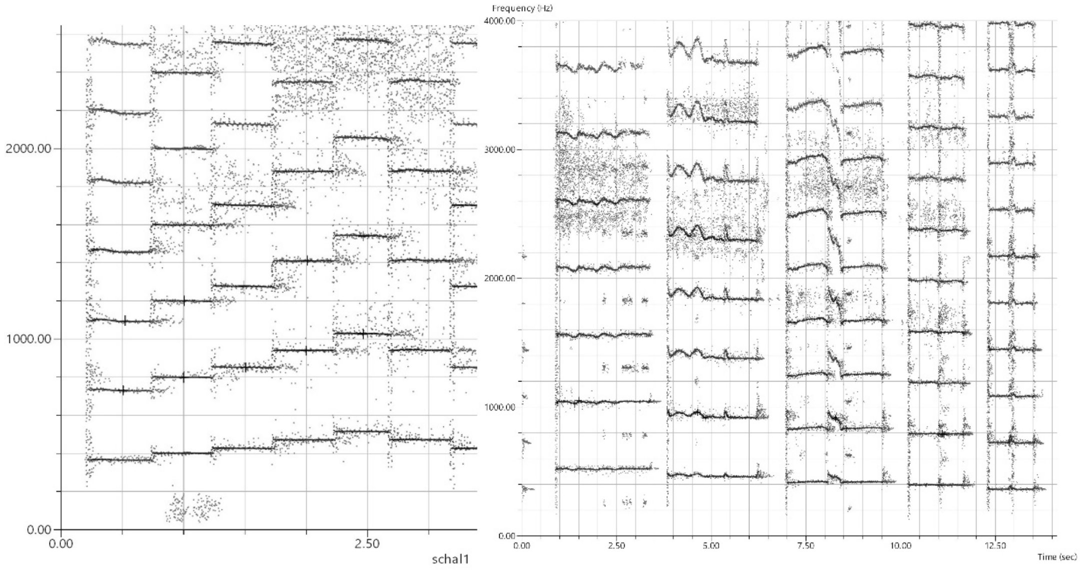
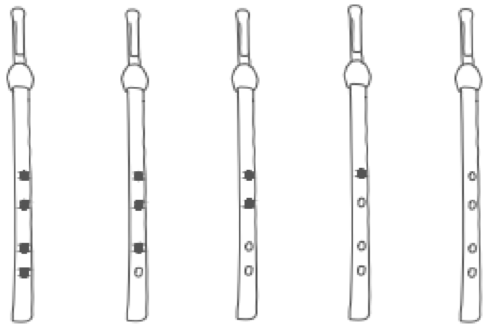


Figure 9: Frequencies of Ist1 played as a shawm. Left: relatively stable air pressure; right: lower and higher pressure.



frequency (Hz)	730.64	797.30	850.63	938.95	1025.61
pitch	F♯$_5$	G$_5$	G♯$_5$	A♯$_5$	C$_6$–C♯$_6$
Deviation (cent)	-22	29.14	41.23	12.25	-34.90
semitone steps	–	1/2	1/2	1	3/2
minimum pressure	724.16	785.61	832.87	915.59	1021.95
maximum pressure	743.07	795.06	915.59	958.13	1052.67
f1 : f2	1.03	1.01	1.10	1.05	1.03

Table 4: Pitches of Ist1 played as a shawm. With a little more air pressure, position 4 yields pitches up to a fifth above the bass note. This table results from the frequency analyses in Figure 9. The tonal structure might be perceived as: bass note, minor second, major second, major third, perfect fifth.

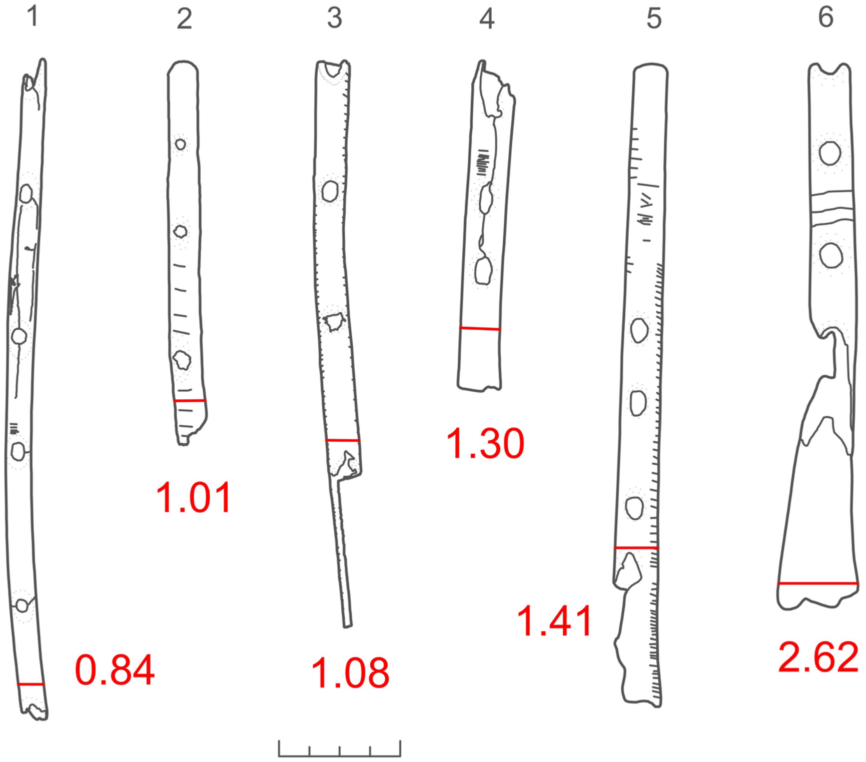


Figure 10: Diameters in cm of the radius (1–2) and ivory (3) aerophones from Germany, and the ulna aerophones from Isturitz (4–6).

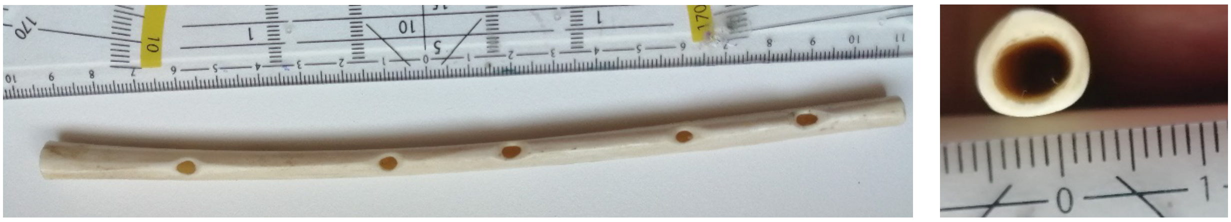


Figure 11: Swan-radius aerophone corpus based on the swan radius find from Geißenklösterle (left). The minimum internal diameter measures about 4 mm (right).

4 The ethnographic record

A look at ethnographic material, even though not fully comprehensive, might contribute to the question whether different aerophone diameters facilitate specific blowing techniques. An argument in favour of a clear mutual influence might be the very restricted distribution of duct flutes and aerophones with fingerholes in the indigenous cultures from Australia and Africa.[43] In contrast, indigenous Americans and Northern Eurasian modern-day hunter-gatherer ethnic groups do make use of duct-flutes[44] and single-reed aerophones[45] with fingerholes. The diameter of the

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[43] Blench 2007.

[44] Blench 2007; Omerzel-Terlep 1997: 205.

[45] Emsheimer 1964.

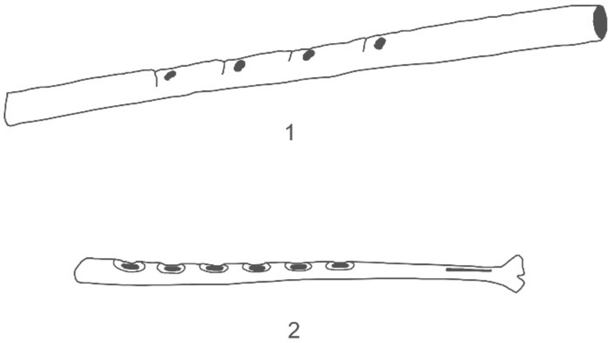

Figure 12: 1: Elder wood flute, Blackfoot Native Americans of the Plains (according to Morley, 2013, Figure 2.1); 2: *Fadno*, Saami, indigenous people from Northern Eurasia (according to Emsheimer, 1964a, Figure 2).

elder-wood rim-blown flute presented by Morley[46] among the musical instruments of the Blackfoot indigenous Americans is comparable to the Isturitz diameters, while the *Fadno*[47] – a Saami (northern Scandinavia) single-reed aerophone – has a remarkably small diameter (4–7 mm), comparable to radius wing bones (Figure 12).

Are the octave ranges measured in the frequency analyses (HF1 clarinet, both Isturitz flute techniques) incidental or intentionally created intervals? Do they depend solely on the individual peculiarities of the reed I made and on my own personal playing methods of these aerophones? Whenever a prehistoric aerophone carver places a fingerhole halfway along an aerophone's effective length, the resulting frequencies will come close to an octave. The 2:1 relation of the frequencies can be clearly seen in Table 1–Table 3. As the pitch relations of flutes and reeds differ, the fingerholes have to be positioned differently. A flute physically represents a tube with two open ends, with wavelengths of $\lambda_n = 2s/n$ (s: length of the tube, n: number of natural oscillation) and therefore natural oscillations following integer relations (1, 2, 3, ...). A cylindrical tube with one closed end, such as a clarinet, in turn produces wavelengths of the form $\lambda_n = 4s/(2n{-}1)$ so that the natural oscillations follow odd relations (1, 3, 5, ...).[48] I propose that the octave intervals received with the HF1 clarinet replica (with my reed design) and the Ist1 flute versions have been purposely constructed with the intention of locating the uppermost fingerhole at the octave.

In my opinion, the melodic sophistication of these early aerophones seems to surpass many aerophones from ethnographic or archaeological contexts of modern and prehistoric hunter-gatherer societies. Iain Morley and Ian Cross stated that "the sophistication of these instruments exceeds that of many medieval and contemporary examples of such pipes".[49]

The Upper Palaeolithic melodic instruments constitute a key element in the period of deliberate and elaborate artwork that is preserved in the European caves. We might extend Morley's argument for the sophistication of these instruments to the visual arts. The ice age depictions in

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[46] Morley 2013: Figure 2.1:f.

[47] Emsheimer 1964: Figure 2.

[48] Hall 1997: 238–43.

[49] Morley and Cross 2009: 74.

rock arts and mobile arts between 40 000 and 10 000 ya seem to surpass many prehistoric and modern-day hunter-gatherer visual arts in their naturalistic expression and narrative composition. The most convincing interpretations of Upper Palaeolithic cave arts decode the activities as initiation rites.[50] I assume such rituals to have been related to educational matters and the early aerophones to reflect early mathematical and physical concepts. This can be explained by the multicultural environment of these communities, which catalysed the creative behaviours in Upper Palaeolithic Europe.[51]

5 Conclusion

Simple forms of mirlitons, flutes, and reed pipes might have constituted part of the hunting equipment of early humans (perhaps also in Middle Stone Age Africa and in Middle Palaeolithic Europe). The Divje Babe Neanderthal find and the bones perforated by carnivore gnawing do not attest that Neanderthals used melodic musical instruments. All the other perforated bones in the archaeological record of the Palaeolithic are from Aurignacian layers. The non-human origin is in my opinion the most plausible explanation. The aerophones of Upper Palaeolithic Europe (including HF1 and Ist1) stand out for their melodic sophistication when compared to modern-day hunter-gatherer or medieval aerophones.

The reconstructions of Divje Babe (DB1), Isturitz (Ist1), and Hohle Fels (HF1) demonstrate how different approaches to aerophones or wind instruments can lead to different results. When we look closer at the flute reconstructions of the southwestern German aerophone finds, we find that the diameter of HF1 is exceptionally small, with a maximum external measure of 0.84 cm, and a minimum internal diameter of about 0.4 cm. The two other best preserved aerophones from the context of southwestern German cultures have somewhat wider maximum external diameters – a swan radius from Vogelherd with 1.01 cm, and the famous mammoth ivory aerophone from Geißenklösterle with 1.08 cm. The inner diameters could not be assessed with precision. The French aerophones from Isturitz have still wider maximum diameters ranging from 1.30 cm to 2.62 cm (Figure 10).

The smaller diameter of the instrument body and the possible achievement of a scale of six pitches in an overall spectrum of an octave may support the hypothesis that HF1 represents a stone age clarinet. Furthermore, we have to reckon with the possibility that reed whistles might have been part of the human hunting toolkit. Perhaps humans used duck calls or deer calls with reed technology before the concept of melodic aerophones left traces in the archaeological record of Upper Palaeolithic Europe. A survey on the beginnings of music and the musical instruments from Palaeolithic, Mesolithic, and Neolithic periods is forthcoming in cooperation with Adje Both.[52]

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[50] Lewis-Williams and Clottes 1997; Till 2018; Till 2014.

[51] Praxmarer 2023.

[52] Both and Praxmarer forthcoming.

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On Experimental Reconstructions of the Mammoth Ivory Flute from Geißenklösterle Cave (GK3) and Other Palaeolithic Wind Instruments from South-West Germany

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Abstract

The present paper provides a multidisciplinary approach integrating musicological, acoustical, and manufacturing aspects to the archaeological study of the mammoth ivory instrument from Geißenklösterle Cave (GK3). We present information on the archaeological background and the find history, and new insights into the playing technique of the instrument, confirming that GK3 was designed as a flute with a notch (M. Malina, S.C. Münzel). Subsequently, physical parameters causing pitch variability in general and their impact on the response of the low register of extended reconstructions are explored (G. Dalferth), before actual experiences of the *chaîne opératoire* of the GK3 ivory instrument are supplied (W. Hein). Due to its incompleteness, this Palaeolithic instrument allows for variability in reconstructing. A comparative tonal analysis of eight GK3 reconstructions in different lengths was conducted (A.F. Potengowski), offering new clues to possible musical intervals of the original instrument. Finally, the requirements for future research are considered.

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Keywords

Palaeolithic wind instruments – Reconstructions – Musical analysis – Notched flutes – Mammoth ivory – Geißenklösterle Cave – Aurignacian

1 Introduction, archaeological background, and state of the art

Susanne C. Münzel

1.1 Introduction

During the years 2020/21 the authors met in regular online meetings to prepare a workshop for the ISGMA 2021 in Berlin. The work presented here is the productive outcome of this workshop. The working group includes experts in many different fields, such as the person who refitted the ivory instrument (M. Malina); scientific museum assistants from the Urgeschichtliches Museum Blaubeuren (URMU: B. Spreer, H. Wiedmann), where some of the Palaeolithic wind instruments are housed; experimental archaeologists with a huge amount of experience in the reconstruction of Palaeolithic artefacts (W. Hein, H. Wiedmann); active flutists responsible for testing and analyzing the reconstructions[1] (A.F. Potengowski, G. Dalferth); and finally an archaeological scientist (S.C. Münzel). The joint effort of all members resulted in a workshop, held on the occasion of the ISGMA 2021, focusing on the mammoth ivory instrument from the Aurignacian layers of Geißenklösterle, a cave site near Blaubeuren in the Ach Valley, Swabian Jura, Southwestern Germany.

The first musical analyses of experimentally reconstructed instruments from the Swabian Jura were conducted in the 1990s by Wulf Hein (Hahn and Hein 1995, Hein und Hahn 1998) and Friedrich Seeberger † and were presented during the ISGMA 2000 in Michaelstein, Harz, Northern Germany (Münzel et al. 2002). Their experiments gave the first insights into the tonal diversity of the swan radius instrument from Geißenklösterle (GK1), the first artifact to be recognized as a wind instrument (Hahn and Münzel 1995). In this framework, A.F. Potengowski continued the musical analyses of these instruments in 2009, first on F. Seeberger's flute reconstruction of GK1, and later by using her own reconstructions. A comparative study of the reconstructions of four different wind instruments (GK1 and GK3 Geißenklösterle, HF1 Hohle Fels, F3α Isturitz) was presented at the ISGMA 2014 in Berlin (Potengowski and Münzel 2015; Münzel et al. 2016). Isturitz was included in the analysis, because of the completeness of the vulture-ulna instrument F3α (Lawson and d'Errico 2002).

Since the other three instruments GK1, GK3, and HF1 from the Swabian Jura are not preserved completely, there is an ongoing debate about how they originally might have been voiced. There is no final evidence whether they were flutes or another kind of a wind instrument. Thus, the question of the appropriate terminology for these instruments was also discussed at the ISGMA 2014. We will refer to the tenor of this discussion: if the blowing methods cannot be proven we use the

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[1] Since none of the original instruments is fully preserved, the term 'reconstruction' here implies interpretations of the supplemented parts.

term 'wind instruments'. If an artifact is reconstructed and voiced as a flute, we use the term 'flute' (Münzel et al. 2016: 226, 1.2).

One of the aims of our working group was to focus on the mammoth ivory instrument from Geißenklösterle (GK3) and on the different possibilities in reconstructing this instrument. Specifically, W. Hein experimented on reconstructing GK3 using two types of ivory, mammoth and African elephant (chapter 3.2); G. Dalferth compiled a list of parameters causing pitch variability and summarised the basic knowledge for understanding their effects on the tonal material of reconstructions (chapter 2); A.F. Potengowski tested eight GK3 reconstructions of varying length with one voicing method (straight on the notch) in an in-depth analysis (chapter 4).

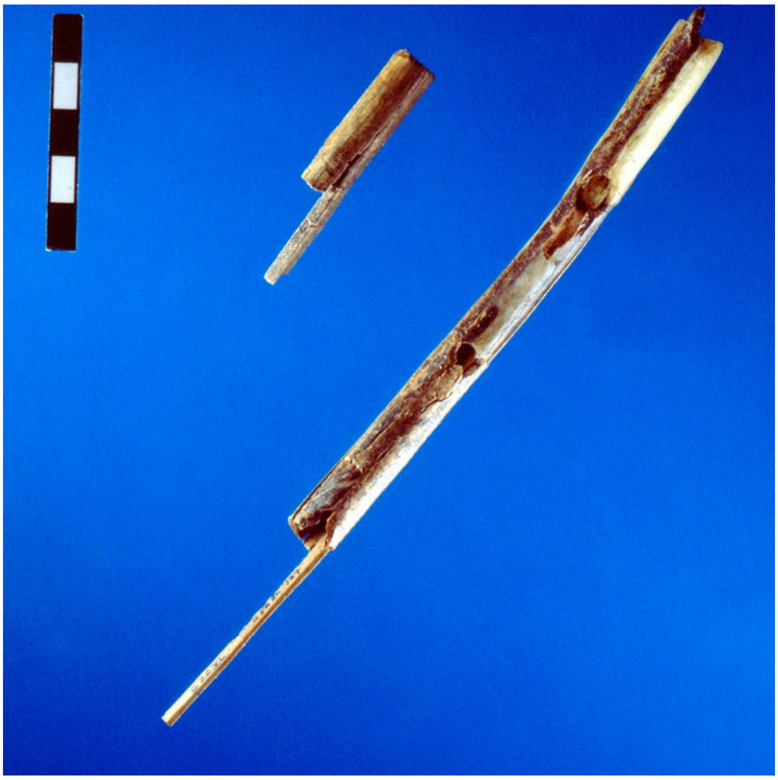

Figure 1: Mammoth ivory instrument, interpreted as notched flute, from the Aurignacian layers of Geißenklösterle, Blaubeuren (Swabian Jura, South-western Germany). Photo by H. Jensen, Tübingen University.

1.2 Archaeological background

The oldest known musical instruments are from around 40000 BP and were retrieved from three cave sites, Geißenklösterle, Hohle Fels (Ach Valley), and Vogelherd (Lone Valley), all located in the Swabian Jura (South-West Germany). Together with three other caves, Sirgenstein, Hohlenstein-Stadel, and Bockstein, they have been listed as UNESCO World Heritage since 2017 (Conard and Kind 2017). All of these sites have yielded some of the oldest examples of figurative art and personal ornaments attributable to the Aurignacian. Along with the musical instruments, they reflect the new innovative culture of modern humans (Conard et al. 2004; Conard and Malina 2006; 2008; Conard et al. 2009).

The first two wind instruments of the Swabian Jura, both made from swan radii (GK1 and GK2),[2] were discovered 22 years after their excavation in the Geißenklösterle Cave (Hahn and Münzel 1995). The pieces were identified during the study of the faunal material by S.C. Münzel.

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[2] Swan radius instrument GK1 is exhibited in the *Württembergisches Landesmuseum Stuttgart*, Baden-Württemberg, and GK2 – fragments of a second swan radius instrument – are exhibited in the Urgeschichtliches Museum Blaubeuren (URMU), Baden-Württemberg, both found in the Geißenklösterle cave.

They were recognized by the fingerholes that had been characteristically scraped into the cortex of the bird bones. Nine years later, the mammoth ivory instrument (GK3)[3] was discovered. Again, this was a post-excavation find made by M. Malina during the inventory of the numerous ivory fragments from the Aurignacian layers of Geißenklösterle (Conard et al. 2004; Conard and Malina 2008). The fourth instrument, made from a vulture radius, was discovered *in situ* during excavations in the Hohle Fels Cave (HF1)[4] (Conard et al. 2009). In addition, fragments that are very likely part of ivory wind instruments were found in Hohle Fels, and bird bone and ivory fragments with significant features similar to broken wind instruments were retrieved from the back dirt of Vogelherd Cave, Lone Valley (Conard and Malina 2006; Conard et al. 2009) around 80 years after Gustav Riek's first excavation.

1.3 State of the art

The mammoth ivory instrument (GK3) raised an extensive discussion of how the instrument was played. In the first publications (Conard et al. 2004; Conard and Malina 2008) the authors followed F. Seeberger's suggestion concerning the blowing end. Through his attempts at playing the reconstructed instruments, he concluded that the distance between the notched end and the first fingerhole was too short to produce a good sound (Conard et al. 2004: 457; Conard and Malina 2008: 15). The notched end was therefore interpreted as the distal end of the instrument, while the blowing end was seen as missing and reconstructed by Seeberger with a straight cut off end (comparable to an Arabic *nay*). In the meantime, the argument of bad sound quality from blowing the notched end was disproved by several flutists (A.F. Potengowski, G. Dalferth, see also S. Schietzel in Holdermann et al. 2013). Both ends, the notched one and the formerly reconstructed straight end, have good playing properties (Potengowski and Münzel 2015; Münzel et al. 2016). Furthermore, another piece, which has not been included in the discussion of GK3 reconstructions so far, is a small ivory tube fragment with a carefully worked straight end, which could have been the missing distal end of the instrument (Figure 1; also Conard et al. 2004: fig. 13d). Because of shape, dimensions, and work traces it would be likely that it belongs to the main piece but could not be refitted so far. Another supporting argument to this hypothesis is that this piece comes from the same find concentration of GK3 in the Aurignacian layer AH II (Conard et al. 2004: fig. 4). Therefore, the total length of the mammoth ivory instrument is probably given by the sum of the lengths of the main piece (including the thin splintered distal end), which measures 18.7 cm, and that of the end part, which could have lengthened the main piece between 3.5 and 5.5 cm, depending on how it is refitted to the main piece (Figure 1).

We argue that the notched end is the actual blowing end, because the rim/edge as well as the notch were already described as being carefully worked by Conard et al. (2004: 457), and this

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[3] Mammoth ivory instrument GK3 is also exhibited in the Urgeschichtliches Museum Blaubeuren (URMU), Baden-Württemberg; it was found in the Geißenklösterle cave.

[4] Vulture radius instrument HF1 is also exhibited in the Urgeschichtliches Museum Blaubeuren (URMU), Baden-Württemberg; it was found in the Hohle Fels cave.

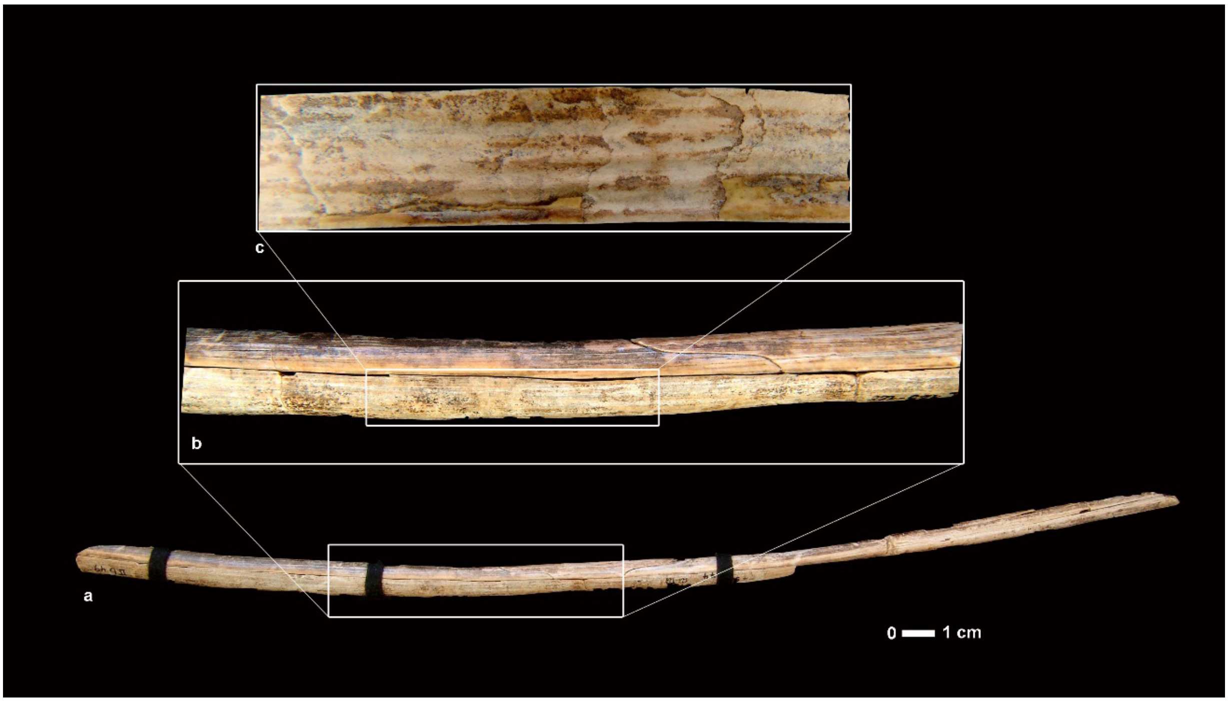

Figure 2: Ivory rod, pre-form for a flute from the Aurignacian layers AH II and III in Geißenklösterle. Photo by Ralf Ehmann.

impression is also supported by some recent close-up photos published in Ewa Dutkiewicz's dissertation (2021: 283, pl. 31). The playing properties of the notch are very good. To install a single or double reed, the shape of the notch is too short, and the angle of flattening is not appropriate.

Nevertheless, alternative playing methods, such as the use of a reed, as a trumpet, interdental or '*nay*' embouchure as suggested by Ringot (2011; 2012), Lawson and d'Errico (2002), Garcia Benito et al. (2016), and Wyatt (2012; 2016) cannot be completely excluded.

To conclude, we interpret the notched end as the proximal blowing end, thus the mammoth ivory instrument from Geißenklösterle (GK3) can be reconstructed as a notched flute (comparable to the *quena*). The distal end was probably a straight cut end. Concerning the length of the instrument, we refer to the preform of a mammoth ivory instrument from the Aurignacian layer, which was split lengthwise into two halves, but not hollowed out (Figure 2; cf. Hahn 1988: 204–5, pl. 43,1,2; Malina and Ehmann 2009: 104).[5] Its length could have originally been around 35.1 cm (Hahn 1988: 204–5), if the thinner end had not broken off, probably during manufacturing. The remaining length of the pre-form measures ca. 25 cm and was thinned out after breakage. If we take this into account, the total length of the instrument could have reached even between 25 cm and 35.1 cm.[6]

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[5] The pre-form of a mammoth ivory instrument is also exhibited in the Urgeschichtliches Museum Blaubeuren (URMU), Baden-Württemberg; it was found in the Geißenklösterle cave.

[6] We wondered if ivory wind instruments could have exceeded 35 cm in length, in other words if they were longer than bird bone instruments. However, in order to construct an ivory wind instrument both halves of either the cementum or the dentin must be of the same thickness and the cementum layer becomes gradually thinner towards the tip of the ivory tusk limiting the length of the ivory flutes. The broken pre-form mentioned above is probably an example of this. We should also mention here that the cementum layer of mammoth tusks is much thicker than that of African elephants (Bernhard Röck, ivory carver [Erbach, Odenwald], personal communication).

2 Basic parameters causing pitch variability in reconstructions of flutes

Gabriele Dalferth

2.1 Summary

This chapter explores the reasons behind pitch variations in reconstructions of the same Palaeolithic wind instruments from the Swabian Jura. The focus is on instruments reconstructed as flutes, although the lack of evidence regarding whether they were flutes or other types of wind instruments, for example reed instruments, justifies various types of reconstructions. In order to make this review comprehensive, my investigations are not limited to the mammoth ivory instrument (GK3), but extended to the three best preserved Swabian wind instrument findings, including the swan radius instrument (GK1) and the vulture radius instrument (HF1).

Being a flutist myself, I conducted several sound experiments which demonstrate that the pitch is significantly affected by various parameters such as length and diameter, shape, size, and position of the fingerholes, the mouthpiece, and the playing technique. Due to the incompleteness of all the instruments, these parameters cannot be fully defined. This article's purpose is to demonstrate and describe pitch changes resulting from structural modifications of the missing parts and from different playing techniques, as well as to describe related issues such as overblowing and the response of a flute in different registers, but it will not include frequency analyses of any instrument.

Additionally, the article discusses the relationship between the impressive phenomenon of a wide bending range on each tone of mainly thin bird radii instruments, interpreted as *nay* flutes, and the technique of human whistling.

Figure 3: Swabian Jura wind instruments. GK1: whooper swan radius, GK3: mammoth ivory, HF1: griffon vulture radius. Photos: GK1 by H. Jensen; GK3 and HF1 by Juraj Lipták. © Tübingen University.

2.2 Pitch variability in reconstructions

An important aspect of our group's work is the exploration of the tonal possibilities of the Swabian Jura wind instrument findings (Potengowski and Münzel 2015: 173–91). Admittedly, none of the three depicted original Swabian Jura instruments is preserved completely (Figure 3). Due to unknown parameters such as the length, the number of holes, the shape of the mouthpiece, and the diameters of lost parts, there are differences within reconstructions, due to diverse decisions on

Figure 4: Selection of reconstructions and free experimental flutes made by G. Dalferth, except flute 7 from the left, made by Rudolf Walter, with blowing end modified by G. Dalferth. Photos by G. Dalferth.

how to supplement the missing parts. Friedrich Seeberger, for example, regarded the missing end of the swan bone instrument GK1 as its blowing end and first interpreted the mouthpiece as a notch – like on a *quena* – (Seeberger 1998: 31–33) or, as he later preferred, as a beveled mouthpiece – like on a *nay* flute (Seeberger 1999: 155–57, Münzel et al. 2002: 107–18). The *quena* and *nay* hypotheses respectively lead to significant differences in the playable tones, primarily due to the different blowing techniques (see also below on thin *nay* flutes). A.F. Potengowski and I can play GK1 from either side, which also implies new pitch variations (Potengowski and Münzel 2015: 173–91).

Questions regarding the impact of structural differences in tonal possibilities repeatedly arose in our group, as well as during my own experimental making (Figure 4) and playing of numerous Palaeolithic flute reconstructions. Beside my own ones, I gathered experiences with several reconstructed Swabian Jura instruments due to personal contacts[7] with Frances Gill, Anna Friederike Potengowski, Barbara Spreer, Wulf Hein, Frank Trommer, Rudolf Walter, and Johannes Wiedmann.

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[7] Frances Gill, flutist and composer; Anna Friederike Potengowski, flutist; Barbara Spreer, flutist, Urgeschichtliches Museum Blaubeuren (URMU) and the archaeo-technicians Wulf Hein, Frank Trommer, Rudolf Walter, and Johannes Wiedmann, Urgeschichtliches Museum Blaubeuren (URMU).

This contribution aims to provide answers by discussing the following main questions: which parameters influence the pitches of flutes,[8] and, equally importantly, how do these parameters interact with each other?

Therefore, I focused on practical experimentation with references to common theoretical knowledge.

I approached the subject methodically by conducting experiments to discover how specific changes in the construction of the *missing parts* affect the pitch. I used instruments and tubes made both from authentic materials, like bird bones and mammoth ivory, and also from modern materials, like metal and plastic. In each experiment only one parameter of a flute was altered. Through such experiments, I gained insights regarding the physics of a flute. Although not intended as innovative from a scientific perspective, these insights form the basis for the following compact compilation of parameters, meant to facilitate access to fundamental facts of flute physics for everyone who engages in research on incomplete flutes. As not all of these researchers are flute players themselves, the parameters' impact will often be demonstrated by short videos, in order to make the sonic effects of various structural aspects more understandable and also somewhat predictable.

Acknowledging that the outcome of the investigations is applicable to flutes in general, I used the instruments from the Swabian Jura as excellent examples to transfer the results to incomplete Palaeolithic flutes. A well-preserved instrument like the Isturitz Flute F3α (Lawson and d'Errico 2002: 119–42) would not be comparably suitable for such a purpose.

Inspired by experimental playing on reconstructed flutes, I also pursued the question of why it is possible to play a wide glissando range on each fundamental tone on very thin *nay* flutes (Potengowski and Münzel 2015: 173–91). I will discuss this issue towards the end of my contribution.[9]

2.3 Basic parameters causing pitch variability

There are countless parameters that cause pitch variability. All these parameters interact with each other. Very important parameters are tube length, tube diameter, size and shape of the mouthpiece, and size and location of the fingerholes (Figure 5).

As mentioned before, none of these parameters can be defined precisely for the missing parts of the Swabian Jura wind instruments. In addition to these structural parameters, the playing technique itself has a significant impact on the pitches produced (Potengowski and Münzel 2015: 173–91).

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[8] Since I am a flutist, my investigations focused on these instruments interpreted as flutes rather than reed instruments. Friedrich Seeberger had suggested the possibility of attaching a reed and Jean Loup Ringot was a pioneer in reconstructing and playing them as reed instruments (Seeberger 1999: 155–57; Ringot 2011: 188–97 and 2012: 389–91).

[9] During casual conversations at ISGMA 2021 in Berlin, I found that this unanswered question was a concern of many participants engaged with Palaeolithic wind instruments.

2.4 *Length of a tube*

The original length of all three instruments is unknown. The possible maximum length is limited by the length of the unmodified bird radius, which can be up to 18–20 cm for a swan radius (GK1, see Hahn and Münzel 1995: 1–12) and "roughly 34 cm" for a griffon vulture (HF1, Conard et al. 2009: 737–40); for GK3, according to an unfinished mammoth ivory pre-form, it could be a maximum of 35.1 cm (see above chapter 1.3 with note 6).

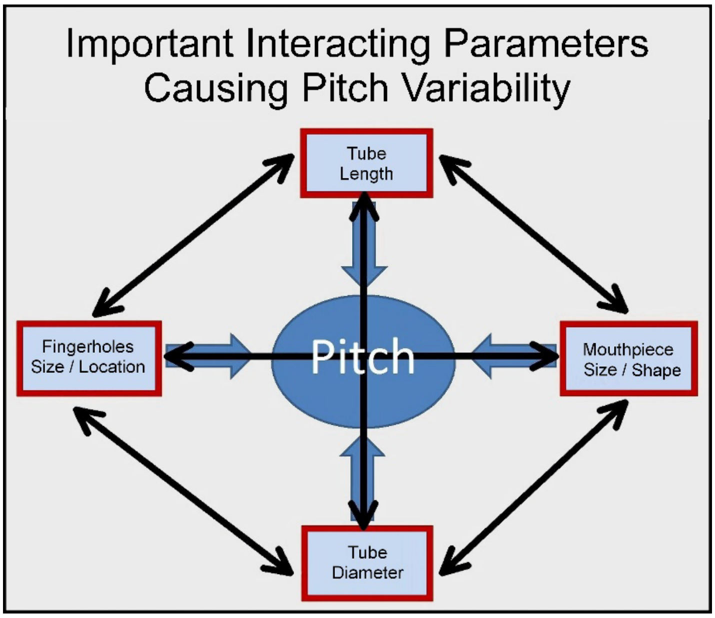

Figure 5: Interacting parameters. © G. Dalferth 2023.

When blowing over the edge of a tube, the air flow is split and the air column inside the tube starts vibrating, producing a standing wave with antinodes at open ends of a tube, and nodes at closed ends (see Halliday et al. 2019: 320 and Figure 6).

The illustration in Figure 7 shows that in open tubes the complete wave would be twice as long as the green wave section inside the tube: in tubes closed at one end the complete wave would be four times as long as the red wave section inside. Therefore, a tube closed at one end or a tube with an attached reed mouthpiece sounds an octave lower than an open tube. Tubes that are partially closed at one end sound lower the more closed they are. Figure 6 also shows that the overtone series is not identical. If a tube is closed at one end, every second overtone is missing. There is no first octave, but the fifth tone above the first octave is the first overtone, a twelfth above the fundamental.

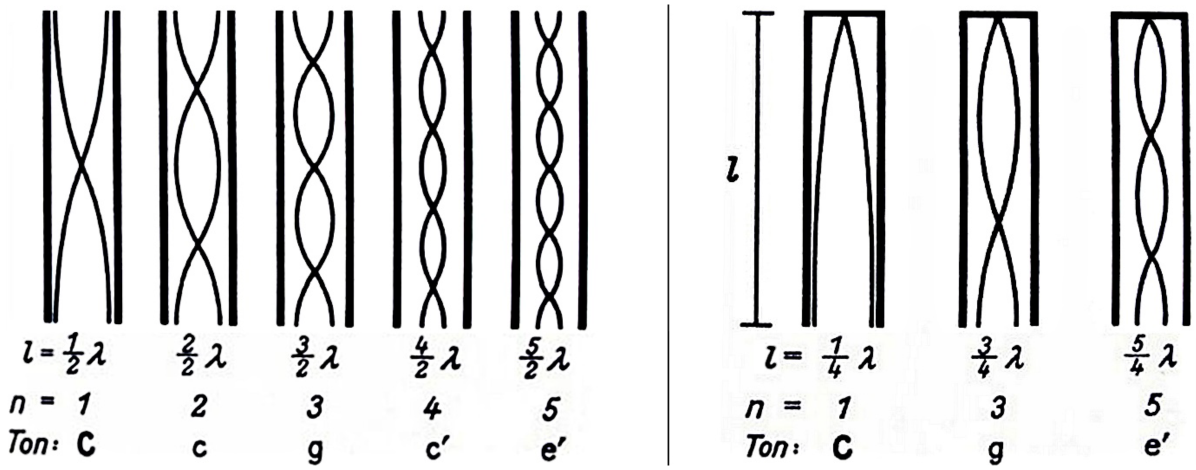

Figure 6: Position of nodes and antinodes in open pipes and pipes closed at one end. https://www.kr.perihel.ch/Material/Praktikum/Anleitungen/pfeifen.pdf [Accessed: 5 August 2023].

2.5 *Diameter of a tube*

Regarding the diameters of the missing parts of the three instruments, one has to consider the fact that the long pre-form of an ivory instrument mentioned above becomes thinner at one end (Hahn 1988: pl. 43; Malina and Ehmann 2009: 93–107). Swan and vulture radii are thinner at the anatomically proximal end and widen at the distal end.

It is notable that the diameter of the tube does not appear in any of the equations given in Figure 7. Since these equations are only basic approximation formulas, the question arises: does the diameter influence the frequency and thus the pitch at all?

Seeberger (1998: 33) compared two of his reconstructions of the GK1 as flutes of the same length, one made from a swan ulna with a proximal inner diameter of 6.5 mm and another one from a swan radius with a proximal inner diameter of 4.3 mm. He reports that the thinner flute produced almost the same tones as the wider one, but was more challenging to play.

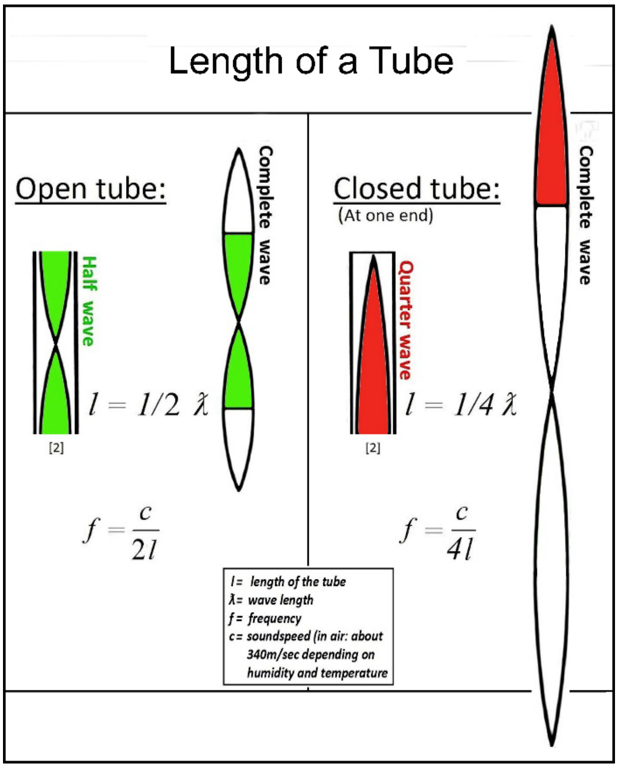

Figure 7: Wavelengths in open tubes and tubes closed at one end. © G. Dalferth 2023; equations according to Schröder 1990: 23–25.

This is noteworthy insofar as those were notched flutes, like *quenas*, and not *nay* flutes, which are the only flutes with the pronounced pitch-bending capability mentioned above, with a range of up to more than an octave, which Seeberger started reconstructing later and preferred ever since (Münzel et al. 2002: 108).

Figure 8: Wide and narrow tube, same length. © G. Dalferth 2023.

Experiment 1 (Video 1): For the investigation of the influence of the diameter, I trimmed a wide and a narrow plastic tube to exactly the same length and, in order to prevent pitch changing influences of any special mouthpiece, blew straight over the rim opposite to my lips, not oblique like on a *nay*, but in the way one would blow a pan flute to produce tones (Figure 8). I decided to use plastic tubes of a modern standardized material to make the results reliably comparable. The wider tube sounded a bit louder – as the volume increases with an increasing amplitude (Scherfgen 2006: 429). Both tubes provided a bending range of approximately one semitone. As a result, the pitch could not be determined precisely. Due to the end correction (see next subchapter), the thinner tube's range was slightly sharper than that of the wider tube, but it was still possible to produce identical tones from both tubes. Before giving an explanation as to why the pitches of both tubes did not differ, a few more issues need to be discussed in the following two chapters.

The first sound example seems to confirm a *common physical rule*: the pitch of a tube is determined by its length, meaning the longer the tube, the lower the tone. The volume is determined by the diameter: the wider the diameter, the louder the sound (see also Scherfgen 2006: 429; Halliday et al. 2019: 320).

This basic rule is – like the equations above – a useful tool for approximating the effect of the length on pitch, but is not entirely precise, as the following example will show.

2.6 End correction

If we examine the length of the vibrating air column (that determines the pitch) a little more precisely, it turns out that the sound wave reflects back into the tube as a spherical wave, causing its effective length to be slightly longer than the actual tube length, which lowers the tone. This phenomenon is called *end correction* and calculated as $k = 0.6133\,r$ for open tubes, with r being the radius.[10] That means, the wider the diameter of a tube, the stronger is the impact of k to lower the tone.

But as the diameters of all Swabian Jura instruments are very thin, the pitch lowering impact of the end correction remains very small as well, because there are some parameters influencing the pitch more than the end correction: mainly the size and shape of the mouthpiece or embouchure and the blowing technique of the player.

2.7 Mouthpiece/embouchure

A flute needs an edge/rim, or a labium, to split the airflow to produce tones. In the case of Swabian Jura instruments, this works with the preserved cut off end of GK1 (like a *nay* flute). Splitting the airflow also works with the notch of GK3 – like a *quena* or a *shakuhachi* – (see above chapter 1.3) and with a blowhole (like a transverse flute). From my own playing experience, the intentionally thoroughly scraped concave holes of all three Swabian flutes can be used as blowholes without any special processing. However, my own experience contradicts Seeberger's assumption from 1998 that the modification as a blowhole would have been an almost unachievable task for Palaeolithic people (Seeberger 1998: 31–33).

Could one imagine flutes with a constructed wind channel like recorders, fipple flutes, beck flutes, or whistles for the Aurignacian period? There is no proof for this. But there is evidence for such a construction in Magdalenian times (Figure 9, left; Luzy and Dedonder 2011: 61). The whistle or flute fragment from Abri Laraux dates back to 17000 BP (Magdalenian period) and is therefore not comparable to the three Aurignacian instruments. This does not mean that flutes with a labium could not have existed during that time as well. Technique-wise this should have been possible.

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[10] As the end correction was an empirical value for a long time, there exist different but similar values. Nowadays, 0.6133 is generally accepted (Egry 2020: 4–6).

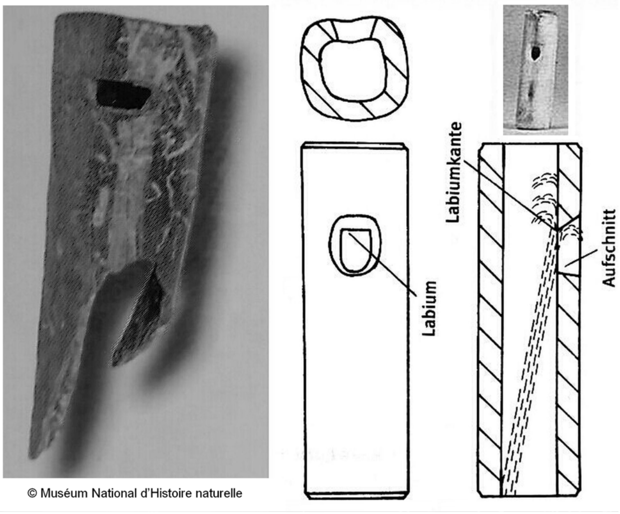

Figure 9: Photo left: Abri Laraux, bird bone. © Muséum national d'Histoire naturelle. Photo right: Gudenus cave, tubular bones. © Kunsthistorisches Museum Wien (Austria-Forum n.d.). Drawing © B.Käfer 2000, CD Booklet.

A whistle from the Gudenus cave in Austria is also thought to come from that period, but its Magdalenian age is discussed controversially (Figure 9, drawing and right photo).

So besides mainly focusing on *quena*-, *nay*-, and transverse-flute mouthpieces I also started – to a very small extent – experimenting with wind channel constructions in three different variations (Figure 10).

There are many more possibilities and variations to design a mouthpiece or some other form of a blowing device, but the following applies to all of them: the actual pitch of so called 'open flutes' with an open distal end will always be lower than what one would calculate for open tubes because the blowing end is never completely open. Thus – strictly speaking – an 'open flute' is a tube that is partially closed, because the proximal blowing end is always closed to a certain extent either by the lips of the players (see Figure 11) or due to the construction of the mouthpiece (see Figure 12).

Figure 10: Left: mute swan ulna: HF1-type mouthpiece with an applied wind channel; middle: mute swan radius with notch and 'external' wind channel; right: mute swan radius: Gudenus whistle-type wind channel. © G. Dalferth 2023.

Experiment 2 (Video 2): More covered blowholes of a transverse flute (Figure 11b) and of a *quena* (Figure 11d) produce lower pitches than the two less covered ones (Figure 11a and c).

The virtuoso flutist James Galway describes this, when he writes about tuning correction: "In some instruments, some notes are too high, and the player has to blow deeper into the blow hole; for too low notes, he blows slightly outward" (Galway 1988: 145).

Blowing more inside or more outwards means changing the angle of the airstream. Figure 11b shows the position that allows the player to blow deeper into the mouth hole, Figure 11a, the position that allows blowing more outward.

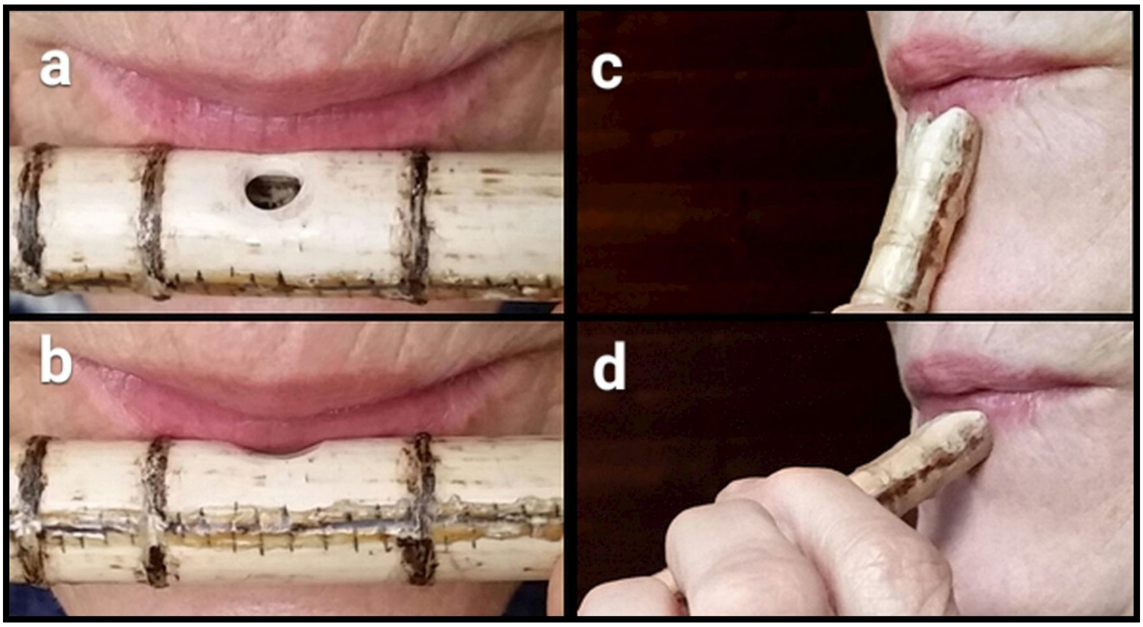

Figure 11: Coverage of the blowhole with the lips. © G. Dalferth 2023.

This also applies to Seeberger's notched GK1 reconstructions mentioned above, as well as to pan flutes. It finally gives an explanation for why his thin and wide flute, as well as the thin and the wide tube in experiment 1 (Video 1), could produce the same pitches, although, regarding the end correction phenomenon, one should have expected a lower response from the wider tube: due to its wider diameter the blowhole was less covered and thus the pitch raised by roughly the same amount as the end correction lowered it.

This also happens to *nay* flutes (end blown flutes) with significantly bigger diameters than the very thin Swabian Jura instruments. The special case of 'very thin *nay* flutes' will be discussed later.

Experiments 3 and 4 (Videos 3 and 4)**:** Again, I used modern standardized materials and instruments to demonstrate the following phenomenon: a tube with a wider notch (Figure 12, left) and a pennywhistle with a wider window (Figure 12, right) produce higher pitches than a tube of the same diameter and length with a narrower notch or the same whistle with a narrower window. In Ireland I learned that it used to be a common technique to tune flutes like recorders or whistles by reducing the size of the window, and thus of the labium as well, with wax or an adhesive pad.

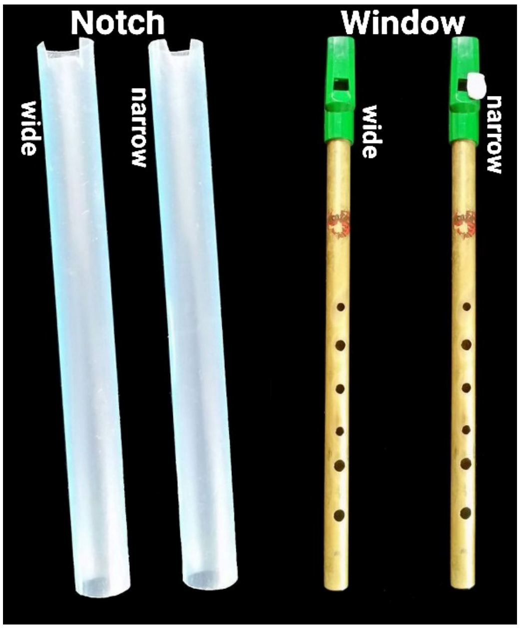

Figure 12: Coverage of the blowhole by construction, left: two tubes with a narrow and a wider notch; right: pennywhistle with a narrow and a wider window. © G. Dalferth 2023.

All these examples underline the following observations: the narrower the openings of the blowing devices, the lower the pitches. There is also an impact on volume/loudness and timbre: “A wide windway […] makes the whistle louder, the sound becomes a bit breathy, and more air is needed; a narrow windway […] makes the whistle quiet, the sound becomes sweet and clear, and less air is used.”[11]

We do not know if the Jura wind instruments were ever used in a musical context with other melodic instruments, such as e.g. sounding stones, or if they were adapted or tuned for such purposes. Theoretically, it is possible to build a flute with a specific lowest tone by using a tube that is initially too long for the desired frequency and gradually shortening it step by step to approach the desired tone. However, this adjustment must be done with a completed mouthpiece, as this significantly affects the pitch.

There is still another influence concerning the shape of a mouthpiece: longer labial edges of a window (Figure 13, top) support the response of low tones, whereas shorter ones support the response of high tones (Figure 13, bottom). This applies to other devices like notches or blowing holes as well. The longer the windway to the labium, the better the response of low tones, whereas the shorter it is, the better the response of high tones.[12] This only works up to a certain limit. Overdoing it might lead to no response at all.

Figure 13: Long and short wind ways. © G. Dalferth 2023.

2.8 Fingerholes

If the fingerholes of a flute remain open, the vibrating air column is shortened accordingly, and the frequency becomes higher. The sound wave will not be reflected from the first opened hole directly, but again from a certain end correction distance below, which lowers the tone. The reflection point of the sound wave will be lengthened and lower the pitch even more if one or more holes are skipped due to fork fingering.

Small, opened holes lower the pitch in comparison to large holes, because with a small hole the wave extends further downwards than with a large hole. That last fact might be of interest if one should intend to build a very long GK3 mammoth ivory reconstruction with additional fingerholes on an extension below the extant part.

The holes of long flutes can be placed in such a way that they can still be reached by the fingers without spreading too much. If a hole is smaller, it can be placed a bit upwards. This method can be seen in the following example of three Irish whistles.

The deepest holes were made increasingly smaller as the instruments’ length increased (Figure 14) because it produces a lower pitch when only that particular hole remains open, compared

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[11] Gonzato 2016: 7–8 on Irish whistles.

[12] Gonzato 2016: 8.

Figure 14: Location of fingerholes. © G. Dalferth 2023.

to a larger hole. Therefore, it can still be reached by the ring finger without excessive spreading. A larger hole would raise the pitch and would need to be drilled further down accordingly.[13]

2.9 *Fingerhole-size/tube-diameter ratio*

The hole-size/tube-diameter ratio has a significant impact on the pitch. The larger the opening of a fingerhole *in relation to the circumference* of the tube, the higher the pitch.

This is demonstrated by the following experiments with three turkey bone flutes: one narrow radius flute (Video 5) and two wide ulna flutes.

Experiment 5 (Video 6): If one compares the narrow Flute 1 and the wide Flute 3 of the same length with the same hole sizes and locations, Flute 3 will sound lower on all tones with open holes.

Experiment 6 (Video 7): If one enlarges the holes of the wide flute, the result (Flute 2) is a flute with the same pitches as the thin Flute 1.

Figure 15: Three turkey bone flutes (radius and ulnae), same lengths. © G. Dalferth 2023.

It is important to take this into account when building reconstructions because bones with exactly the same diameter as the originals are sometimes hard to find. For example, our local mute swan radii are often a bit thinner than the original GK1 whooper swan radius instrument. To avoid that pitches and intervals of this instrument differ significantly from the original, the hole sizes should be adapted to the diameter difference. It should be mentioned that this applies only (approximately!) for the preserved segments, i.e. in the case that the preserved end of GK1 is assumed to be the embouchure. More precise frequency analyses would require a method such as a 3D-printing, where the reconstruction of these segments would exhibit the same geometry as the original.

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[13] See also the following chapter.

Figure 16: HF1 reconstruction made by G. Dalferth. Self-made claylike material, hole sizes not yet adapted to the original. © G. Dalferth 2023.

2.10 Blowing pressure, length/diameter ratio and overblowing, cut-off frequency

The blowing pressure is an important pitch parameter. Blowing more strongly raises the blowing pressure. A higher pressure raises the pitch of all kinds of flutes while blowing more weakly lowers it. “The player’s blowing pressure can alter the pitch of a note by a third of a tone, or even more.”[14]

This aspect applies to all kinds of flutes, as long as no other playing techniques are used to compensate for such pitch shifts, as well as for organs: if one increases the strength of the airflow through the gap of a lip pipe of an organ, the pitch becomes higher. If one wants to amplify or weaken the volume of the organ, but avoid such pitch shifts, one has to use more or fewer pipes of the same pitch, and/or pipes with a sharper or softer timbre (Berliner 1928: 260).

The thinner a tube, the higher the blowing pressure. If the air pressure gets too high, the fundamental tone flips into the first overtone of the natural overtone series. Steadily increasing pressure will cause flipping into the following overtones. Overtone flutes (comparably thin long flutes with no fingerholes) work like this. This is a reason why not every long tube is suitable for building a flute with a low ‘all-holes-closed tone’ (this again is good to know if one wishes to build a very long GK3 mammoth ivory flute aiming to get considerably lower tones than with shorter flutes).

The larger the diameter, the weaker the blowing pressure. One has to blow harder to make the tone flip into an overtone. Above a certain size diameter, there is no flipping into an overtone at all. Flutes with larger fingerholes reach this limit faster. This limit is called *cut-off frequency* (Baumgartner and Messner 2010: 223–24).[15] “The cut-off frequency [...] predicts whether any hole will be able to sound the upper octave. The cut-off frequency should be at least 2 times the second octave note.”[16]

Compared to its narrow diameter, the HF1 flute is very long. The deep V-shaped notch produces a very breathy sound. If one closes one hole after the other of my reconstructed instrument (Figure 16), one gets an increasingly weak or almost nonexistent response from the two lowest tones, whereas it is easy to make them flip into the overtones (Video 8). The cut-off frequencies of

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[14] Gonzato 2016: 8 on Irish whistles.

[15] Explanation for cut-off frequency according to Baumgartner and Messner (2010: 223–24): “To allow the sound to emit through the tone holes, the air mass in the chimney of the tone hole must be accelerated by the sound wave in the flute within a time interval of half its period. As the frequency increases, the time interval of half the period [...] decreases. This means that from a certain frequency, which [...] is referred to as the acoustic cut-off frequency, the acoustic adaptation through the tone hole is so bad that the air column swings beyond the opening and therefore no sound emission takes place at this point.”

[16] Chuck Tilbury, an American Irish whistle maker, in a personal email.

the tones could be calculated, but for most reconstruction purposes there is no need to do this. If one intends to elongate an incomplete flute and seeks to achieve good response across all tones and registers, it is helpful to examine contemporary instruments, e.g. Irish six-hole whistles. According to my own measurements from the labium to the distal end, they often have a diameter to length ratio of between 1:17 and 1:24, because then both the low and high notes respond well and sound balanced. These ratios are a good guideline for many kinds of flutes.

That does not mean that all Palaeolithic wind instruments had this ratio – as is to be seen and heard in the example of HF1. But it can help to predict whether a reconstruction as a flute is supposed to have a good response in all registers or not. It will make troubleshooting easier if one knows what kind of response can be expected based on the construction: the preserved part of the HF1 is about 21.8 cm long and has an inner diameter of about 0.8 cm. The ratio is about 27.25 : 1. In this case it would be a waste of time trying – for example – to improve the notch to get a better response from the low register. Should one decide to elongate the instrument according to the available bone length, the ratio will become larger, and so the response from the low register will get even worse, but it will boost the overtones, which could be a desired effect as well.

If an ivory flute has a weak low register response, despite the length/diameter ratio allowing for balanced tones, you might also consider whether the two halves had been fitted together tightly or whether there might be hairline cracks in the material.[17]

Nowadays the ability to sound properly in both registers is an important reason not only to change the length within a flute family when building higher or lower instruments, but also to keep the proportions steady, enlarging or diminishing the whole instrument to scale (except the small hole size and position adjustments described before, which serve to avoid an excessive spreading of the fingers on long instruments). Another reason, among others, to scale it up or down proportionally is that despite the changing of the pitch, the intervals will stay the same. If one plays melodies with exactly the same fingerings they will be the same, just transposed to another pitch.

When exploring the possibilities of any Palaeolithic wind instrument, it is undoubtedly always the best solution to adhere precisely to the known dimensions of the original. However, this turns out to be a challenge with the swan wing bone instrument GK1, which was originally made from a radius. Personally, I have not yet succeeded in finding a swan radius that matches the original in

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[17] In chapter 3 of this article, W. Hein discusses the experience required for achieving a perfect glue consistency. He also talks about a flute that initially had air leakage issues and required additional bindings. The process of sealing can be particularly challenging for less experienced builders. Additionally, I encountered problems with air leakage in both a flute made by B. Spreer and one of my own ivory flutes. These flutes consistently struggled with low register response. Unfortunately, after I tried to clean Spreer's flute with water (as two of my ivory flutes respond better when humid), previously invisible hairline cracks suddenly appeared in the ivory within minutes. I experienced the same with another of my flutes, where moisture from excessive playing caused cracks. A colleague also shared a similar experience with an ivory pendant, where cracks would open and close depending on air humidity. However, it is important to note that a poor low register response can also be due to the flute's shape, in which case efforts to seal the flute would be useless.

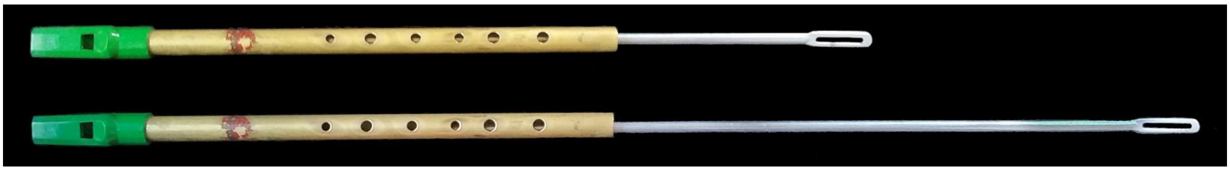

Figure 17: Whistles with a fully and a partly inserted rod. © G. Dalferth.

terms of diameter, and upon inquiry, neither have my colleagues, F. Trommer, B. Spreer, and A.F. Potengowski. The radii were at least 1 to 2 mm thinner.

So when reconstructing a Palaeolithic bone flute from a bone with a bigger or smaller diameter, one has to decide whether one wants to build the instrument to scale or whether one prefers to stick to the measurements of the original.

A scaled interpretation is an especially valuable tool if one aims at exploring its musical possibilities despite a differing diameter: the intervals will be the same and the 'overblowing behaviour' will be the same compared to an instrument of the original diameter, because the length/diameter ratio is kept. So it is possible to explore the interval structure and the range of a flute independently of its absolute pitch.

To keep the same distances between the holes and also keep the same hole sizes would mean a change of intervals and possible melodies compared to the originals. If the reconstruction is meant to produce the same frequencies and intervals, one needs to modify the hole sizes accordingly (see above chapter 2.9).

There is also another reason why working with bones that deviate strongly from the original diameter while keeping the original length and distances does not make much sense. Due to the cut-off frequencies, too thick flutes would lose higher tones, whereas too thin flutes would lose lower tones, or at least have a poorer response.

2.11 Irregular diameters

Usually the inner diameter of bone flutes varies throughout a bone. In many cases there are wider and narrower sections or, occasionally, deformations inside the tube that influence pitches and timbre.

Experiment 7 (Video 9): To diminish the air volume of a whistle, a rod is inserted fully from the distal end until it reaches the labium of the window. The pitch of the instrument does not change significantly (Figure 17, upper flute). This confirms again that the pitch is determined mainly by the length and there is nearly no impact by altering the effective diameter beneath the blowing device throughout the *complete length* of the flute.

Experiment 8 (Video 10): A rod is inserted about halfway into a whistle to diminish the air volume of the lower section of the instrument. This partly inserted rod lowers the pitch significantly in the section around the beginning of the rod, in this experiment about one semitone (Figure 17, lower flute).

The same result occurs when there are conical sections within a bone or a tube. Sections narrowing downwards lower the pitch, while sections opening downwards raise it. This effect is used for tuning open organ lip pipes. To raise the pitch, a conical tuning cone is inserted into the open end of the pipe to expand it. To lower the pitch, the open end is inserted into a conical funnel and constricted (Locher 1896: 46).

The pitch lowering effect can be useful if one intends to build a long flute with low tones. If the flute diameter narrows downwards, the flute can be built a bit shorter and so the distal holes are in easier reach for the fingers, provided one does not exceed the limit concerning the cut-off frequency described above.

2.12 Special case: very thin nay flutes

As mentioned before, transverse and *quena* flutes allow for about a semitone of pitch variability. This range may vary slightly depending on the player's technique and embouchure.

The pitch of thin end blown *nay* flutes is highly variable. The blowing device of a *nay* flute is usually just the bevelled rim of an open tube. A.F. Potengowski's analyses show: the thinner the diameter of these flutes, the higher the variability in pitch (Münzel et al. 2016: 230–33 and 242). Glissandi are possible up to well over an octave without moving any finger to open or close the holes. As different glissando ranges can be played from various tones, the range expands. So nearly every melody that is covered by this range can be played, only restricted by some challenging tones with a weak or nonexistent response right in between register changes.

Figure 18: Swan ulna (a) and radius (b). © G. Dalferth.

Videos 11 and 12 present two swan bone flutes with an enormous glissando range, but the range of the thinner radius is still significantly wider than the range of the thicker ulna (Figure 18). To ensure comparability, I closed the first fingerhole of the radius flute so that the distance between the labium and the first open hole was as similar as possible between both flutes, 7.6 cm for the radius and 7.4 cm for the ulna. I played in the fundamental register of both flutes and did not overblow.

The peculiar phenomenon that the tone can be varied so widely on very thin *nay* flutes can be explained by comparing it to human labial whistling, which works without any instrument. According to J.W. Strutt, the oral cavity acts as a Helmholtz resonator in human labial whistling. By changing the position of the tongue and the volume of the oral cavity, the pitch of the tone can be changed (Strutt 1945: 223–24).

A Helmholtz resonator consists of a larger air space that is connected to a narrower neck of the resonator. The inert mass of the neck of the resonator is related to the elasticity of the entire volume of air in the connected air space. Such a so-called 'mass-spring system' has a defined natural frequency (Egry 2020: 4–6).[18]

Toshiro Shigetomi and Mikio Morio researched whistling through experiments and expanded Strutt's findings: "We demonstrated that the principle of resonance in human whistling includes not only the Helmholtz resonance but also an air-column resonance [...]. The findings of this study are expected to be useful for engineers because the principles of sound production in wind instruments (including human whistling) are not yet completely known" (Shigetomi and Morio 2016: 86).

Through experimental playing while observing my lip and mouth activities I tried to explore the question of why increasing the diameter of *nay* flutes causes the possible glissando range to decrease more and more. Some parallels to human labial whistling were found: the lips work as a labium in human whistling. When playing a *nay* flute, the blowing edge of the flute replaces the lips. But the blowing technique feels much the same. So I conclude that in the case of a very small diameter, the flute volume is dominated by the bigger volume of the oral cavity and – as when whistling – the pitch of the tone can be changed by changing the position of the tongue and the volume of the oral cavity. In the case of a wide diameter, the flute volume approaches or exceeds the mouth cavity volume. As the proportion of the instrument's own resonance increases in comparison to the Helmholtz resonance of the oral cavity, it causes a reduction in the glissando range.

It should be emphasized that this playing technique is by no means to be understood as mere *human whistling*. Depending on the size or volume of the flute, different frequency results are obtained, indicating that the instrument itself plays a role in generating these frequencies, especially regarding the characteristic break during register changes. This break can, according to Potengowski, clearly be attributed to a specific frequency and cannot be manipulated by the oral cavity volume (Potengowski et al. 2015: 232).

Although it does not concern any of the narrow instruments of the Swabian Jura, it should be mentioned that also a wider *nay* flute can produce a considerable glissando range, if fingerholes are located very close to the blowing end and kept open, because then the volume of the vibrating air column inside the flute is very small as well and the volume of the oral cavity can approach or exceed it.

2.13 Conclusions

If one tries to find answers to the question of frequencies of the Swabian Jura wind instruments by reconstructing them as flutes, one has to keep in mind that every small modification of all

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[18] Wolfram Language and System Documentation Center n.d.

previously described interacting parameters will cause pitch changes – and that there are still many more parameters influencing the pitch beside these basic ones.

Such modifications significantly contribute to pitch variability in reconstructions since none of the original instruments is entirely preserved. That incompleteness prevents an exact definition of all pitch relevant parameters necessary for achieving exactly the same results.

Trying to define frequencies related to missing sections of the original instruments must necessarily remain speculative. Nevertheless, reconstructions of original instruments with missing sections can provide valuable data on pitches related to the preserved parts and offer insights into the potential frequency ranges of instruments that might have originally been longer.

However, as the analyses of different GK3 reconstructions conducted by A.F. Potengowski show (see chapter 4 below), there are many similarities in terms of frequencies and intervals among the instruments, if one adheres closely to the measurements of the preserved parts of the original instrument (see below), and assuming that one uses the notched end as the embouchure end, as it was indicated in chapter 1.3 (p. 62 above).

On the other hand, as long as reconstructions are handmade from mammoth ivory that occasionally warps visibly when exposed to humidity[19] and from naturally slightly deviating bones, it is to be expected that the reconstructions will not be entirely accurate concerning the frequencies, compared to the originals, even within their preserved sections.

The wide field of digital 3D-printing (see chapter 5, below p. 98) could nowadays be an additional way to reconstruct the instruments from the Swabian Jura because one could adhere to the original dimensions, thus achieving better pitch accuracy and rendering considerations (see above) of proportionally scaled instruments based on deviating bone sizes obsolete. But still, the original materials for reconstructions remain essential and irreplaceable in all cases where one aims to experimentally explore their properties and to discover various processing techniques.

3 Reconstructing the mammoth ivory wind instrument from the Geißenklösterle Cave: A progress report

Wulf Hein

3.1 Summary

Since the discovery of the wind instruments from the Aurignacian layers of the caves in the Swabian Alb, interpreted as flutes, the author has been engaged in reconstructing these so far oldest musical instruments in the world. The following report describes the experiences gained during the work, using the example of the latest replication of the mammoth ivory instrument from the Geißenklösterle cave.

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[19] I encountered flattening of the initially round diameter of one of my mammoth ivory flute reconstructions and becoming oval-shaped.

“… little more than a tube with a few holes …”

These words attributed to the French composer André Jolivet (1905–1974) describe the flute as a “[…] musical instrument par excellence […] which allows the player to express his deepest feelings with the simplest means.” Apparently, the people of the Ice Age were aware of this; it is not without reason that the oldest certain evidence of melodic-musical instruments in the world to date is an assembly of wind instruments and wind instrument fragments, which come from karst caves in the Swabian Jura (Conard et al. 2009) and can be reconstructed and played as flutes.

Interesting in Jolivet’s quote are the two incidental words “little more” because indeed all extant Palaeolithic wind instrument findings in the archaeological record are made of bones, mainly the wing bones of large birds. These bones are natural ‘ready-made’ pipes with human modifications such as fingerholes made by drilling or scraping into the bone (Buisson 1990; Hahn and Münzel 1995; Käfer 1998; Conard et al. 2009; Ringot 2012). The exception to the rule, however, is a mammoth ivory instrument, interpreted as flute, recovered from archaeological horizon (AH) IIb belonging to the Aurignacian technocomplex, from the cave site of Geißenklösterle in the Ach Valley near Blaubeuren (Conard et al. 2004). Concerning this object, a “little more” work was undoubtedly spent!

Tusks of woolly mammoths are hollow in the proximal part, which sits in the alveoli of the upper jaw (*maxilla*). This cavity is funnel-shaped, because “figuratively speaking, the tusk consists of numerous dentin cones pushed into each other” (Banerjee et al. 2011: 3), rather like a stack of tightly-packed ice cream cones. It is not as easy to make a flute from this material as it is from a bird bone, where diameter and wall-thickness measurements along the entire length of the bone are approximately uniform. Nevertheless, the Aurignacian occupants of Geißenklösterle chose to undertake a task which was not only extremely time-consuming, but also difficult work.

The question of “why bother to go to so much trouble” (Lawson 2020) might be answered by the fact that even the wing bones of the largest birds of prey and water birds such as vultures, eagles, or swans, limit the maximum length of a wind instrument made from them; typical ulnae and radii measurements are rarely longer than about 26 cm.[20] Making a longer flute therefore requires an artificially-designed tube in some shape or form. The tusk of a mammoth is an ideal material for this; ivory is very hard and elastic at the same time and can be easily worked with stone tools. The ivory instrument find GK3 measures 187 mm. Despite the preserved state of the instrument (Figure 1), some of its extant features are fragmentary; the original length cannot be determined with absolute certainty. Together with other ivory finds in context from Geißenklösterle, including a 35 cm long ivory-stave artefact, it is assumed that it was possible to produce roundish cylindrical bars or rods of worked ivory up to one metre in length (Hahn 1988: 204–5, but consider footnote 6).

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[20] But see Wyatt (2012: 393), who joins two goose bones together with beeswax to make one tube.

3.2 *Previous attempts at reconstruction*

In an archaeological experiment, M. Malina and R. Ehmann demonstrate how an ivory rod is split and hollowed out (Malina and Ehmann 2009). In addition, they re-examined ivory fragments from the archaeological context and were able to determine that the 35 cm ivory stave from AH IIb and III of Geißenklösterle (mentioned above) was worked in this way (ibid., 104). For this purpose, first a stave is taken from the outer layer of the tusk, scraped into a cylindrical round form (Figure 19.1) and a groove is made on each lateral side along its entire length (Figure 19.2). This is followed by using a flint knife to incise many small notches down each side of the rod, perpendicular to the conjunction between the cementum and dentin; in preparation for gluing the two longitudinal halves back together after subsequent splitting (Figure 19.3). Most probably, these notches served to enlarge the gluing surface, a procedure understood to be the case for the production of projectile points in the Palaeolithic (Stodiek 1993: 167). Next, the rod is split by means of small wedges, which is only possible at the exact boundary point between the very outer tooth cementum and the dentin below (Malina and Ehmann 2009: 102, fig. 16). Finally, both halves are scraped out with a small flint scraper and reassembled. Malina and Ehmann refrained from further reconstruction at that time because the length of the original instrument could not be determined.

Friedrich Seeberger (1938–2007), who studied the Ach Valley wind instruments and their playing techniques like no other (Seeberger 1998; 1999) and knew how to make his reconstructions sound masterfully, first made a reconstruction from elder wood after the discovery of the mammoth ivory instrument (Conard et al. 2004: 458; Seeberger, personal communication), and later reconstructed another from ivory (Malina and Ehmann 2009: 94).[21]

In 2013, a team associated with the Urgeschichtliches Museum Blaubeuren (URMU) traced and described the process of making an ivory flute reconstruction for the first time (Holdermann et al. 2013). The context in which this research was performed postdates an experiment in 2012 by some members of the same team together with Frances Gill, using material coming from the same mammoth-ivory tusk from which the first reconstruction following the length of the 35 cm ivory rod was constructed (full results in Gill forthcoming; Gill 2012: 60; 74–5; Gill 2014b; Atema 2014: 30).

3.3 *Current attempts to reconstruct the flute GK3*

I have been engaged in the construction of these unique finds since the discovery of the first wind instruments in the Ach Valley, during which time, together with the excavator of the Geißenklösterle, Joachim Hahn (1942–1997), I also made the first reconstruction attempts (Hahn and Hein 1995; Hein and Hahn 1998). Numerous replications of ivory finds followed during the course of my work, including the Lion Man statuette from the Hohlenstein-Stadel cave (Hein and Wehrberger 2010) and the Venus and animal figures from the Swabian Alb (Hein 2018), many of

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[21] Unfortunately, F. Seeberger was unable to publish his specific contribution to the research about GK3, but see Gill forthcoming for an appraisal and analysis of his valuable work concerning GK3 from other available sources.

them found with authentic tools. Extensive experience was gained in the handling of mammoth tusk material, including the reconstruction of seven GK 3 type flute to date, some of which have already been the subject of music archaeological investigations (Potengowski and Münzel 2015; Münzel et al. 2016).

Here I can present the results of my most recent experiments (Figure 23; Table 1: Instruments (e), (f), (g)) correlating them with some discussion points that were raised by my colleagues in Blaubeuren. First, I did not encounter the same degree of difficulty as the Holdermann team (2013: 65) in evenly hollowing out the two halves of the stave (Figure 19.4) all the way to each end. This is likely due to the fact that I have accumulated extensive experience working with ivory through many hundreds of hours of work and practice. F. Gill recalls in a poster presentation for ISGMA in Berlin (2014a) in connection with an interview that I had given that "I heard the scraping of ivory in my dreams" during the time period in which I was carving the Lion Man. Ultimately, then, it is also a matter of patience and practice in which precision is finally achieved through tacit knowledge (e.g. Polanyi 1966).

Provided that a fresh mammoth tusk has (approximately) the same properties as fresh recent ivory, I can answer questions posed by the Blaubeureners (Holdermann et al. 2013: 63) regarding workability as follows: the African elephant tusk from which I made the Lion Man was just as hard and difficult to work as the fossil mammoth ivory that I used for other replications coming from the same source as used in their experiment. However, this need not be true for every fossil material; an incident during my workshop at the British Museum in London (2013) demonstrated that ivory from different parts of the same fossil tusk can have very different properties (Hein 2018: 442). However, it is questionable whether such material is then suitable for the production of a flute, for which one would rather select the best quality, because the wall thickness of the artificially created tube is very thin at only 1.5 mm, and it is above all the stability and accuracy of fit of the edges that is important when both halves are put together.

Unlike the Blaubeuren team, I did not bevel the edges, but merely ground a small chamfer on the outside. Also, I did not put the halves together, fix them, and then apply the glue, but first applied the glue to both halves (Figure 19.5), heated them evenly over a grease lamp, and then joined the two parts together (Figure 19.6). I also used birch pitch for gluing, which was made by the double-pot method and therefore turned out very fine. It is unclear whether such a quality could be produced aceramically in the Aurignacian, but in principle the adhesive can be obtained from birch bark without pots (Palmer 2007; Schmidt et al. 2019). When thickening the extracted tar into pitch, the duration of the process allows the viscosity to be adjusted relatively accurately after mastering the process. When bonding ivory or other materials, great care must be taken to ensure that the pitch is not too soft, or it will melt at low temperatures and smear instead of stick. But it also must not be too hard, or it will become brittle and crumble back out of the glue joint.

On my own GK3 flute reconstructions, which I made in 2012, 11 years ago, and which I have since carried, shown, and (with my very modest skills as a flutist) played at countless events and trips, the glue joints are still completely intact. With the last three flutes reconstructions which I

Figure 19: Manufacturing of an ivory flute reconstruction: 1. Round scraping of the released stave; 2. Applying the splitting groove with a narrow burin; 3. Cutting the notches above the adhesive joint with a blade; 4. Hollowing out the halves with a scraper; 5. Applying the adhesive birch pitch to the glued surfaces; 6. Joining the two halves together and carefully heating them; 7. Scraping off the excess glue with a burin; 8. Wrapping the body of the flute with wet animal sinew; 9. Scraping the fingerholes with a burin; 10. Attaching the labium by grinding on a fine sandstone. Photos by W. Hein.

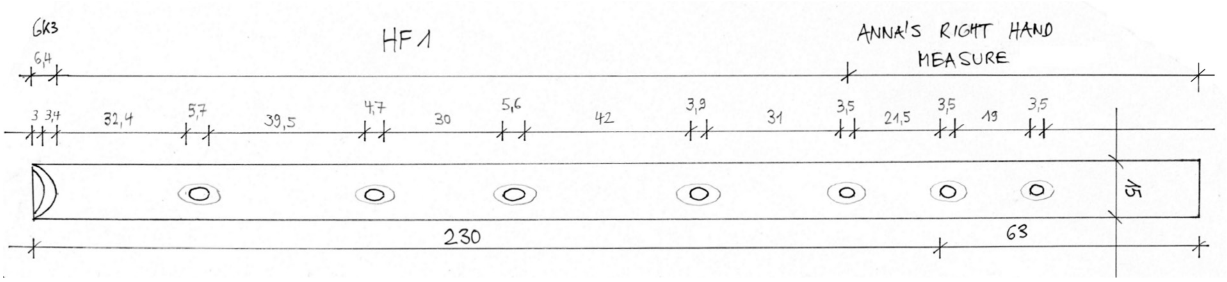

Figure 20: Construction sketch for the Haskell flute reconstruction. © W. Hein.

made from African elephant ivory in 2021, I secured the connection with additional sinew wrappings as a precaution. They are also still working well, one of which is a recent commission by F. Gill who has played it frequently, even outside in colder temperatures (personal communication). If birch-pitch beads form in the tube when the halves are joined, the interior can be warmed slightly, and the beads can be carefully smoothed out with a bone or wooden stick that has also been warmed. Excessive protruding beads would affect the airflow and thus the playability. Finally, the excess pitch on the surface is carefully scraped off with a burin (Figure 19.7).

One thing is certain: without glue, an airtight connection of both halves, without which the flute would be unplayable, is impossible to achieve. However, it is still unclear what material was actually used for this purpose on the GK3 artefact (Conard et al. 2004: 456). Frank Trommer, a member of the Blaubeuren experimental team, has successfully used a mixture of resin and wax – and in some cases even oil – for new replicas (personal communication). The use of such a mixture or individual components in the Palaeolithic has been a source of speculation (Stodiek 1993: 151), whilst it has been proven elsewhere in context (Thieme et al. 2014: 68; Baales et al. 2017: 1160).
Finally, the flute tube must be secured by means of binding (Figure 19.8). Both A. Holdermann's team (Holdermann et al. 2013) and I used animal sinew for this, in my case reindeer leg tendons. These are beaten between two pebbles (if dried, soaked in water, otherwise in fresh condition) and subsequently divided into very fine threads. Then they are laid individually and wet in several layers around the flute, the loose end – as thin as possible – is pulled once or twice under the last winding so that it cannot come off again. During drying, the winding contracts very strongly, and at the same time the individual fibres stick together, so that a stable and durable connection guarantees cohesion between the two halves of the flute. Of course, other materials such as plant fibres, for example, the bast of willow, or nettle fibres, and possibly even thin strips of leather or rawhide are possible, but we have had the best results with sinew so far. In addition, a binding with this material wears very little, which is an advantage when playing the flute, because it is easier to grip. It is still unclear whether an adhesive was also used (Conard et al. 2004: 456); it could be hide glue, which has now been proven at least for the Neolithic (Bleicher et al. 2015). This would indeed further improve the adhesion of a (tendon) binding.

Whether the fingerholes were made before the halves were put together or only afterwards cannot be determined, but in any case, this happened only after at least one half was hollowed out, according to M. Malina (personal communication). The Blaubeuren team scraped fingerholes prior

Figure 21: The completed ivory flute reconstruction. Photo by W. Hein.

to gluing, whereas I prefer to do this after the two halves are assembled and glued (Figure 19.9). Then the tube is more stable again and easier to handle. As I learned when working on the Lion Man, it is always easier 'to go with the grain' when scraping, i.e. from the surface of the flute down into the fingerhole. If you work the other way around and against the grain, the stone tool starts to rattle and leaves small unsightly heels. I do not understand the remark in A. Holdermann's report that the edges of the fingerholes must be sharp in order to break the air flow. After all, the flute tone is produced exclusively at the mouthpiece, at whose labium the air stream must be divided. If this were not the case, modern recorders or the flute reconstruction from the Austrian site Grubgraben (Einwögerer and Käfer 1998) with drilled holes would not work at all. Finally, the blowing notch is made, which I do by applying the rim to various grinding stones that have varying degrees of surface fineness (Figure 19.10).

In spring 2020, David Haskell of the University of the South, Sewanee, Tennessee, USA, asked me to make a reconstruction of the mammoth ivory instrument GK3 (Figure 23; Table 1, Instrument (g)). The remit was that it should not necessarily be an exact replica of GK3, but primarily demonstrate the technical skills of the Ice-Age hunter-gatherers. Since I had at my disposal a mammoth ivory stick of 35 cm, I suggested that I should make a replica of GK3 but also extend it to this size. At the same time I contacted Anna Friederike Potengowski, a flutist, and music-archaeological researcher and performer on Palaeolithic flute reconstructions; this was a unique additional chance for us to incorporate her perspectives into the design right at the start of the experimental work

(Figure 20). The design that we decided on can be described as follows: dimensions and positions of the fingerholes and labium follow: the mammoth ivory instrument (GK3) for the labium; the wind instrument from Hohle Fels (HF1) for the five holes running from the proximal end; and the dimensions of A.F. Potengowski's hand for two holes at the distal end. The proposition was acceptable to D. Haskell, and so another Aurignacian ivory flute was constructed from mammoth tusk (Figure 21).

The gluing of the two halves was handled invisibly with a modern two-component glue for reasons of better durability; I considered that the flute could manage without an additional winding directly at the blowing end. However, I was quickly proven wrong, because of how ivory actually 'works', i.e. it warps, as Malina and Ehmann had already noted:

> "During the experiment care had to be taken not to let the two halves lie independently of each other for too long. Only when tightly laced to each other, they could remain fitted." (Malina and Ehmann 2009: 107; translation by the author)

After A.F. Potengowski had played the flute reconstruction for a few days, the halves became detached from each other at the end with the notch. Two additional windings remedied this, however, and since then the two halves have remained tightly in position and have not changed.

4 Comparison of eight different reconstructions of the mammoth ivory instrument from Geißenklösterle Cave. Constants and differences in playability and resulting tonal material

Anna Friederike Potengowski

4.1 Summary

This chapter deals with the comparison of the tonal material of 8 different reconstructions of the mammoth ivory instrument from Geißenklösterle (GK3). We here provide a detailed description of the reconstructions and of the practice process that precedes the collection of usable musical data. As a result, not only expected differences between the various reconstructions are recorded, but also obvious similarities, which specify the range of possible tonal material producible by the original instruments. Our research also offers new insights regarding the playability of reconstructions that are longer than the original.

4.2 Introduction

The incompleteness of the Palaeolithic musical instruments from the Swabian Jura led to a long series of questions, including what frequencies, what intervals and what tonalities were played on these instruments 40 000 years ago. Our work attempts to answer these questions through a systematic comparative study of the tonal results produced on the different reconstructions.

A previous study of four different Palaeolithic wind instrument reconstructions from Geißenklösterle, Hohle Fels, SW-Germany, and Isturitz, France (Potengowski et al. 2015; Münzel et al. 2016) yielded considerable insights into voicing methods, offering suggestions for defining basic

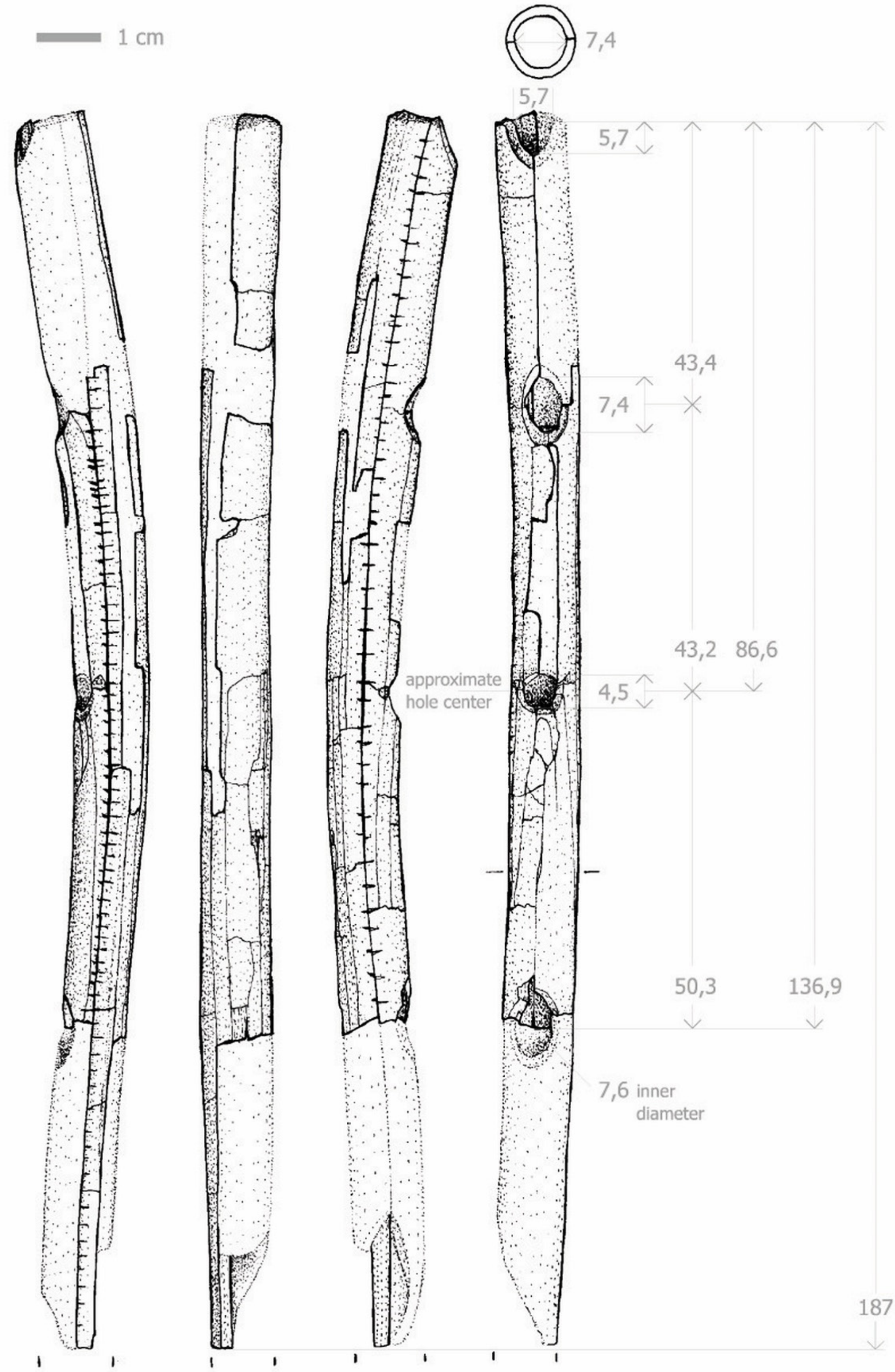

Figure 22: Measurements of the original find GK3 in mm.
Drawing by R. Ehmann, supplemented by Stephan Hahn, measurements from Conard and Malina 2004; 2006.

Figure 23: Eight reconstructions of GK3 (cf. Table 1).
Photos a, b, c, e, f, g: A.F. Potengowski; d: G. Dalferth; h: M.C. Thumm. Design H. Wiedmann.

notes and for building a richer tonal material than that previously described by F. Seeberger (1998; 1999; cf. Münzel et al. 2002). This was done by considering the possibilities of the glissando effect, i.e. a substantial gliding pitch change obtained by altering the embouchure. This is both a curse and a blessing. On one hand it enriches the possibilities of artistic expression, on the other it makes the search for specific musical material from Palaeolithic times more difficult.

The following study attempts to reduce the frame of possibilities by focusing on one find – the mammoth ivory instrument GK3 (Figure 1). Since the method of playing on the notch compared to the method of oblique playing on the edge reduces the possibilities of the glissando effect to zero, the tonal material of this instrument is more limited, compared to the other Palaeolithic aerophones, which were purportedly voiced obliquely on the edge. Reconstruction of the possible tonal framework of the original instrument is achieved by searching for similarities in tonal results despite changing parameters, such as length and number of fingerholes.

An open door may tempt a saint: during the last years the present author was given the task to record audio examples of several GK3 reconstructions made by different constructors with different intentions. This unique opportunity allowed the collection of scientific data – measurements, tonal material, as well as musical and technical playing experiences including audio examples.

4.3 Measurements of wind instrument finds and their reconstructions

The measurements of the original find (Figure 22) taken by F. Seeberger (a former engineer and experimental archaeologist) differs from the way A.F. Potengowski measured the reconstructions. Depending on which content is to be discussed, one focuses on different distances. Seeberger's intention in collecting the data is unfortunately not documented. Presumably, he surveyed from an engineer's point of view. He focused for instance on the distance between the rim of the notched end of the instrument and the centre of the following hole. In contrast, Potengowski as a flutist focused on measurements that influence the pitches of the respective instrument. For example, the distance between the lower edge of the notch and the upper edge of the following hole, since this distance essentially determines the pitch (see chapter 2 above). Thinking ahead, if the first fingerhole is closed, then the distance between the lower edge of the notch and the upper edge of the second fingerhole is relevant.

4.4 Description of the studied GK3 reconstructions

Before going into detail on the musical analysis, a careful description of the eight different handmade reconstructions is called for (Figure 23). Deviations from the original mammoth ivory instrument GK3 depend on the constructors' respective skills, on the raw material properties, on use of stone tools during construction, and on the different aims of the instrument makers (Figure 23; Table 1).

The influence of deviations in measurements on the pitches was not on focus for all constructors. With one exception, Instrument (a), none of the instruments was especially made to be compared to other reconstructions.

	Name	Template	Fingerholes	Length (mm)	Material	Designer/Constructor	Owner
(a)	GK3_2H_SwU_Pot	GK3	2	129.5	Ulna, mute swan	A.F. Potengowski	A.F. Potengowski
(b)	GK3_3H_SwU_Pot/Spreer	GK3	3	183	Ulna, mute swan	B. Spreer A.F. Potengowski	A.F. Potengowski
(c)	Gk3_3H_MI_Hein	GK3	3	185	Mammoth ivory	W. Hein	A.F. Potengowski
(d)	GK3_5H_MI_Dalferth	GK3	3	187.8	Mammoth ivory	G. Dalferth	G. Dalferth
(e)	GK3_4H_AI_Hein	GK3	4	242.5	African elephant ivory	W. Hein	W. Hein
(f)	GK3_4H-AI_Pot	GK3	4	255.5	African elephant ivory	A.F. Potengowski	A.F. Potengowski
(g)	GK3/HF1_7H_MI_Hein/Pot	GK3, HF1	7	296[22]	Mammoth ivory	A.F. Potengowski (idea) W. Hein (idea and construction)	D. Haskell (USA)
(h)	GK3_5H-MI_Trommer	GK3, HF1	5	305	Mammoth ivory	F. Trommer, A. Holdermann, H. Wiedmann	F. Trommer

Table 1: Key parameters of eight different GK3 reconstructions.
The name contains the following information: scientific name of the find, number of holes, material, producer. SwU – swan ulna, MI – mammoth ivory, AI – African elephant ivory.[23]

Instrument (a) was especially made for comparative use, to gauge similarities independently of length. The inner diameter of swan ulnae is very similar to the inner diameter of the original GK3. For comparison, the inner diameter of the notched end of instrument (a) is 7.5 mm, that of the original 7.4 (measured by Malina and Seeberger). Swan ulna was used here to avoid waste of rare material and high costs of using mammoth ivory. The size of the notch and holes was defined by measurements taken from the cast of the original artefact GK3.

Instrument (b), an earlier version of this instrument, was originally made for the Urgeschichtliches Museum Blaubeuren as part of a group of instruments for demonstrating different playing methods in the exhibition area (idea of B. Spreer). A.F. Potengowski, who was involved in the production of audio examples for the museum, came up with the idea of building similar reconstructions herself for demonstrative, analytical, and comparative purposes. The natural diameter of the ulna shaft is very close to that of GK3. The reconstruction has the same length as the original, as measured between the two ends including the thin sliver at the distal end. The notch and holes were made according to measurements taken from the original instrument. The third hole was reconstructed by mirroring the preserved half (idea of B. Spreer).

Instrument (c), of mammoth ivory, was commissioned by A.F. Potengowski as a concert instrument with the request that it should be reconstructed true to the original. Its diameter is determined by the natural conditions of the ivory segment out of which it is made. As with Instrument (b), the notch, holes, and length were made to measure like those of the original instrument.

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[22] Deviation in measurements from Figure 24 and Figure 25 are due to problems with data transfer. Correct measurements are reported in Table 1.

[23] CITES certified material. We participate in the critical ethical discourse on the necessity of using original animal materials for the construction of reconstructions and have carefully weighed the use of this material.

Instrument (d), also of mammoth ivory, was designed and made by G. Dalferth, after the original measurements. Because weathering by taphonomic processes is believed to have modified the extent of the notch on the original instrument, G. Dalferth made the notch of this reconstruction slightly smaller than that of the original. Her idea was to produce a good playable instrument for demonstration purposes. The length was limited by the properties of the material available for reconstruction.

Instrument (e), of African elephant ivory, arose from a cooperation between W. Hein and A.F. Potengowski with the financial support of the Deutsche Musikrat 'Neustart Kultur'. The Research objective was to test the tightness and playability of fresh ivory as opposed to fossil ivory (A.F. Potengowski). The reconstruction is based on the original instrument but is extended in length according to the maximum length of the available raw material. A fourth hole was added, positioned according to a comfortable position of the right-hand fourth finger of A.F. Potengowski (see chapter 3 above).

Instrument (f), also of African elephant ivory, was designed and produced by A.F. Potengowski parallel to Instrument (e) and for the same purposes as the latter, but also with the intention of gaining first-hand experience in the processing of ivory flutes. The total length of the reconstruction differs from that of the original instrument and was determined by the conditions of the available material. A fourth hole was added, positioned according to a comfortable position of the right-hand fourth finger of A.F. Potengowski.

Instrument (g) was commissioned by D.G. Haskell (University of the South, Tennessee, USA) in the context of his studies for the book *Sounds Wild and Broken* (Melbourne, VIC: Black 2022). The length of the instrument was given by the proportions of the available material. The griffon vulture instrument from Hohle Fels (HF1) was chosen as a template for the spacing and size of the first 5 fingerholes. The position of holes 6 and 7 was chosen according to a comfortable position of the third and fourth fingers of A.F. Potengowski (see chapter 3 above).

Instrument (h), of mammoth ivory, was designed and produced by F. Trommer, A. Holdermann, and H. Wiedmann (Holdermann et al. 2013). Its length was inspired by the existence of longer instruments like HF1, as well as the ivory rod find from Geißenklösterle (Figure 2) and determined by the dimensions of the material available for reconstruction. The spacing of the first three fingerholes follows GK3 measurements. Holes 4 and 5 repeat these measurements.

4.5 Development of playing skills – preparation steps for the musical analysis

To gain comparable musical data it was first and foremost necessary to carefully develop the basic playing skills. Since we assume that the notched end of the original instrument was used for tone production – it was necessary to develop the embouchure, the individual position of lips, tongue, oral cavity, to direct the air flow with an optimal tonal result on the notch. Attention was paid to identifying the most effective fingering, in other words, to understanding which finger serves which hole the best.

The acquisition of playing skills like overblowing to reach the overtones of the instrument required considerable time and practice, especially because of physical differences between the reconstructions that affected the way of blowing. From my experience it takes years to get familiar with instruments like these and it is an ongoing process. After 12 years of performing on reconstructions of Palaeolithic wind instruments I am still improving my playing skills and developing new techniques. Therefore, it is useful from time to time to take pauses in the learning process in order to describe and consolidate the results. At the bare minimum, I would practice for 3 weeks to explore the musical possibilities, playing an individual reconstruction at least 1 hour a day with maximum 3 days off. The next step was to describe the musical potential of the respective instrument 3 times with a few days break to record the results over separate time periods in order to avoid biases depending on physical conditions of the player. Frequency measurements were taken with the Tuner T1 App Version 4.15 (JSplashApps). Tone pitch was also noted down in modern music notation.

4.6 How to image the tonal material for comparison

Modern stave notation evolved simultaneously to the development of our instruments, playing skills and musical preferences, and is adjusted to contemporary musical traditions. However, no notation system has been handed down to us from Palaeolithic times. There is no knowledge about the playing skills of Palaeolithic humans, their musical traditions, or their musical perception. Were people familiar with the whole tonal spectrum of their instruments as we know them from our modern reconstructions? Did they consider microtonal possibilities? Did they know and prefer intervals resulting from physical factors like the overtone scale? These are all questions to which no certain answer can be given.

Tonal results from the reconstructions are not comparable with the currently used tuning systems of either pure or tempered musical intervals. Distances between tones might sound wider or smaller than the musical intervals to which we are familiar. Therefore, the imaging of the musical potential of these reconstructions should be handled and perceived with care to avoid an uncritical application of our modern musical tradition and experience to the past. Hence the choice of representing the results on one hand through frequency values (Figure 24 and Figure 25), which despite their accuracy are hard for the reader to visualise, and on the other hand through transcription of the results in the modern five stave notation system (Figure 26), which due to intrinsic limitations cannot describe the results accurately.

A third way of describing the tonal material of the reconstructions is to notate the resulting musical Intervals. Again, this method generates inaccurate descriptions of the relationship between the resulting tones and carries the risk of inappropriately applying modern musical categories to the past.

Figure 24: Four reconstructions – measurements and frequency numbers. Design by Matthias Kraus.

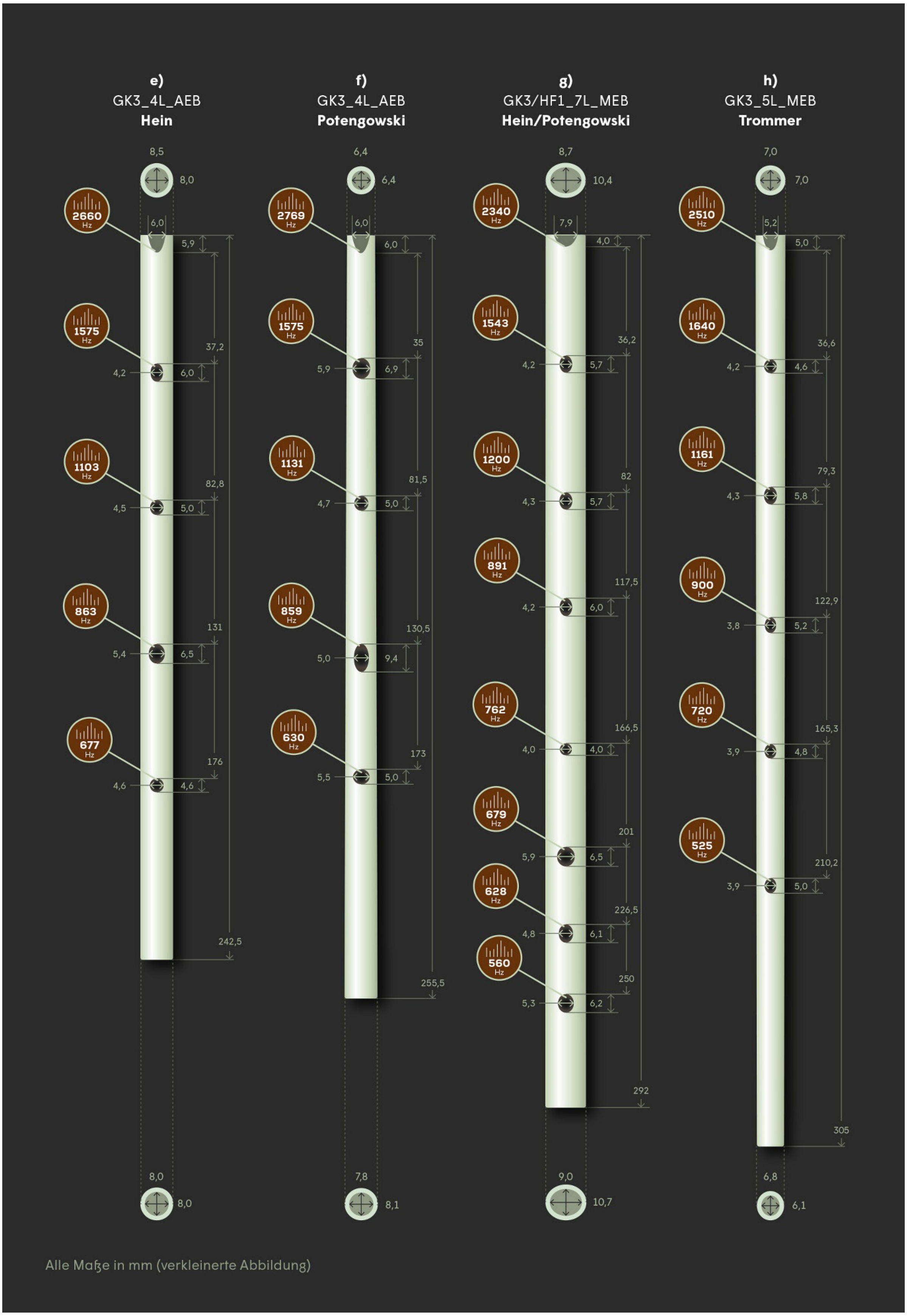

Figure 25: Four more reconstructions – measurements and frequency numbers. Design by Matthias Kraus.

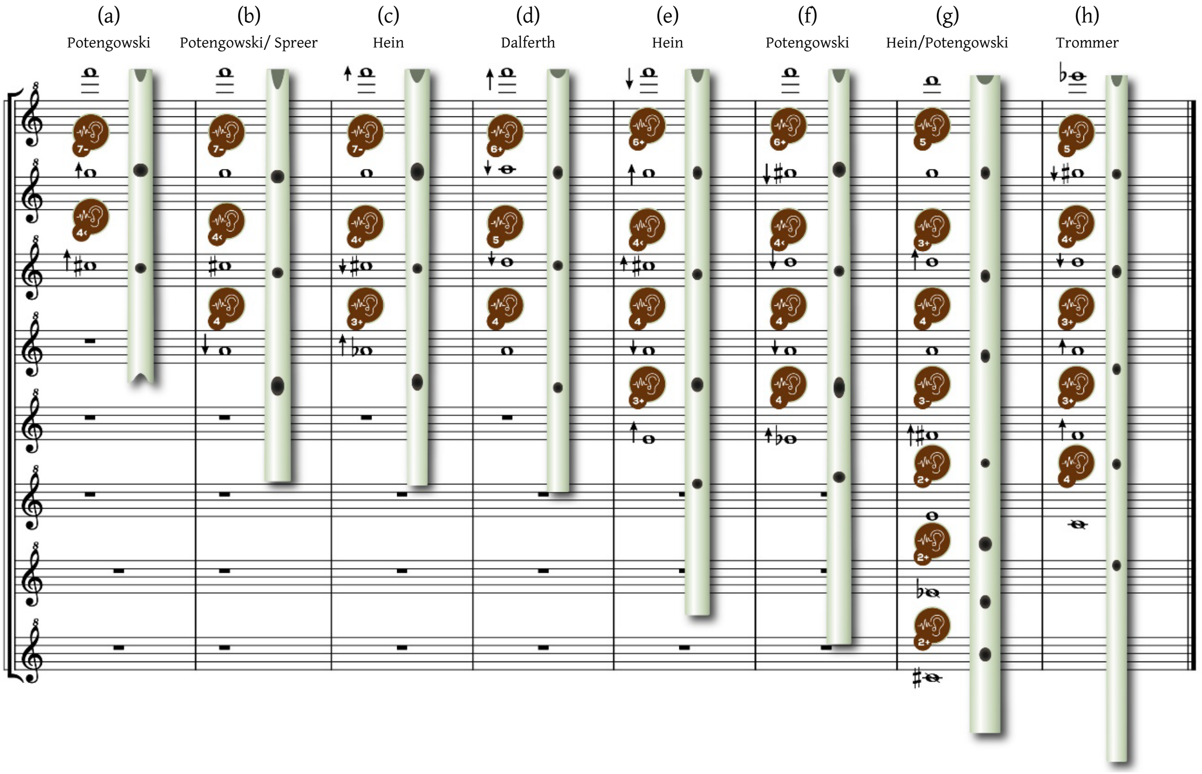

Figure 26: Tonal analyses of eight reconstructions of GK3 (cf. Audio Examples a–h). Design by Matthias Kraus.

4.7 *Explanation of the graph*

The results of the comparative analyses of the 8 different GK3 reconstructions are shown in Figure 26, which is a simplified representation of the resulting tonal material. The reconstructions are labelled at the top with their name, followed by the name of their maker. Pitches are abstracted in noteheads representing the results of the frequency meter Tuner T1. The reference pitch used is 440 Hz. The arrows beside the noteheads indicate a strong deviation from the note mean. Scaled down sketches of the reconstructions are included. Each hole is flanked by its corresponding notehead in the five-line staff representation to mark clearly where the intervals occur. Only simple fingering is applied. Accordingly, the graph must be read from top to bottom. The noteheads beside the notches in the first stave represent the pitches produced when no holes are closed. The second stave represents the case when the first hole is closed. Similarly, the third and fourth stave represent, respectively, the cases when the first and second holes and the first, second, and third holes are closed and so on. Intervals were analysed by ear by taking as reference values those of a modern recorder flute (440 Hz). These are visually represented by red ear icons with interval numbers between the related noteheads and should be read vertically.

Attention must be given to the fact that the distances between the notes differ from time to time from the ear-analysed intervals. An example of this is the following: Instrument (e) produces a C♯ when the first two holes are covered and an A when the third hole is also covered – normally this is described as an interval of a major third, but the analysed interval is represented in the graph as a fourth. In fact, as the arrows show, the C♯ is particularly high, and the A is low. The distance between both tones is therefore wider than that representable by the note system. The resulting interval sounds to the human ear like a fourth.

4.8 Description and discussion of the results

Differences in the resulting tonal material of the individual reconstructions, are attributable to a variety of components (see chapter 2 above). These include not only the length of the instrument but also differences in notch design, hole size and shape, and the distance between the blowing edge and the next open hole. The diameter of the tube mainly influences the volume of the instrument, but also the pitch to a small extent through the phenomenon of end correction (see chapter 2 above). The influence of the other parameters is much stronger, so that the influence of the diameter on the difference in pitches of the reconstructions with respect to a given tone hole can be neglected in this analysis. Regarding the playability of low notes, the diameter must be taken into account, as will be explained in the following.

For the sake of clarity, I will discuss the results of the analysis by using tone and interval names. Subtle variations in pitch or pitch spacing are represented in Figure 26 (see frequency numbers and compare the Audio Examples). Alternatively, in the text they are described in the musical sense as ‘different shades’.

On the first stave, with no closed holes, the note F_7 is clearly dominant. Only Instruments (g) and (h) deviate from this pattern. In line two, with the first hole closed, everything seems to revolve around shades of the tone G_6. Five of the eight reconstructions play a G_6 and two a $G\sharp_6$. Instrument (d) shows the greatest difference with a pitch equivalent to A_6. Pitch shadings around the notes $C\sharp_6$ on (a), (b), (c), (e) and D_6 on (d), (f), (g), (h) are predominant in line three when 2 holes are closed. When 3 fingerholes are covered, seven reconstructions play an A_5 while one plays an $A\flat_5$. With 4 closed holes, line 5, differences in pitch become greater, and they are hardly comparable with each other when 5 holes are covered. This is both due to the small sample of the reconstructions, there being only 2 instruments with corresponding length and number of holes, and also to the playability of the notes, which is made more difficult due to the relation between the increasing length of the vibrating air column and the narrow diameter of the tube (see again chapter 2). It is not possible to voice the lowest notes of Instruments (g) and (f) properly. This is an important result of the comparative analysis. In fact, it proves that elongating the instrument while maintaining the same diameter, with the intention of achieving lower tones, is not effective (see chapter 2.4 above). This part of the analysis deals primarily with the fundamental tones of the instruments. The intention behind longer instruments (Figure 2) with the same diameter could still have been the extension of the tonal range, but only in the overblown, higher register. Overblowing of the tones is possible (see chapter 2 above) up to all closed holes. However, to keep the graph clear, overblown tones are not represented in Figure 26.

Summing up, there are clear similarities between the tones produced by the reconstructions when the first 3 holes are progressively covered. Differences between the various reconstructions concerning the pitch of the same hole are never larger than a whole tone. It is therefore possible, when searching for the tones of the original instrument, to limit the range of possible pitches belonging to a certain hole to the range within a whole tone.

In musical practice, when stringing together tones to form scales and melodies, pitch differences even within this range have a nature-changing effect on the music. We all know the crucial difference that even a semitone can make in the reception of our modern major-minor system. For this reason, we should look at differences and similarities in the resulting intervals for the respective fingerings.

The tone spacing between all holes open, and first hole closed, corresponds to a minor seventh on Instruments (a), (b), and (c), a major sixth on Instruments (d), (e), and (f), and a fifth on Instruments (g) and (h). Here, no apparent constancy can be detected. On the other hand, the interval of the augmented fourth (tritone) is clearly predominant between holes 1 and 2, despite differences in length between the reconstructed instruments (Audio Example i). Only Instruments (d) and (g) deviate from this pattern. It is very likely that a 'shading' of this interval could also have been played on the original instrument. The most frequent musical interval between holes 2 and 3 is the fourth. The intervals produced on Instruments (b), (d), (e), (f), and (g) correspond to fourth, while the same fingering generates a major third on Instruments (c) and (h).

The intervals between holes 3 and 4 can be compared only between reconstructions (e) to (h), albeit with reservations, since the fingerholes of (g) and (h) are placed at very different distances. Three instruments, (e), (g), and (h), produce a third, specifically two major thirds and a minor third, and one instrument, (f), produces a fourth. With 5 closed holes, Instrument (h) already reaches its fundamental tone, in contrast to the 7-hole-instrument (g), which does not. This explains the large interval differences between holes 4 and 5. The comparability for the intervals between hole 5 and 6 and hole 6 and 7 is not given. The respective tones are nearly unplayable and comparable reconstructions are missing.

4.9 Conclusions

In this study we have compared the various reconstructions of GK3 to detect similarities, differences, musical possibilities, and also limitations in the reconstruction of the original tonal material of GK3. Even if the original length of GK3 remains unknown, our study shows that several tonal materials can be excluded, and the possible range of the original tone material can be narrowed down. The analyses of the reconstructions of the mammoth ivory instrument GK3 indicates that increasing instrument-length without adapting the diameter causes problems in the voicing of the lower fundamental notes even though overblown tones still remain playable. Thus, elongating the mammoth ivory instrument in the attempt of reaching the lower fundamental tones is not effective, whereas the aim of extending the tone range with new tones can be achieved by overblowing.

Regardless of instrument-length, clear similarities emerge in the results obtained for the upper 3 fingerholes. Therefore, the original interval between hole 1 and 2 might have corresponded to an augmented fourth, and between hole 2 and 3 to an interval around a fourth or major third. We conclude that the comparative analyses of the different reconstructions of GK3 may be regarded as a reasonable method to gain knowledge on the original tonal material of the instrument.

5 Future research

Even though the variability in the reconstructed instruments allows for the exploration of different musical possibilities, it also poses a limitation to the study of GK3. Therefore, our next step will be to compare our results with those produced on 3D-printed reconstructions in order to exclude biases generated by differences between the reconstructions and the original instrument. Additionally, the replicability of the results will be tested by other players so as to exclude errors derived from the subjective interpretation of a single player. Future work will additionally include the creation of spectral analyses in order to present more exact data. The development of a more neutral representation system is also called for. In this way we can avoid an uncritical application of our modern understanding of music to 40000-year-old instruments. A standardised system for analysing and representing the tonal material of different reconstructions might become a useful tool in the study of other instrument findings, such as those from the Ach and Lone Valleys. Analyses concerning the influence of embouchure morphology on the tonal material of the reconstructions as well as the different effects of fresh and fossil ivory on the sound properties of reconstructions are in progress.

Acknowledgements

Foremost we would like to thank the excavators of the oldest wind instruments, the professors Joachim Hahn † (Urgeschichtliches Institut, Universität Tübingen) and Nicholas Conard (Department of Early Prehistory and Quaternary Ecology, Universität Tübingen), whose instrument finds opened up new horizons in music archaeology and appreciation. Fritz Seeberger † we thank *posthum* for his pioneering work in experimental musical analysis of the wind instruments from the Swabian Jura. And we should not forget to express our gratitude to Frances Gill, who always is a very supportive person when it comes to discussing results. Last but not least we would like to thank Giulia Toniato, who handled our earlier version of this manuscript and transferred it into readable English.

Video Examples

1: Wide and narrow tube, same length. © G. Dalferth 2023.
https://youtu.be/ikIFVY1jue0

2: Coverage of the blowhole with the lips. © G. Dalferth 2023.
https://youtu.be/71JLQByPoYc

3: Two tubes with a narrow and a wider notch. © G. Dalferth 2023.
https://youtu.be/jzhH_s02AiU

4: Pennywhistle with a narrow and a wider window. © G. Dalferth 2023.
https://youtu.be/bDW4Lv9ZbTs

5: Flute 1: Narrow turkey radius flute, small fingerholes. © G. Dalferth 2023.
https://youtu.be/r9-H9bXzJ-U

6: Comparison between Flute 3 and Flute 1, Flute 3 being a wide turkey ulna flute with same finger hole sizes as the narrow radius flute. © G. Dalferth 2023.
https://youtu.be/rMOUxJzyk7Q

7: Comparison between Flute 2 and Flute 1, Flute 2 being a wide turkey ulna flute with larger fingerholes compared to the flutes in Videos 5 and 6. © G. Dalferth 2023.
https://youtu.be/J7TfYcbHJmo

8: Reconstructed HF1 flute, response from the low and from the overblown register. © G. Dalferth 2023.
https://youtu.be/hFy_I7XI8SU

9: Whistle with fully inserted rod. © G. Dalferth 2023.
https://youtu.be/17NqyK7kgp4

10: Whistle with partly inserted rod. © G. Dalferth 2023.
https://youtu.be/zzlOAILb_Gk

11: Swan ulna, glissando range (low register only). © G. Dalferth 2023.
https://youtu.be/w6GB7OGhzs0

12: Swan radius, glissando range (low register only). © G. Dalferth 2023.
https://youtu.be/3xmiMl4o2IYv

Audio Examples

a) GK3: basic notes from no hole closed to all hole closed from instrument (a). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/a-gk3-2h-swu-potengowski/s-1UOddO9b5MN

b) GK3: basic notes from no hole closed to all hole closed from instrument (b). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/bgk3-3h-swu-potengowski-spreer/s-pHQGdza3Mzu

c) GK3: basic notes from no hole closed to all hole closed from instrument (c). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/c-gk3-3h-mi-hein/s-ngD5322yabM

d) GK3: basic notes from no hole closed to all hole closed from instrument (d). © G. Dalferth 2023
https://soundcloud.com/friederikepotengowski/d-gk3-3h-mi-dalferth/s-P3RIhaHWSOC

e) GK3: basic notes from no hole closed to all hole closed from instrument (e). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/e-gk3-4l-ai-hein/s-Elde1eJ7rvV

f) GK3: basic notes from no hole closed to all hole closed from instrument (f). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/f-gk3-5l-ai-potengowski/s-lUegFY7Z9q1

g) GK3: basic notes from no hole closed to all hole closed from instrument (g). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/g-gk3-7l-mi-hein/s-RXH2C9aAEvE

h) GK3: basic notes from no hole closed to all hole closed from instrument (h). © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/h-gk3-5h-mi-trommer/s-C9CmvujibCj

i) GK3: Reconstructions (a) to (h) from 2 holes closed to 1 hole closed. © A.F. Potengowski 2023
https://soundcloud.com/friederikepotengowski/8-reco-comparison-example/s-DDlMdZUtI6O

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Sounds from a Base Camp. Different Ways of Reconstructing and Playing the 'Grubgraben' Wind Instrument

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Abstract

Since the discovery of a fragmented Ice Age wind instrument was made in 1994 at a base camp of Palaeolithic reindeer hunters in Grubgraben/Kammern in Lower Austria, several attempts to reconstruct the instrument have been made. Due to the fact that both ends of the bone are broken pre-depositionally, varying options for reconstruction have been discussed since 1997. The most prominent research questions remain: How was the instrument likely played, how did it sound, and how can the sonic results of reconstruction experiments be displayed and interpreted? This paper will build a bridge from the first detailed research, carried out in the late nineties, to today's more wide-spread field of scientific research on Palaeolithic aerophones, in order to shift attention to possibilities for reconstructing the Grubgraben artefact beyond those first attempts. It will also contextualize the instrument within recent music archaeological research and data. Throughout this paper, the main focus will be on studies of the instrument as an end-blown flute and the resulting tonal properties and pitch ranges, as they were presented and discussed at the 11th Symposium of the International Study Group on Music Archaeology in Berlin in November 2021 by Maria Hackl and Veronika Kaudela.

Keywords

Palaeolithic wind instrument – Bone flute – Epigravettian – Kammern/Grubgraben – Experimental archaeology

Figure 1: The perforated bone artefact from Grubgraben, Lower Austria.
Photo with kind permission of Landesmuseen Niederösterreich

1 Introduction : More than twenty years of research on an Epigravettian artefact

In 1994, excavations at the Upper Palaeolithic site 'Grubgraben' near Kammern in Lower Austria produced a well-preserved fragment of a 165.3 mm long bone with three perforations. The right tibia of, presumably, a reindeer,[1] was punctured with three holes of nearly the same diameter, transforming the bone into a wind instrument. Unfortunately, this unique specimen is broken at both ends. This means that it remains unclear whether there was a specific mouthpiece, and if so, where it was placed.

A few years after the artefact was found, archaeozoological attempts were made to identify to which animal species the bone fragment belonged. Additionally, the stratigraphical context of the object was researched, and microscopic and other analysis on how the perforations were produced were undertaken. In 1997, Bernadette Käfer and Thomas Einwögerer conducted several reconstruction experiments with both reindeer and red deer bones, which resulted in the satisfactory reconstruction of different end-blown flutes, played from the distal end of the bone. The sound of one of those instruments can be heard on two CDs.[2] A master's thesis on Palaeolithic wind instruments in the Eastern Alpine region[3] by Bernadette Käfer, which includes these reconstruction attempts, remains, until now, the most detailed work on the Grubgraben instrument within the context of other wind instrument finds.

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[1] In 1998, Florian Fladerer proposed that the bone belonged to a young reindeer; Einwögerer et al. 1998: 21–25; Käfer and Einwögerer 2002: 93.

[2] Käfer 2001; Käfer, Scherner 2004.

[3] Käfer 1998.

In the following years, the Grubgraben artefact was listed in different databases on Palaeolithic wind instruments[4] and a few reconstructions of the Grubgraben instrument as flutes were made.

Since 2015, research on the Grubgraben wind instrument has intensified again, with Maria Hackl not only experimentally reconstructing the object in a series of experiments assuming different methods of play[5], but also researching the morphology of the bone and the site context. For the first time, different plausible types of instrument (other than end-blown flutes) were taken into account, and playing reconstructions from the proximal end of the bone was also explored by experiment. Furthermore, Ljubomir Nikolić, a composer and researcher on the Academy of Arts Novi Sad, used recordings of the newer reconstructions for the music and soundscape of an interactive exhibit installed in four museums along the Danube, and is currently exploring experimental playing techniques and the tonal possibilities of the instruments in his research and compositions.[6] In 2021, Veronika Kaudela, a researcher for the Austrian Archaeological Institute (ÖAI) of the Austrian Academy of Sciences (ÖAW) at the Grubgraben site, where excavations and research are still conducted today, supported the ongoing research on the instrument with new data regarding the artefact and the site.

This paper will cover the tonal output of reconstruction experiments conducted in Austria since the discovery of the find. Finally, it will conclude by summing up questions and widespread future plans for research on this fascinating piece of Ice-age art and craftsmanship.

Since the first reconstruction experiments were conducted more than 20 years ago, the scientific approach to reconstructing archaeological instruments has evolved, and the dating of the Grubgraben site and artefacts have changed. These new insights and the difference between the older and the more recent reconstruction experiments, including additional forms of play, will be highlighted in this paper. Therefore, in the following chapter the find and site history, as well as the new data will be presented. After that, the research approach, assumptions, and reconstructions of the Grubgraben instrument during the nineties will be described by Bernadette Käfer who conducted the first research. In chapter 4, the research which was conducted since 2015 and the reconstructions and tonal results which were produced in this period will be explained. Chapter 5 provides a summary and future research attempts concerning the Grubgraben instrument.

2 The site and the circumstances of the discovery of the Grubgraben wind instrument

(Veronika Kaudela)

The archaeological site Grubgraben, where the object of research was found, is located near the village of Kammern, in the North of Austria. It lies in the Southeast extension of the Moravian-

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[4] Morley 2013, Appendix Table 1; Neal 2013: 74–97; Praxmarer 2019, 89–92.

[5] More than 15 bone instruments have so far been constructed by Maria Hackl as possible reconstructions for the Grubgraben wind instrument. Two of the reconstructions were constructed together with Sarah Defant.

[6] Nikolić 2019.

Figure 2: The site during the excavation, 1993. Photo by Gerhard Trnka

Bohemian highland, near the Danube. The site is situated in a trough-shaped valley, opening southwards to the Danube plain, and flanked by two hills which today are called Heiligenstein and Geißberg. In recent centuries this area was formed into a narrow terrace, surrounded by more terraces on the hills, to benefit the cultivation of grapes for wine-making.[7]

The site was first mentioned in 1885, when objects appeared in the profile of a modern ravine-like narrow pass which cuts into a Palaeolithic occupation layer. Different kinds of investigations followed, and the first authorised excavations were conducted by Friedrich Brandtner and Anta Montet-White between 1985[8] and 1990, and F. Brandtner and Bohuslav Klima between 1991 and 1994. Unfortunately, the documentation of the stratigraphy and finds was inconsistent and imprecise, compared to today's standard, and challenges the archaeologists in retracing their work until today.[9]

The artefact of interest was found in 1994 when a reindeer antler shovel[10] was recovered in a block[11] and taken apart by Brandtner himself.[12] The block contained the antler shovel, fragmented bones and a long bone with three perforations.[13] The block was assigned to the "Kulturschicht" or

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[7] Händel et al. 2021: 138.
[8] Brandtner 1990.
[9] Einwögerer 2019: 8.
[10] For further remarks on the reindeer shovel see p.18 below.
[11] Einwögerer et al. 1998: 21.
[12] Neugebauer-Maresch et al. 2016: 228.
[13] Einwögerer et al. 1998: 21.

archaeological layer III,[14] which is the main archaeological layer with the highest density of finds. It is called archaeological horizon 2 in the recent framework.[15] A bone of this layer was sampled for radiocarbon dating[16] and produced a result of 18,920 ± 90 uncalBP. In 2016 Paul Haesaerts, who dealt with the stratigraphy of the site, published some old dates newly calibrated with the IntCal13 calibration curve using the OxCal v4.2.3. web tool. Hence, the layer where the artefact was found, and presumably therefore also the artefact itself, is now dated to 22 915 to 22 635 calBP.[17]

A number of radiocarbon dates from bone and teeth samples, place the archaeological layers of the site between 23 000 and 20 000 calBP.[18] This period counts to the Upper Palaeolithic and the at least 4 different phases of occupation[19] took place during the Last Glacial Maximum.[20] Based on the lithic industry and chronology, the site was assigned to the Epigravettian.[21]

Since 2015, the Austrian Archaeological Institute (ÖAI) of the Austrian Acadamy of Sciences (ÖAW) has been surveying and excavating parts of the site. Before that, the find inventory of the past excavations was examined and inventoried.[22] In future, it is expected that annual investigations at the site at Kammern-Grubgraben and ongoing research, including the documentation of Montet-White and Brandtner, will deliver improved insights into, and new conclusions about the site.

3 First reconstructions of the Grubgraben instrument in retrospective

(Bernadette Käfer)

As mentioned above, due to predepositional breaks distally and proximally, there is no clue as to what kind of blowing mechanism the instrument had and thus as to how it was played. Therefore, in 1997, the assumption was made that the perforated Grubgraben artefact was a flute and experiments were conducted to reconstruct the object as a set of end-blown flutes with different blowing mechanisms. The aim of these experiments was to discover which blowing mechanism would be suitable for the original instrument. In the following section, the discussions and conclusions which were made prior to the experiments, as well as the process of the experiment itself, will be described and explained.

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[14] Einwögerer et al. 1998: 21.

[15] Händel et al. 2021: 140.

[16] Einwögerer et al. 1998: 21.

[17] Haesaerts et al. 2016: 274.

[18] Einwögerer 2019: 8.

[19] Neugebauer-Maresch et al. 2016: 226.

[20] Einwögerer 2019: 8.

[21] Montet-White and Williams 1994: 127.

[22] Neugebauer-Maresch et al. 2016: 228.

3.1 Observations on the artefact

The bone, which is the right tibia of a ruminant, most probably a reindeer[23], displays three holes arranged in a straight line. The diameters of the three openings vary between 5.1 mm and 5.5 mm and are conical in cross-section. The horizontal grooves on the inner wall[24] indicate that a tool was used in rotating motion.

The similarity of the micromorphology of the edges of all three holes, as well as the only slight variation in the individual diameters, indicate that they were bored using a single tool. The overall picture of this perforated bone fragment conveys the impression that the drill holes were produced in accordance with certain norms, placed deliberately and executed carefully.

3.2 Reflections on how the instrument might have been played as a flute

In 1997, two main possibilities of playing the instrument as a flute were considered. Depending on the angle of blowing, either a side- or an end-blown method of play were possible. However, researchers concluded that if the wind instrument had been originally played as a transverse flute, an additional blowhole, that would have been located at one of the two ends of the bone, must be missing on the artefact. This kind of hole was argued to have been precluded by the natural length of the bone and, therefore, the possibility of the instrument being a transverse flute was excluded.[25] The decision was therefore made to reconstruct the instrument as different types of end-blown flutes, of which the following variants were discussed:

3.2.1 Flute without any special blowing mechanism (oblique)

For this kind of flute, at least one end below the epiphyses would be cut off straight. The most suitable end for this purpose was considered the distal end with its small, rather evenly rounded cross-section. The proximal end, with its pronounced larger triangular cross-section at the end of the bone, was considered less suitable for this purpose.

3.2.2 Flute with a special blowing mechanism (sharpened edge)

For this purpose, the edge of the bone would be cut obliquely on one side, so that a sharp edge is created on which the stream of air, expelled by the player, can break. In principle, it would be possible to make this oblique cut anywhere, but on account of the shape of the bone the distal end seemed preferable for this purpose. Equipped with this kind of blowing mechanism, the flute can be held vertically in front of the body or at an oblique angle directed horizontally to the left or right away from the body, with the oblique edge coming to rest horizontally or vertically, respectively.

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[23] Einwögerer et al. 1998: 21–25; Käfer and Einwögerer 2002: 93.

[24] Einwögerer et al. 1998: 25–26.

[25] The possibility of a fourth hole either as a blowhole or a fingerhole will be discussed in the introduction to chapter 4 as well as in 4.1.1 *The Grubgraben artifact as a transverse flute*.

3.2.3 *Flute with a special blowing mechanism (notch)*

For this version, a V- or U-shaped cut would be made into one end of the bone, forming a notch. In the case of the Grubgraben instrument, in 1997, the distal end was considered more suitable for this kind of blowing mechanism.

3.2.4 *Duct flute*

To construct a duct flute, a core of organic material (beeswax, resin, wood) would be inserted into one end of the bone. In addition to that, another opening is needed which acts as aperture and lip/labium. A core of this type could have been placed distally or proximally in case of the Grubgraben instrument.[26]

3.3 ***Experimental reconstructions of the Grubgraben artefact as an end-blown flute***

In 1997, several flutes were constructed as possible reconstructions for the Grubgraben instrument in order to test the blowing mechanisms described above. All of the flutes were constructed to be played from the distal end of the bone. As a result of these experiments, the most successful form proved to be that of a vertical flute with a simple blowing mechanism in the form of an obliquely cut edge at the distal end of the bone combined with a stopped manner of playing.

For this specific flute, the tibia of a juvenile deer was used, the proportions of which largely corresponded to the original. The bone was cleaned and dry-stored for several months and was not soaked before being worked. Custom-made stone implements of Nordic flint were used, corresponding in shape to original objects found at the excavation site. The first step involved separating the distal end from the shaft of the bone by making a circular groove around the bone using two retouched flint blades, which went so deep that the end of the bone could be easily struck off with an antler hammer. The other end of the bone was removed in a similar manner. The bone marrow was extracted and the outer edges carefully smoothed with stone implements. Removing the marrow is a work step which would not be necessary for bird bones due to their naturally hollow cavity but is required for a mammal's long bone to be playable as a wind instrument.[27] The next step was to measure the position of the holes from the original and mark them. In order to create a precise starting point for a silex borer on the surface of the bone, which was extremely convex in this area, crosswise notches had to be incised with a flint flake. The actual boring of the holes proved to be particularly difficult as the individual diameters could not exceed an average of 5 mm and to match the original should only taper towards the inside by 0.2 to 0.8 mm. This meant that the borers had to be very long and delicate, which meant they would snap very easily. After only six minutes the first tool had to be resharpened and after another nine minutes it was

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[26] If this is possible has to be implemented experimentally in future studies still and will be further discussed theoretically and referenced to in chapter 4.1.2 *The Grubgraben artifact as a duct flute*.

[27] Nonetheless, bone marrow would have most likely been a precious nutrition component for people living in Ice Age conditions and thus the marrow extraction would have been done in some form anyway, not necessarily exclusively for flute construction.

operation/step	time in minutes	tools
severing of the distal end	30	2 retouched blades
severing of the proximal end	41	5 unretouched flakes
making the holes	3 × 57.5	8 borers per hole
finishing the holes	1	2 borers
making blowing mechanism	3	unretouched flake
working time spent on flute	247.5 (~4h 8min)	
making and sharpening of tools	45	
total time	292.5 (~5h)	

Table 1: Working protocol of an end-blown flute, 1997, illustration by Bernadette Käfer

no longer usable. It took 41.5 minutes and a total of six borers to break through the solid bone for the first hole, and another 16 minutes and two borers to complete the hole as can be observed in Table 1.[28] Holes 2 and 3 were achieved in the same way and timeframe. In a final step all three holes were finished using a single borer in order to ensure uniform diameters and degrees of tapering as in the original instrument. The outer form of the flute was completed by adding an oblique blowing mechanism at the distal end. However, the desired sound could only be achieved after the angle of the obliquely cut edge was refined several times. The whole reconstruction of the flute took around four hours and eight minutes, not counting the time needed to make and resharpen the stone implements.

3.4 *Acoustic results*

Experiments of bones of different sizes have demonstrated that the playability, the pitch, the sound, and the volume of a bone flute depend on factors such as the blowing mechanism and position of the holes but, above all, on the morphology of the bone, its length, cross section and also on the surface quality of the inner wall.

The individual notes of the flute constructed during the experiments conducted in 1997 resulted from various finger combinations and from overblown notes in a stopped or unstopped manner of playing. In this case, the player can modify the pitch by varying factors such as the pressure and the angle of blowing or lip tension. If the sounds obtained are ordered in a series of upper partials corresponding to the stopping pipe, the first overblown note is F_6, followed by D_7, representing the third and the fifth partial when assuming a fundamental note of $B\flat_4$, which is, however, not playable. This corresponds exactly to the principle of an ideal stopped pipe, which contains only uneven overtones. Figure 3 illustrates the pitch range of the instrument. The experiments from 1997 represent pioneering fundamental work on Palaeolithic aerophones and successfully demonstrated that the perforated tibia from the Grubgraben site could have been used for the purpose of making music.

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[28] In comparison, perforating bird bones with stone implements takes much less time due to their thinness.

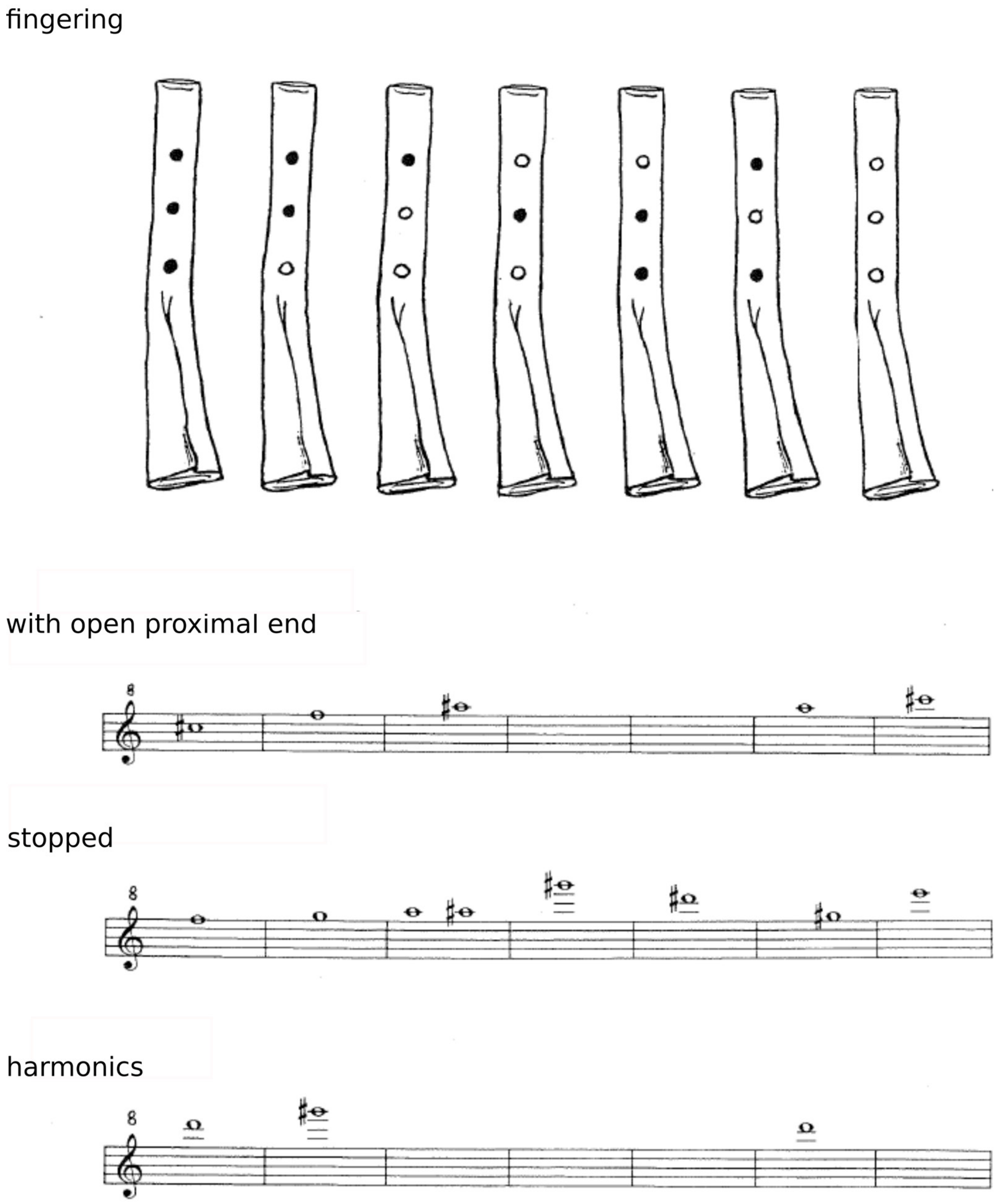

Figure 3: Pitch range of a reconstruction of the Grubgraben instrument as an end-blown flute played from the distal end, 1997. Illustration by Bernadette Käfer

4 The tibia of a ruminant as a wind instrument – new studies on the Grubgraben artefact

(Maria Hackl)

There are different ways to transform a tibia of a medium-sized ruminant, such as a bovid or cervid, into a wind instrument. Constructing a flute from it might be a very (or even the most) plausible method, but it is not the only option. Therefore, for the new experiments since 2015, it was decided to not assume that the Grubgraben artefact was certainly a flute, but to consider a wider range of possible types of instruments.

The Grubgraben object is man-made[29] and most likely represents a musical instrument. However, as it is fragmented, it cannot be reconstructed as a flute with certainty, because the possibility that it is a different type of wind instrument also needs to be considered. Therefore, research on this topic is both difficult and exciting. Another factor, which is hampering research on possible ways the Grubgraben instrument was played in prehistory, is the fact that there are only a few or no other finds of Ice-age mammal long bones with holes, which can be used as comparable and scientifically grounded references.[30]

All the reconstructions, described in the following, were made from fallow deer tibiae, most of them right, some left. (Nonetheless, this does not influence the pitches of the instruments.) All the bones fit well into the range of possible length of the original Grubgraben bone, which is estimated[31] between 165 and 220 mm[32] provided the original bone represents the tibia of an Ice-age reindeer.[33]

All but one of the reconstructions discussed in this paper were made with three finger holes following the measurements and spacing of the original bone artefact. The option of adding a fourth hole on the proximal half of the bone was tried once and proved to expand the pitch range of the instrument upwards. Further research and additional reconstructions are needed in order to prove the presence or absence of a fourth hole. At this point, however, it cannot be definitely excluded for the original.[34] Furthermore, it should be taken into consideration, that – if the original bone is indeed juvenile[35] – it could be possible rather than cutting the bone ends entirely off, to instead drill or cut through them.

4.1 Possible kinds of wind instruments the Grubgraben artefact could represent

Probably the easiest and, at the same time, very effective method to turn a tibia bone into a musical instrument would be to make an end-blown flute out of it. This will be the main topic of this chapter, as discussed in the next section, and was the primary method considered in the experiments conducted during the nineties, too. Before describing the construction and the tonal analysis of different kinds of end-blown flutes, other possible options for wind instruments for the reindeer bone fragment from Grubgraben will be listed and briefly discussed in the following section. By doing so, some variants and options will be added to the ones already described in chapter 3.

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[29] Einwögerer et al. 1998: 25–26.

[30] Hackl 2020: 9; Praxmarer 2019: 77–84.

[31] Käfer 1998: 103.

[32] If the original bone tube had been cut obliquely, the length could have been even a little bit less than the remaining 16.5 cm of the artefact.

[33] This was proposed in 1998 by Florian Fladerer; Einwögerer et al. 1998: 21–25; Käfer and Einwögerer 2002: 93.

[34] It can not be excluded that some other tube had been inserted into the Grubgraben artefact originally to prolong the original length of the Grubgraben bone tube.

[35] Einwögerer et al. 1998: 21–25; Käfer and Einwögerer 2002: 93.

4.1.1 *The Grubgraben artefact as a transverse flute*

A transverse flute should, according to the author of this chapter, also be taken into consideration, and should not be completely ruled out as it was in 1997. Playing a deer tibia as a transverse flute actually does work, regardless of whether one of the three perforations in the Grubgraben instrument is used as a blowhole, or whether another additional hole is added to the bone and used as a blowhole.[36] In both ways the bone can be played when held sideways, either with one end closed or open as depicted in Figure 4 A and B.

When the most proximal of the holes is used as blowhole, four different pitches can be played. These are, for example, for a flute with a tube length of 169 mm, $F\sharp_6$ – $A\sharp_6$ – C_7 – $C\sharp_7$.

An extra blowhole on the proximal end of the bone leads to a bigger range of different playable pitches and much lower ones, too, compared to using one of the three perforations copied from the original bone as blowhole as described above. One flute was constructed in 2021 as a transverse reconstruction of the Grubgraben instrument measuring 190 mm in tube length. The proximal end of the diaphysis was closed and the blowhole was drilled into the section of the bone where the Crista tibiae of the deer bone is not too thick by using a hand-held metal drill.[37] The playable pitches from this instrument are F_5 – $F\sharp_5$ – G_5 – $G\sharp_5$ and, additionally, a deeper pitch can be reached by closing the tube on the distal end with the palm of one hand, which makes $A\sharp_4$ sound.[38]

4.1.2 *The Grubgraben artefact as a duct flute*

Bernadette Käfer and Michael Praxmarer both theoretically address in their work the possibility of the Grubgraben instrument being a duct flute.[39] Jelle Atema conducted some reconstruction experiments searching for possible ways to replicate a flute from La Roque, Dordogne. According to him, the original artefact is made from mammalian bone[40] and traditionally dated into the Perigordian period, but it could also stem from Middle Ages.[41] He reconstructed it as a duct flute from a deer ulna.[42] It must not be ruled out that the Grubgraben wind instrument works as a duct flute, a possibility which needs to be explored experimentally in the future. In this case, the distal end would likely be the more suitable one. If a core is inserted on the proximal end of the bone tube, the window would have to be placed onto the *Christa tibiae* section of the bone, which is very thick and irregularly shaped. A lot of material would have to be removed in a specific way to achieve a proper window and labium in order to make the bone sound as a duct flute.

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[36] A simple thumb-flute is not an option because therefore one single hole in the tube would be enough and the Grubgraben artefact shows three perforations.

[37] Constructing a flute this way would, most probably, also work when the proximal end of the bone is not cut off before. Then this end of the bone would stay naturally closed.

[38] To this moment, it has not been tried to drill the additional hole into the *Christa tibiae* section of the bone using a flint tool. This will, most likely, be possible and is yet to be scientifically proven by experiment.

[39] Käfer 1998: 111; Praxmarer 2019: 86.

[40] There seems to be some contradiction within literature concerning the kind of bone which is discussed by Praxmarer (2019: 84).

[41] According to Atema (2014: 32), it would be necessary to accurately date the object scientifically.

[42] Atema 2004: 19; Atema 2014: 31–32.

4.1.3 *The Grubgraben artefact as an end-blown trumpet*

Playing a deer tibia as an end-blown trumpet works as well. Though, this way of making the bone sound produces more noise than defined pitches, which makes this way of playing the bone rather unlikely, according to the author of this section, assuming that the aim of the finger-holes was to make different pitches sound.

4.1.4 *The Grubgraben artefact as a reed instrument*

Changing the bone into a reed instrument is another possibility, too, as was found out by experiment in 2021.[43] Due to the diameter of the hollow long-bone, a narrower bird-bone with its end cut obliquely was attached into the proximal end of the tibia, which was closed with a chunk of beeswax (Figure 4 C). After that, as a reed, both birch bark and a thin fragment of horn were tried in succession. Both mouthpiece-variants resulted in very loud and rather hard to control pitches.[44] The most prominent pitches for a deer bone with 196 mm tube length and an inserted piece of swan radius jutting out 23 to 34 mm are around G♯$_5$ and A$_5$. It takes quite some force to play the bone as a clarinet in this way, even when using birch bark, but at the same time, this is the loudest option for making the deer bone sound. Still, the whole construction is rather complicated and not very durable. The Ice-age weather and living conditions seem to make this kind of instrument reconstruction rather unlikely. This aspect was also discussed by Wyatt, who states that the weather during this period would have quickly led to unplayable instruments due to a warped or destroyed reed.[45]

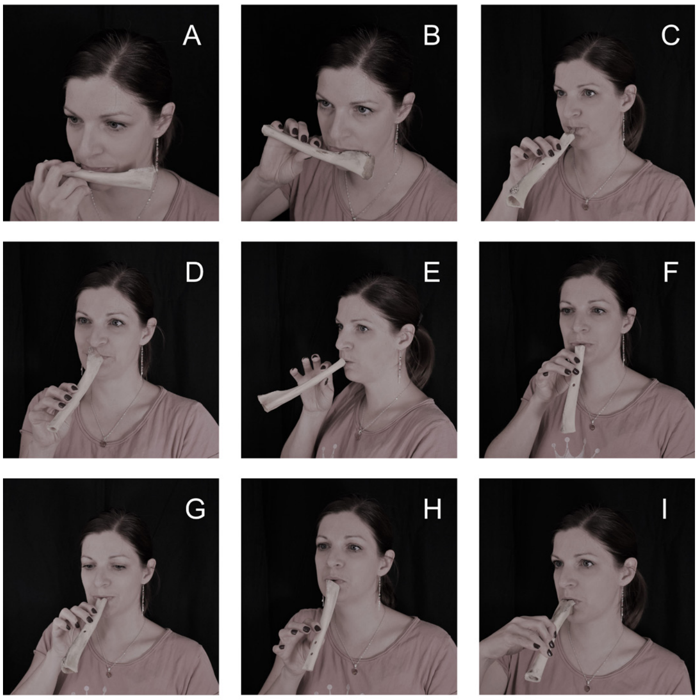

Figure 4: Overview of possible ways to play a ruminant tibia as a wind instrument, 2021. Illustration by Maria Hackl

4.1.5 *The Grubgraben artefact as a kazoo/mirlitone*

A tube kazoo or mirlitone would be another option and the idea of using a membrane to distort the sound of the instrument (or the human voice) should not be neglected. It has not been tried

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[43] Jean-Loup Ringot and Michael Praxmarer have also demonstrated this playing technique, but for thinner Palaeolithic bird-bone instruments; Ringot 2011: 188–98; Ringot 2012: 389–91; Both 2018: 15; Praxmarer 2019: 86–87.

[44] Thanks to Jean-Loup Ringot for his advice and demonstration how to attach birch bark to a bone mouthpiece.

[45] Wyatt 2012:394.

yet, but has been suggested and explained by Jean-Loup Ringot, as well as by Michael Praxmarer for other Palaeolithic wind instruments.[46] Ringot reconstructed a bird-bone wind instrument from Hohlefels as a clarinet with a membrane over one of the holes. This changed the sound, limiting the pitches but, at the same time, made the instrument easier to play.[47]

4.2 Different options of end-blown Grubgraben flutes

Playing a deer tibia as an end-blown flute is possible from both ends of the diaphysis with or without modification as indicated in Figure 5, which could also be shown during reconstruction experiments carried out between 2015 and 2021. A modification could be a sharpened edge or a notch. Most of the depicted ways of playing the bone can be also played in a stopped manner.

4.2.1 End-blown flutes from the proximal end

In addition to the research conducted in the late nineties, which was based on playing the bone from the distal end only, new experiments have shown, that a deer tibia bone can be played from the proximal end without any modification by blowing straight onto the bone (Figure 4 H). By doing so, it is very easy to play scales and tunes as well as glissandi. However, it is difficult or impossible to play harmonics.

In order to create a more concrete sound with less hissing, a little V-shaped notch can be carved into the bone. Reconstructions have been successfully made with either a notch on the Crista tibiae or a notch which was placed further to the side.[48] In order to simplify the direction of the air-stream onto the notch, beeswax can be applied to partially close the proximal end. This, however, will result in an alteration of the pitch.

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[46] Ringot 2011: 192–96; Praxmarer 2019: 88.

[47] Ringot 2011: 195.

[48] Carving the notch laterally offset the axis of the fingerholes offers the possibility to get more length of the bone because for an in-line front notch the bone needs to be cut shorter, to be able to carve the notch beneath the thickest section of the *Crista tibiae*.

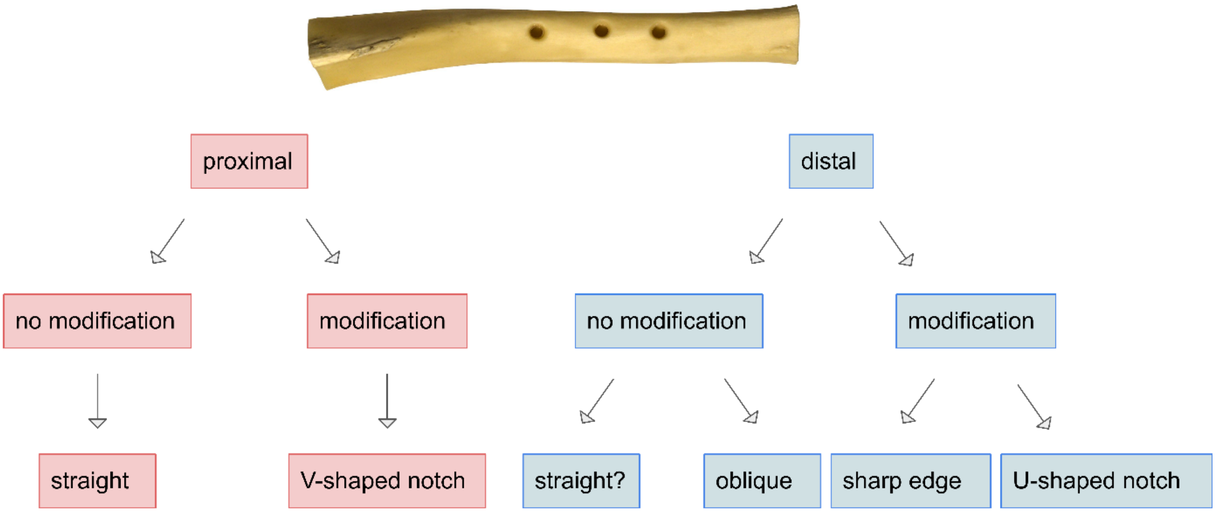

Figure 5: Different ways of constructing an end-blown flute from a ruminant tibia, 2021. Illustration by Maria Hackl

4.2.2 *End-blown flutes from the distal end*

Some bones can be played straight onto the distal end without modification, too. A question mark was added for this option in Figure 5, since this does not work with the majority of flutes constructed by the author.[49]

Playing a deer tibia from the distal end in oblique technique also works well (Figure 4 E), as has been described in the previous section. The sound is slightly weaker, as compared to other playing techniques, and it strongly resembles the sound of the small Palaeolithic bird-bone flutes.

For the author, the most comfortable way of playing a tibia from the distal end is with a U-shaped notch, but a sharpened edge works, too. This is consistent with the description of the research from the nineties. This playing technique produces a high, shrill sound concerning the higher pitches and a rather weak sound when playing lower pitches.[50] When the bone is closed with the palm of one hand on the proximal end, the higher pitches playable like this sound clearer and louder but lower pitches are hard to play.

4.3 *Sonic results from end-blown Grubgraben flutes drawn from new experimental studies*

If the sonic results of deer tibiae played straight distally and proximally are compared, some notable differences appear. These become the most obvious, when the playable pitches obtained from playing each end of the same bone are compared with one another.

This is illustrated in Figure 6 with a flute which is played both proximally, without any mouthpiece, and distally while blown straight onto a small V-shaped notch. As is observable in Figure 6

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[49] Most probably this is due to how the bone-ends breaks after cutting a ring notch around the bone when removing it with by snapping it off.

[50] Due to the physics of the bone, when switching between the second and the third playable note, it is necessary to adapt the lip tension and the blowing angle a little bit, to get a smooth change from one pitch to the other.

in the first line, indicated by the different bone profiles, the fundamental pitches from the proximal and distal ends (all finger holes closed) vary slightly (A♯$_5$ and B$_5$). This effect is most probably due to the different angle of the air stream hitting the edge of the bone and the morphology of the medullary cavity. Additionally, the fundamental pitches can be modified in both cases more or less by oral glissando[51].

When played from the distal end in an oblique manner, with the specific bone used for this analysis, the deepest playable note is G♯$_6$.

To illustrate the tonal possibilities and limits of the bone flutes, the pitches, when played from the proximal end, are described as approximate notes connected with a glissando line, or simply as tonal ranges, which can be seen in the second line of Figure 6 (as the flute analysed in Figure 6 can be found again in Figure 7 as "flute 12"). When playing the flutes from the proximal end, the pitches can be modified to a large extent. With some practice of the player, a glissando over nearly the whole range from the lowest playable tone to the highest playable tone (without harmonics) can be achieved for most of the flutes. The pitch range can be expanded downwards by partially shutting the tube with a finger and upwards with one or two harmonics; one harmonic in the case of the depicted flute.

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[51] Oral glissando is a term introduced and used by Anna Friederike Potengowski when musically researching the bone- and ivory instruments from Schwäbische Alb/Germany. It describes the phenomenon, that the pitch of a certain fingering can be altered by changing both blowing angle and lip tension and it occurs not only with the Aurignacien wind instruments from the Schwäbische Alb region, but also with reconstructions of the Grubgraben bone when played as an end-blown flute as was found by the author of this section; Münzel et al. 2015: 35–37; Münzel et al. 2016: 231–32.

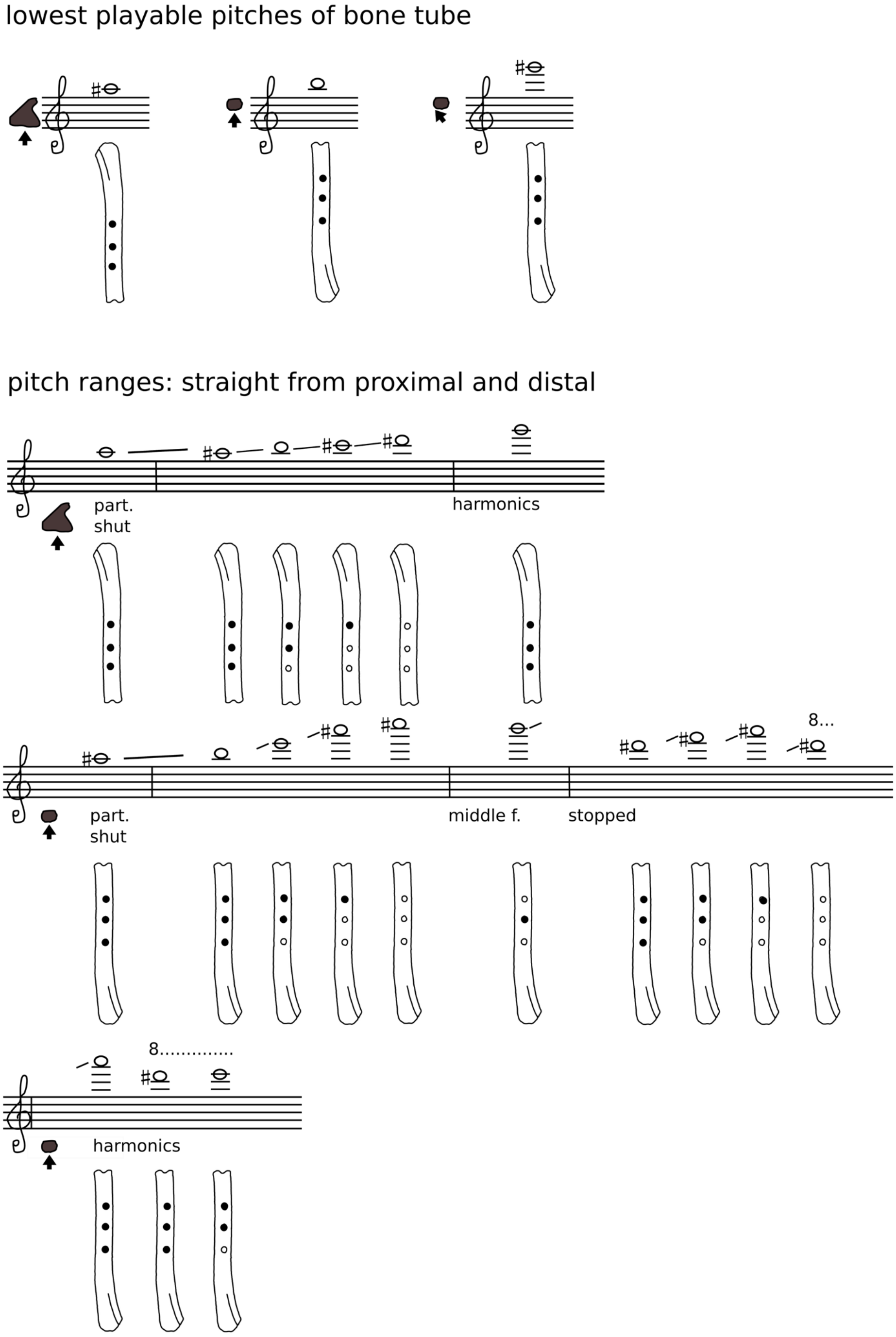

Figure 6: Overview of pitch ranges of a reconstruction of the Grubgraben instrument as an end-blown flute played from both distal and proximal, 2021. Illustration by Maria Hackl

In contrast, as depicted in Figure 6 and Figure 7, the pitches when played from the distal end appear different to those from the proximal one. The pitch range can also be expanded by partially shutting the tube. Lip glissando is also possible, but not to such an extent as when blowing the bone from the proximal end. Lines three and four in Figure 6 show the playable pitches when played from the distal end. When playing glissando, the tone breaks at a certain blowing angle.

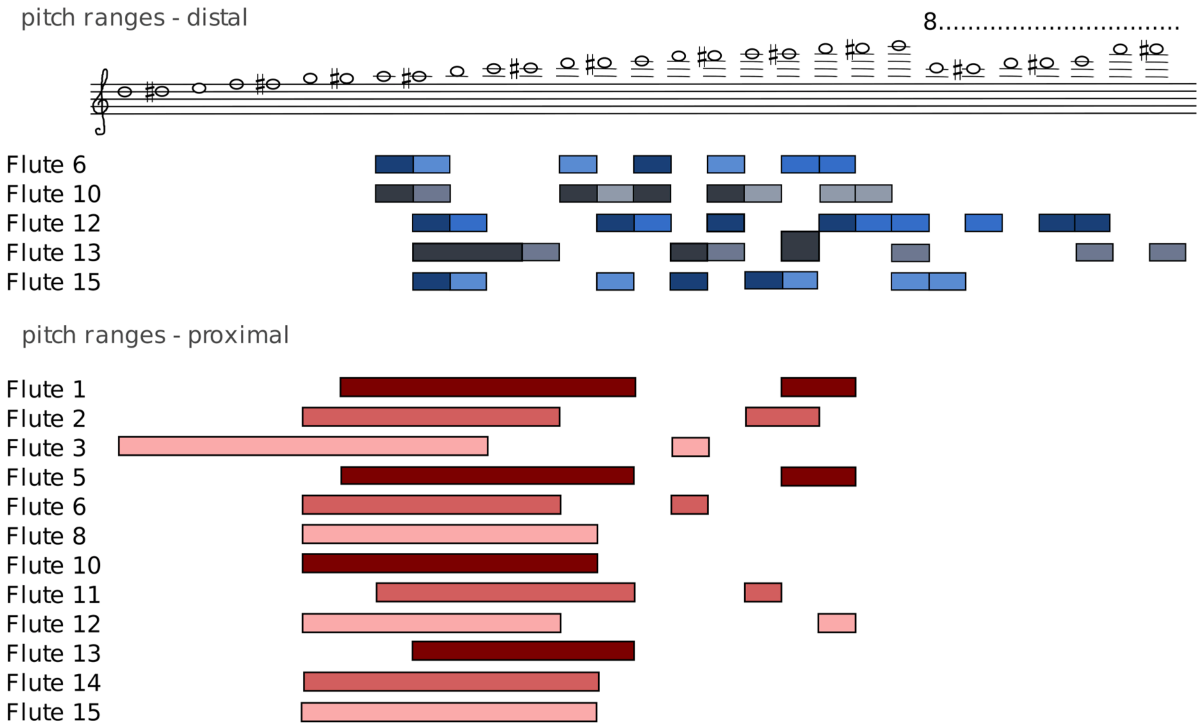

Figure 7: Pitch ranges of different reconstructions of the Grubgraben instrument as end-blown flutes played from the distal end and/or from the proximal end, 2021. Illustration by Maria Hackl)

When this exemplary flute (Figure 6) is put into a wider range of flutes and data, it can be seen that these data patterns occur for the other Grubgraben flutes constructed by the author of this chapter, too. In Figure 7, the pitch ranges of 12 different flutes with different lengths are depicted, both when played straight from the distal end as well as from the proximal one.

Blown from the proximal end, all the instruments' pitch ranges gather around A♯$_5$ and B$_5$. On the basis of this data, it can be stated that the Grubgraben instrument, if it had been played as an end-blown flute from the proximal end of the bone tube, would have also shown a pitch range including these notes. Scales and melodious tunes are easily playable.

The pitches from blowing straight into the distal bone end do not form a continuous line but rather a cluster.[52] In general, it is possible to also play scales, but this action is far more complicated than playing the bones from the proximal end, because the player has to combine different playing techniques when doing so. From looking at Figure 7, it can be observed that the five flutes which can be played from the distal end show some similarities, but there are also some notable differences. These are rooted in factors like the respective bone morphology, technological reasons, and the specific kind of modification or embouchure used for every flute.

To summarize the pitch analyses of both directions of blowing into the bones, it becomes obvious, that from the distal end, higher notes can be reached, whereas from the proximal end, the

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[52] What is illustrated in Figure 8 with lighter bluish colours, are the deepest playable pitches produced by simply opening the finger holes and all darker bluish colours symbolize the use of additional playing techniques as explained before.

pitch ranges start with slightly deeper notes and, as discussed before, do not show "gaps" between the playable notes.

5 Conclusion and Outlook

The series of new experiments add to those conducted in the late nineties and show once more that the Grubgraben artefact represents not only a unique archaeological item, but gives a lively statement on the musical possibilities of Epigravettian reindeer hunter communities. Whereas the artefact had been reconstructed in 1997 as a set of end-blown flutes played from the distal end of the bone with different blowing mechanisms, it was demonstrated within the recent experiments that it could be reconstructed as other types of instruments. Sonic results were discussed for a transverse flute, an end-blown trumpet and a reed instrument. Further types of instruments as possible versions of the Grubgraben instrument were theoretically described in this paper, namely a duct flute and a kazoo/mirlitone, which should also be taken into account.

In addition, the reconstructions as end-blown flutes showed first of all that both directions of playing the bone are equally plausible, despite blowing into the proximal end of the bone having been ruled out in former research, as set forth in the previous section. One argument for playing a ruminant's tibia bone from the proximal end is that this can easily be achieved without any modification, as shown in the new experiments. The pitch ranges from the Grubgraben reconstructions – which are all within the possible original length for the artefact which has a considered length of 165 to 220 mm – are around the notes A♯$_5$ and B$_5$. Glissando is very easy when playing this way, whereas playing glissandi from the distal end is only possible with a smaller range, and not with every note.

In the near future Maria Hackl and Veronika Kaudela plan to review the bone fragments from the exact quadrants and layer from which Brandtner took the block in which the object was found. The goal is to find some fragments which fit with the fragmented bone, in order to clarify how the mouthpiece would have looked and how the instrument was played. But there are some aspects which have to be taken into consideration, for example, if the place where the artefact was discovered is the same place where it was fragmented. As already mentioned, we know from ongoing research that Brandtner's excavations were not up to today's standard, the sediment was not sieved, and big bone fragments and silices are still found in the excavation residues. Therefore, it is to be hoped that all or most of the bone splinters were recovered. Rediscovering the lost pieces might also shed light upon the cause of the fragmentation of the perforated long bone. It could be that the object fragmented due to an accident because of material weakness of the bone, but it is also possible that it was intentionally destroyed, which would open up further research and interpretation approaches.

Furthermore, when looking into the finds, an examination of the reindeer antler with which the instrument was found covered should be undertaken. Maybe it bears marks of use which could possibly be linked to music activities itself, as is the case within an artefact assemblage from Mezin, Ukraine. Among mammoth bones, interpreted as a percussion set, a beater made from a reindeer antler was discovered.[53] Another approach for interpreting the antler's function could be that of a covering. There are finds of burials covered with mammoth scapulas on the Gravettian (Pavlovian) sites of Krems-Wachtberg and Dolní Věstonice/Pavlov. One could compare the intentional deposition of the fragmented instrument under the cover of the reindeer shovel with the covered burials of these Pavlovian sites,[54] but the authors think that this comparison may be too far-fetched. Unfortunately, the exact circumstances of the discovery remain unclear and, as long as no investigations are carried out into the micromarks of the reindeer shovel, the interpretations of the setting of the instrument and the shovel remain speculation.

Concerning the tonal research on the instrument, it is hoped that it will be possible to put into contact all the researchers who have been or are currently working on the topic of the Grubgraben instrument and regularly playing replicas of it. The aim is to construct an acoustic database of all possible playing techniques which can be applied to the instrument, as well as to collect the tonal possibilities. It will be interesting to see if the tonal output varies with different craftsmen on the one hand, and different musicians on the other.

Additionally, as nearly all replicas were made from some kind of deer bone, reconstruction experiments should be planned with reindeer tibiae or other close species.

Still, this fascinating Epigravettian object leaves many questions unanswered, but will hopefully provide more answers and insight in the musical culture of our ancestors in the near future.

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[53] Lbova et al. 2013: 27–30; Bibikov 2008: 77; Kossykh 2018: 34–39.

[54] For Example Svoboda 2006: 15, 16, 17; Einwögerer et al. 2006: 285; Einwögerer 2017: 86.

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Only Pottery Drums in the Stone Age? Advantages and Disadvantages of Wooden versus Pottery Drums Relating to Production and Sound

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Abstract

Hundreds of possible prehistoric pottery drums made in Central Europe, mainly from the Late Neolithic (especially the TRB culture) have been found. Their forms vary from funnel-shaped, goblet to hourglass. It is not difficult to imagine equivalent or alternative forms of drums made from hard plant tissues, which are missing in the archaeological record during these or even other periods. Aside from a thought experiment based on archaeological knowledge, experimental and experiential research is presented here with three main examples of wooden drums – a simple frame drum from a branch imaginable since the Palaeolithic, a cylindrical double-headed drum made from a log with a rotten inside, and a wooden alternative to a TRB goblet drum that is compared to a ceramic replica of the same type of TRB drum in terms of material characteristics, technology, tools, skill, productions costs, time requirements and durability. The experience and results prove that simple frame drums are the fastest and the easiest option, followed by cylindrical drums made from logs, however production costs of wooden vessel drums greatly exceed those of pottery ones. Thin walls make ceramic drums much worse in terms of manipulation, playing and durability, but fairly better in clear and loud sound production. The presented examples are closely related to Central European prehistory, but they may serve as valuable analogies to other geographical or cultural contexts as well.

Keywords

Drums – Woodworking – Experimental archaeology – Stone Age

1 Introduction

There are several hundred possible prehistoric vessel drums made exclusively from pottery. The potential oldest known pottery drum dated back to the Lengyel culture was revealed at Großweikersdorf in Lower Austria.[1] Nevertheless, the vast majority of them come mainly from the Late Neolithic or Eneolithic, as it is called in Central European countries. The Funnel Beaker culture (Trichterbecherkultur, TRB) drums might have originated from other pottery vessels, e.g. pedestal bowls.[2] The rich archaeological record is dated to the chronological phases TRB IV and TRB V (i.e. 3350–2700 BCE), which are related to several archaeological cultures in Germany, Austria, the Czech Republic and Poland (e.g. Salzmünde, Walternienburg, Bernburg, Globular Amphorae, Jevišovice, Baden, Řivnáč).[3] Rare archaeological finds are also known from the Bronze Age[4] and the Iron Age.[5]

Extant prehistoric pottery drums vary in form (funnel- or goblet-shaped, hourglass), dimensions (the height ranges from 4.5 to 46 cm[6]), decoration (mostly without any at all, however Salzmünde, Walternienburg or Bernburg drums are richly decorated), or methods for fastening a drumskin (usually knobs, lugs or pierced lugs under the rim). They have been found in graves, but also within the stratigraphy and pits of settlements. Important discussions on their identification, classification, function or meaning have been held since the end of the 19th century.[7] Although they are replicated and presented quite often in open-air museums, (experimental) studies on pottery drum making are published rather rarely.[8]

To answer the question raised in the title of this paper, we would definitely require direct archaeological finds. Until then, we are left with two main possibilities. On one hand, we may use a simple thought experiment to consider available materials, technological knowledge and toolkits based on the archaeological, historical and ethnographic record. On the other hand, we may provide empirical data by conducting an archaeological experiment. Both possibilities are explored here, including three main empirical experiments that follow standard procedures,[9] and aim at comparing the production, durability and sonic characteristics of the drums made from pottery and wood. Although the results cannot provide us with any accurate vision of the past, they definitely allow us to enhance our considerations about prehistoric drums. Further, I hope they might also arouse a stronger interest in exploring the new and already known archaeological contexts

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[1] Pomberger 2016a: 50, 350.

[2] Aiano 2006; Lindahl 1986; Sachs 1940; Stockmann 1986.

[3] Behrens 1980; Behrens and Schröter 1980; Chroustovský 2010; Gedigowa-Bukowska 1963; Mašek 1954; Mildenberger 1953; Müller 2001; Pomberger 2018; Wyatt 2008; Wyatt 2020.

[4] Lindahl 1986; Pomberger 2011; Pomberger 2016a: 72, 84; Pomberger 2016b.

[5] Clodoré-Tissot and Moser 2005.

[6] Wyatt 2020.

[7] E.g. Fischer 1951; Mašek 1954; Mildenberger 1953; Müller 2001; Seewald 1934; Wyatt 2008.

[8] E.g. Aiano 2006; Alebo 1986; Clodoré-Tissot 2010; Lindahl 1986; Pomberger 2011; Seeberger 2003.

[9] For experimental standards see e.g. Coles 1973; Reynolds 1999. To the author's knowledge, the experimental production of a Stone Age wooden vessel drum is presented here for the first time.

and searching for potential wooden drums and their fragments. I strongly believe that consideration of the organic materials and their role (practical, social, or symbolic) in prehistory may enrich our debates and lead to a more complex view of past music and sound production.

Hard plant tissues have been used to make drums extensively in various parts of the world, and thus it is not difficult to imagine equivalent or alternative drum forms in (Central) Europe. In the (Late) Neolithic, stone or bone tools (e.g. axes, adzes, chisels, drills) were usually used for woodworking, and elaborate manufacturing abilities are recognizable in rare archaeological contexts like pile dwellings, well constructions or wooden tools.[10] Very rare wooden vessels copy their ceramic counterparts, or *vice versa*, and wood may have been a popular material for making them not only during the Neolithic.[11] Considering raw materials, tools and technological knowledge in the (Late) Neolithic, we might simply conclude that it should have been possible to make and use a wooden equivalent or other forms of drums.

2 Experimental drum (re)constructions

2.1 Wooden frame drum

A frame drum without a resonator represents the simplest kind of membranophone present in various cultural traditions.[12] Simple frame drums could have been made since the Upper Palaeolithic from a single bent branch covered by a skin or rawhide. There is no direct archaeological record, yet the principle of drumming is recognizable in a percussion set of decorated mammoth bones and two beaters from the Gravettian site at Mezin in Ukraine, or other possible drumsticks.[13] Neolithic contexts provide a debatable iconographic record of drums, e.g. hunting shrine at Çatal Hüyük;[14] more elaborate drum examples are also depicted later in the Near East.[15]

The hypothetical model presented here (Figure 1a) was made many years ago from a fresh alder branch – 163.5 cm long and 8–17 mm thick – that was soaked in water to make it more flexible. The meat and fat was cleaned from a young goat skin (thickness up to 1 mm); it was then left to rot for a while and quite coarsely stripped of its hair. The *châine opératoire* is described in Table 1. The drumhead was fastened by a band cut from the same skin as the drumhead according to North American traditions – a skin band of unassessed length goes through 16 perforations at the edge of the skin; in order to fasten the skin better, the band was twisted. The finished drum is 76.7 cm long and 21.2 cm wide and weighs 226 g. The necessary toolkit involves only a stone blade and a bone awl.

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[10] E.g. Elburg et al. 2015; Tegel et al. 2012.

[11] Capelle 1976.

[12] Sachs 1940.

[13] E.g. Jiménez Pasalodos and Rainio 2020; Oliva 1996; Stockmann 1986.

[14] Stockmann 1986.

[15] E.g. Doubleday 1999; Dumbrill 1999.

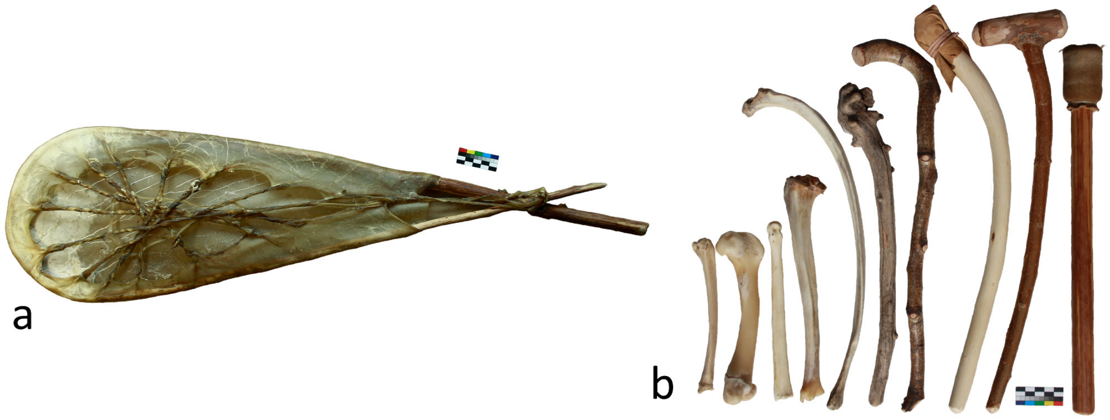

Figure 1: A frame drum from alder wood and a goat skin (a) and various drumsticks (b; from the left: four roe deer bones, a cow rib and five wooden sticks, two of them with leather heads). Photos by the author.

Element	Activity	Tools	Time
frame	cutting a fresh stick to the desired length	stone blade	4 min
frame	removing fresh bark	stone blade	10 min
frame	soaking the stick to make it flexible	(flowing) water	2 days
membrane	removing flesh and fat from skin	stone blades	70 min
membrane	letting skin rot in water	storage vessel	16 days
membrane	removing hair from skin	wooden chippings	90 min
membrane	soaking the goat skin to make it pliable	storage vessel, water, stones	2 days
membrane	cutting a circular drumskin and skin strips (to fasten the drumskin)	stone blade	32 min
drum	bending the stick and fastening the drumskin (fixing both with skin bands)	bone awl	24 min
drum	drying the membrane	–	2 days

Table 1: Main steps in making a frame drum from an alder stick and a goat skin (one person; 2009).

A frame drum is usually held in one hand and played with the fingers, palm or a drumstick (Figure 1b). As it lacks a resonating chamber, the sound of our model is fairly flat, but using a drumstick considerably increases its volume.

2.2 *Wooden cylindrical drum*

Another natural way to make a drum is to use an old log, the inner parts of which are preferably entirely rotten, making it easy to clean and providing a cylindrical shell. Cylindrical drums – single

Figure 2: Wooden cylindrical double-headed drum from spruce and cow rawhide. Photo by the author.

or double-headed – have also been a part of many cultural traditions in Eurasia, Africa and both Americas.[16] Several years ago, I used a rotten spruce log for this purpose. First, I simply removed its bark and cleaned the interior with a stone adze, a wedge and a mallet. After the edges were ground down with sandstone, the shell was 50–51 cm in length. Both rims were ground from slightly oval to roughly circular diameters of almost the same size (17–18 cm and 18–19 cm). The walls near the rims were narrowed to 7–9 mm, as were the rims to 3–5 mm (Figure 2a). Before both rims were covered with cow rawhide (up to 2 mm thick, donated by colleagues), they were impregnated with linseed oil.[17] The cordage included a long strand (length 11.20 m, width 1–4 mm) used to fasten both heads (diameters 27 and 29–31 cm), and three other strands (width 2–3 mm, together 215 cm) used to tighten the cordage in the middle of the drum body and near both drumheads (Figure 2b). They all were made from the same piece of hide as the drumheads. The hide was perforated by a solid roe deer antler awl; perforations were started off by a flint blade. To tighten all the knots both ends of straps were held in a linen cloth. The finished drum weighs 2,474 g.

This kind of drum may be played with one hand while held under the other arm, or both hands when it is attached to some kind of support or suspended from a belt (one made by tablet weaving from white and brown sheep wool can be seen in Figure 2c; width 18 mm). Finger techniques may be applied when the rim is quite narrow. However, loud and clean sounds are best achieved when both heads are played with drumsticks – the heads vary slightly in frequency.

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[16] Sachs 1940.

[17] This was done to prevent water from the wet hide from soaking into the wood too quickly, as the hides would dry much faster near the rims and the rest of the hide would warp (Figure 7a), preventing it from producing a good sound.

Element	Activity	Tools	Time (min)	Persons
body	removing bark	stone wedge, mallet	5	1
body	removing rotten inside	stone wedge, mallet, stick	10	1
body	grinding the exterior surface	sand stones	140	1
body	grinding the interior surface	sand stones	45	1
body	applying linseed oil on the rims	linen cloth, hand	3	1
membrane	soaking the cow rawhide	vessel, water, stones	2 days	1
membrane	cutting both circles and all the stripes	flint blade	32	2
drum	fastening hides	flint blade, antler awl, linen cloth	48	2
drum	drying hides	—	3 days	x

Table 2: Main steps in making a cylindrical double-headed drum from a spruce log and a cow rawhide (2020–22).

2.3 *Wooden goblet drum*

Goblet and hourglass drums have been made from various materials, including wood and they have a rich tradition in many cultures, especially in Africa or Eurasia.[18] The oldest examples were found in Neolithic China,[19] and depictions, which are much closer to our European contexts, come from the ancient Near East.[20] Although there is no archaeological evidence of wooden goblet drums in European prehistory, their counterparts in pottery have quite obviously raised questions in archaeologists' minds. The presented reconstruction is based on a well-preserved TRB ceramic drum body found in the Salzmünde settlement pit together with other pottery vessels and two stone arrow-heads in Prague 5 – Řeporyje.[21] It has a typical funnel beaker shape with a rim wider (27 cm) than its height (22 cm) and its base (13.3 cm). The body is 5 mm thick and just above the narrowest part are five simple lugs.

Three different methods of drum body production were deliberately combined during this reconstruction – shaping with bone and stone tools, grinding with sandstone and burning (Table 3). After removing the bark from a pine log (28 cm wide), which had been drying for two years, the log was shortened to almost the desired length by burning at both ends (Figure 3a). The parts of the log intended for use were soaked and protected by clay mixed with water. Both ends were

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[18] Sachs 1940.
[19] Lawergren 2006.
[20] Dumbrill 2005.
[21] Kuchařík 2008.

Figure 3: A wooden reconstruction of a TRB goblet drum from Prague 5 – Řeporyje.
a: shortening a pine log by burning; b: burning the upper interior part; c: the polished interior of the upper part (notice the cracks caused by burning). Photos by the author.

levelled by grinding with various pieces of sandstone. Then the upper and lower parts of the interior were burned out and removed with stone wedge and bone wedge. It was very important to maintain just a small fire, intensify and direct it with a blowing tube and to protect the finished parts by applying wet clay to them (Figure 3b). Furthermore, the whole interior surface was ground and polished using various pieces of sandstone (Figure 3c).

The exterior surface was shaped (chopped and chiselled) based on the archaeological model with stone axe and adze, bone and stone wedges and a wooden mallet (Figure 4a-b). Pine wood of this diameter has quite strong fibres and proved to be rather unsuitable for fine woodworking, and therefore the lugs were made much coarser and larger than their originals; the same reasons led to much thicker walls – up to 2 cm. The surface was ground and polished using sandstones of various grain sizes (Figure 4c).

A skin membrane and strands for attaching it were cut from one piece of a goat skin (max. 1 mm thick), which was processed in the same way as in the first example – by removing flash, fat

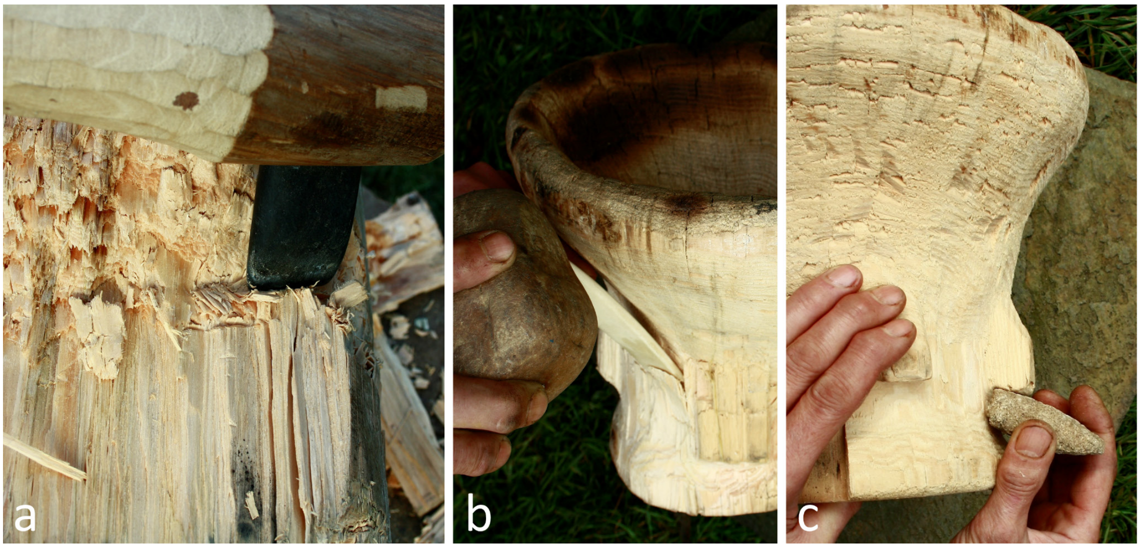

Figure 4: A wooden reconstruction of a TRB goblet drum from Prague 5 – Řeporyje. a/b: shaping of the exterior with a stone axe and bone wedge; c: grinding and polishing a lug with sandstone. Photos by the author.

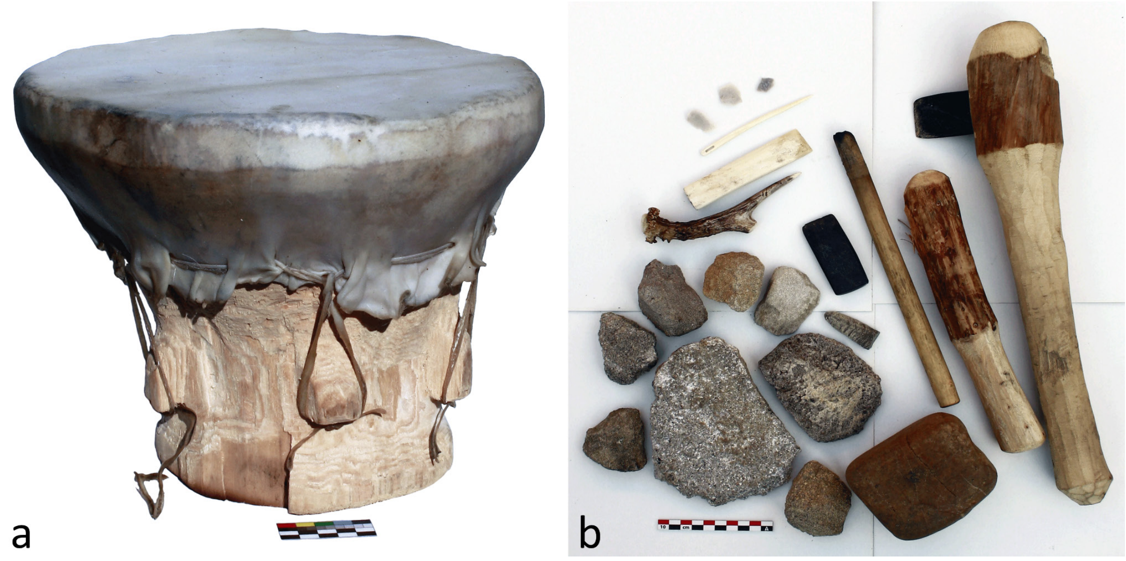

Figure 5: A wooden reconstruction of a TRB goblet drum from Prague 5 – Řeporyje. a: the finished drum with a goat skin; b: replicas of tools from the periods in question used in this reconstruction. Photos by the author.

and hair. The skin was perforated using a bone awl, and a long skin strap (dry length 95.5 cm, wet length 97 cm) was threaded through 23 perforations with a bone needle. With the help of a linen cloth, this strap was fastened with five other straps to the lugs. Two persons were required to stretch and fasten the skin to the drum body. The finished drum (Figure 5a) weighs 1,733 g. Six months later the drum lost its voice, as its body shrunk, therefore the skin had to be slightly soaked, removed (12 min.), attached and fastened again (11 min.). This drum produces quite a low sound.

2.4 Comparison of a pottery and a wooden goblet drum reconstruction

2.4.1 Replication of a pottery vessel drum

The comparison between manufacturing a drum from wood or from clay is relevant when the same type of TRB funnel-shaped drum is considered. Therefore, from a set of replicated Late Neolithic pottery drums, I present the reconstruction of a TRB drum excavated from a settlement layer C2 at the eponymous hilltop site at Jevišovice – Starý Zámek in Moravia.[22] The complete drum is 22.7 cm high, with a 24.8 cm wide rim and 10 cm wide base. It has six eyelets near the waist. The first step in replicating prehistoric pottery is to prepare the potter's clay – in this case two clays were mixed together with a temper (crushed granite, sand) to obtain a material similar to the prehistoric one. Replicating archaeological finds requires adding approx. 12 % to all the dimensions, as the clay shrinks during firing.[23]

This replica was manufactured upside down – starting with the upper part on a board (Figure 6a) – from coils, which is a common technique recognisable in Late Neolithic pottery in Central

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[22] Mašek 1954: 652–3, Figure 299.1; Medunová-Benešová 1981: 28, Table 3.6.

[23] Aiano 2006.

Element	Activity	Tools	Time (min.)	Persons
body	removing bark from a log	stone wedge, wooden mallet	5	1
upper part	chopping a groove for burning	stone axe	15	1
upper part	creating the upper side by burning	firewood, charcoals, blowing tube	530	1
upper part	levelling the upper side (rim) by grinding	sandstone	40	1
lower part	chopping a groove for burning	stone axe	12	1
lower part	creating a base by burning	firewood, charcoals, blowing tube	450	1
lower part	levelling the base by grinding	sandstone	136	1
upper part	burning the interior	sticks, charcoals, blowing tube	310	1
upper part	grinding the interior surface	sandstone	210	1
lower part	burning of the interior	firewood, charcoals, blowing tube	355	1
lower part	grinding and polishing the interior surface	sandstone	80	1
body	chopping the exterior surface	stone axe	99	1–2
body	chiselling the exterior surface	stone adze and wedge, wooden mallet	192	2
body	grinding and polishing the exterior surface	sandstone	320	1
membrane	soaking a goat skin	vessel, water, stones	1 day	1
membrane	cutting a circular skin and skin strips	flint blade	17	2
membrane	fastening the drumskin and fixing it with skin bands	bone awl, bone needle, linen cloth	17	2
membrane	drying the drumskin	—	2 days	1

Table 3: Main steps in experimental making of a TRB goblet drum (Prague 5 – Řeporyje) from a pinewood log and a goat skin (2021).

Europe. It is also possible to make two parts and join them together. The body was shaped and smoothed simply by hands, or with a bone or wooden chisel or pebble. Once the body dried to leather-hardness, six eyelets were attached to it. The drum was fired months later in an open fire (Figure 6b).[24] Unexpectedly, during the firing a light cold rain rapidly lowered the temperature of the vessels' surfaces, and some of them cracked, including this drum.

Despite this fact, the goat skin (up to 1 mm thick) was stretched and fastened, but one eyelet broke off and the skin was attached using a strand of skin threaded through 22 perforations under the rim (Figure 6c, 7c). This method of attachment can be applied to any vessel with a conical upper

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[24] Together with other vessels during experimental firing in the reconstruction of a Late Neolithic hearth situated on a platform formed from clay, stones and old pottery sherds (Boubelová and Chroustovský et al. 2018).

Figure 6: Replicating a TRB goblet drum from Jevišovice in Moravia.
a: fresh clay bodies of drums from Jevišovice and Malemort (France); b: firing of both drums in an open fire; c: the finished drum with goat skin. Photos by the author.

Element	Activity	Tools	Time (min.)	Persons
body	preparation of potter's clay	coarse linen cloth	–	1
body	forming a body from pottery coils (rollers)	stone pebble, bone chisel	420	1
body	forming knobs on the lower part	bone chisel	60	1
body	drying of the clay body	plank	14 days	
body	firing the clay body	open hearth, firewood	360	1
membrane	soaking a deer hide	vessel, water, stones	180	1
membrane	cutting a circular skin and strips	flint blade	15	2
membrane	fastening a drumskin and fixing it with skin bands	bone needle, textile	19	2
membrane	drying of the drumskin	–	2 days	–

Table 4: Main steps in replicating the pottery TRB goblet drum from Jevišovice (2017).

section because after the skin dries and shrinks it cannot come loose. The finished drum weighs 3,300 g. The drum can be played by one or both hands and when dried well the skin produces a nice dry and bright sound.

2.4.2 *Comparing replication in clay and in wood*

Considering material requirements, simple frame drums are the easiest option,[25] followed by cylindrical drums made from logs that have rotted inside.[26] Standard logs for manufacturing vessel

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[25] When a frame is made only from a bent branch in which case the membrane has to be highly strained to produce a satisfactory sound.

[26] Such logs produce resonating idiophonic sounds without any modification when beaten or when some other sound tool or instrument is placed on them (e.g. Lund 1991: 37 Figure 17). They are irreplaceable sources for segments usable as frames for frame drums.

drums should be stored for several years – depending on species, diameter and environmental conditions – to provide a good raw material that will not crack. Potter's clay must also be made in advance and stored in the proper conditions. However, once prepared it can be quite easily modified to fulfil intended tasks, e.g. to add more temper for larger vessels with thin walls like the Late Neolithic drums.

Cleaned raw skins and hides were probably the common raw materials available in prehistoric villages – for drum making, the thinner and stronger the better for vibrations and resonance. Aside from traditional domestic animals (goats, sheep, cattle) and wild species (red, roe and fallow deer), it is possible to use fox, dog, badger, wild boar or even otter or fish skins for smaller drums.[27] The preparation of skins/hides is very simple in the presented examples, but various techniques may be used.[28] It is possible that different skins/hides would need different attachment techniques. The skins/hides used for drumheads serve effectively as sources for cordage, because as they dry they compress in the same way as membranes and can be fixed much better than any other material (leather, or any other plant fibres, including a bast) would do; however sinew would also work well.[29]

Considering the necessary toolkits, skills and time requirements, frame drums are again the fastest to produce. The knowledge and skills for woodworking are documented by the archaeological record (see above). Nevertheless, knowledge of drumming via vibrating membrane must be present. Pottery drums are easily made by skilful potters using only simple tools.[30] Since the Neolithic, people have been able to manufacture various vessels from prepared potter's clay and fire them successfully (in an open fire, a pit, or simple pottery kilns).

When considering the handling of goblet drums and playing techniques, wooden ones are without a doubt more durable during transport, handling and performance, as they can surely survive vigorous use or being dropped on the ground, unlike thin-walled pottery drums. Both materials have to be kept in dry places, however wood absorbs moisture – providing the appropriate conditions for mould – whilst ceramic drums may be fired again to get rid of mould.

Drum making involves many risks, such as hairline or large cracks in the body (Figure 7b), which can prevent a drum from producing a solid sound. For the most part, cracking is caused by rapid changes in temperature while firing a pottery drum or burning the interior of a wooden one.[31] Another major risk lies in the breaking of an important functional feature like lugs, eyelets

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[27] Aiano 2006.

[28] Cf. Aiano 2006; Alebo 1986.

[29] Aiano 2006.

[30] During archaeological workshops for the public held at the open-air museum in the Pilsen ZOO (e.g. Boubelová and Chroustovský 2018), people of any age were able to make usable pottery vessels under the tutelage of a professional potter. However, to manufacture a middle to larger drum body with 5 mm thin walls requires an experienced potter.

[31] Late Neolithic drums in Central Europe were probably fired mainly in open hearths or pits, as there is no evidence of pottery kilns. The most unreliable firing method is in an open fire as it is the most vulnerable to weather changes, including strong winds or precipitations. Of the nine pottery drums made by the author or his colleagues, five cracked during firing. The wooden version of the Prague 5 – Řeporyje drum suffered

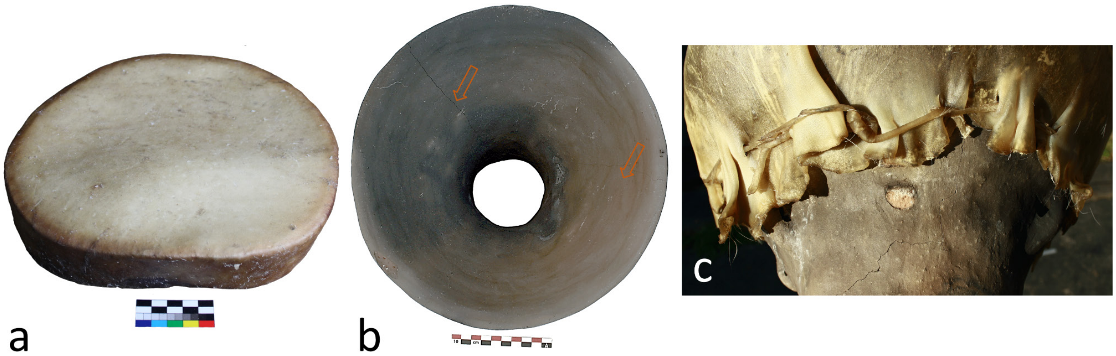

Figure 7: Reconstructions of prehistoric drums involve risks such as warping of drumskin (a), cracks in the shell (b) or breakage of lugs (c). Photos by the author.

or handles (Figure 7c). Based on my experience, this can be prevented by making such elements more robust in wood or by achieving proper firing in clay.[32]

Sound production is influenced by many factors, such as the volume of resonating space – the greater the volume the lower the frequencies –, overall shape – wide shallow bowls on long feet provide higher frequencies than deeper bowls on shorter feet, even if their resonating volumes are equal –, wall thickness – the thinner the walls, the brighter the sounds –, rim diameter – the larger it is, the more playing techniques can be applied and the more pitches produced –,[33] and the material of a body – vibrations caused by oscillation of a membrane transmit to the body. Especially in double headed drums, the ceramic surface is much harder and reflects sounds better than wood, and a ceramic body provides drier, higher and brighter sounds. In addition to the body, the membrane also plays a major role in sound production. In general, the thicker the skin, the shallower and duller the sound. Even though any flexible skin may function as a drumhead, subtle differences are recognisable between various species. The tightness of a membrane also largely impacts the frequency range. If a head is not tightened evenly all around the rim, it produces slightly different tones at different places – the best example is a traditional larger hand-made frame drum. Tuning in drum terminology means achieving equal tension all around a rim, or increasing/decreasing the head tension – traditionally by heating a membrane in the sun or by fire – to get higher/lower frequencies.

Volume is influenced greatly by the resonator (volume, shape, material) as evidenced by the measurements of sound pressure levels of the presented drums (Table 5). The simple frame drum – without a resonator – gives the lowest levels, followed by the cylindrical wooden resonator closed at both sides by the drumheads. Open goblet-shaped resonators of similar size vary slightly

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from wall cracking – small parts even separated along the annual rings – while its interior was burned, even though its walls were protected by wetting or clay cover.

[32] The breakage of an eyelet of the Jevišovice pottery replica was caused by weak firing in an open hearth caused by situational factors – rapid weather changes.

[33] In general, small diameters produce only one tone, while larger diameters make it possible to play up to three different tones (deep bass tone at the centre, middle tone between the centre and rim, and a high tone at/on the rim, cf. 'bass – tone – slap' in djembe playing terms), but actual numeric values depend heavily on rim and membrane thickness.

Drum	One finger		Cupped fingers		Soft beater		Hard beater	
	centre	edge	centre	edge	centre	edge	centre	edge
frame drum	79.2	76.5	78.7	79.4	86.8	85.9	90.2	87.7
cylindrical (17–18 cm head)	89.4	81.8	85.6	88.6	95.6	90.4	95.9	87.9
cylindrical (18–19 cm head)	86	85.9	95.2	90.7	101.3	92.3	95.6	90.1
Prague 5 – Řeporyje (wooden)	90.2	93.7	96.4	99	99.5	97.2	99.1	95.3
Jevišovice (pottery)	95.1	97.3	95	97.3	103.9	98.3	101.3	95.7
Otaslavice (pottery miniature)	95.2	94.1	–	–	91.5	94.6	95.3	90.9

Table 5: Loudness (measured in decibels as maximum sound pressure levels in the measurement period, LAFmax) of the wooden drums (the frame drum – chapter 2.1, the cylindrical drum – chapter 2.2, the Prague 5 – Řeporyje drum – chapter 2.3) and ceramic drums (the Jevišovice drum – chapter 2.4.1, the Otaslavice miniature drum) according to various playing techniques (one finger, cupped fingers, soft beater – wooden stick with a leather head, Figure 1b.8, hard beater – animal bone, Figure 1b.3,5).[35]

according to their material – the hard ceramic one is a bit louder, but this also depends on playing techniques). A smaller resonator usually produces a lower level, as evidenced by the pottery miniature drum.[34] As a matter of fact, the desired character of tone may vary greatly (bright or muddy, loud or quiet, high or low tones) and anyway it is hard to define a drum sound solely on the basis of the characteristics of its body, like in the case of the archaeological finds.

In this paper we have focused on the practical aspects of drum making, handling, durability, playing techniques, and sound characteristics. Social or symbolic aspects of the different materials also deserve our attention. Nevertheless, with a huge imbalance between the evidence for pottery and wooden artefacts in the European archaeological record we have departed greatly from informed and reliable inference and can only propose general thoughts; we cannot even roughly assess the proportion of pottery and wooden artefacts in the past living culture. Pottery combines earth and fire during its transmutation from natural clay to an intentional expression of cultural knowledge and creativity – the drums forming only a tiny part of ceramic production, which has been a common practice and experience since the Neolithic. We cannot assess the importance of the transforming power of fire during burial practices.[36] On the other hand, wooden artefacts preserve their original material character, which might have been associated with various species of

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[34] The miniature drum (9 cm high, 6.4 cm in diameter) was revealed at Otaslavice in Moravia (Behrens 1980: 150–53, Figure 4.2).

[35] The measurements were taken indoors (24 °C) by NTi Audio XL2 handheld audio and acoustic analyser and they were inspired by the works by B. Pomberger (2011; 2016a). The measurement periods for every drum involved 10 beats to eliminate haphazard variations of beats.

[36] Pottery drums usually accompanied inhumated – not cremated – individuals during the Neolithic. In some periods, only selected individuals were buried in burial grounds or monuments, the remains of the others were treated in ways that cannot be verified.

trees, more or less exotic, and thus could support the meaning and significance of the drums. It is also possible that symbolism was not related so much to the material, but more to decoration or other aspects (cf. Wyatt 2010).

In general, both materials being equally available, a potential difference in meaning might have been associated with specific places of their origin, or specific extraction and processing activities, including ritual aspects. Experimental results have proven that the manufacturing process of wooden drums is much more demanding in terms of energy, time, skills as well as tools, but that does not necessarily imply that such instruments would *a priori* have been associated with individuals of special status.

3 Conclusions

This paper serves as a brief contribution to the debate on drums in European prehistory. The presence of wooden drums, especially in the Late Neolithic from which hundreds of pottery drums have been discovered, has been hypothesised explicitly several times (see above). Four main examples of different materials (hard plant tissues, pottery, skins/hides), construction principles, manufacturing, playing techniques and their impacts on sound production are presented here. Considering material requirements, toolkits, skills, and energy/time requirements, simple frame drums are the fastest and the easiest option, followed by cylindrical drums made from logs that have rotted inside. On the other hand, production costs of wooden vessel drums greatly exceed those of pottery as long as we may assume that ceramic drums were manufactured and fired together with other kinds of pottery. Thin walls, which are almost always ready to crack, make ceramic drums much worse in terms of handling, playing and durability, but fairly preferable in terms of the production of clear and loud sound – in a modern ensemble they would recommend themselves for drum solos. Nevertheless, it is not possible to estimate the characteristics of sound production solely on the basis of a drum body, because a membrane (material, attachment, fastening, actual tightness) plays a major role in this regard. The presented examples are closely related to Central European prehistory, but they may serve as empirical analogies to other geographical or cultural contexts.

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Metallic Idiophones 800 BCE–800 CE in Central Europe: Function and Acoustic Influence – A Progress Report

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Abstract

Our project is focused on metal sound objects of the Early Iron Age (Hallstatt Culture), the Roman period, and the period of the Avar Khanate in the Carpathian Basin (Early Middle Ages). The idiophones originate from burial and settlement contexts. Our goal is to gain new information on their function, on tonal influence on ancient peoples' daily lives, and their impact on society. This interdisciplinary project combines archaeological, metallurgical, acoustical, psychoacoustical, ethnomusicological, and psychological methods supported by experimental archaeology and handcraft experience, as well as by ancient written and iconographic sources. In this article we report on the status of our current results. We present three case studies, one for each period, and an acoustic and psychoacoustic overview of all currently investigated sound objects. Analyses of textile remains adhering to pellet bells complete this paper.

Keywords

Bells – Pellet bells – Costume accessories – Acoustics – Psychoacoustics – Archaeometallurgy – Archaeological textiles

1 Introduction and the project

The research project "Metallic Idiophones between 800 BCE and 800 CE in Central Europe" will investigate metallic sound artefacts (idiophones) of different kinds, dated to three different archaeological periods. It is funded by the Austrian Sciences Funds FWF and supported by the Natural

History Museum Vienna. The selected sites are located in the heart of Europe, from Western Switzerland, across Austria, and to Western Hungary and Western Slovakia (see Figure 1). The items date to the Early Iron Age, the Roman Period, and the Early Middle Ages.

The Hallstatt Culture (800–450/400 BCE) dominated the Early Iron Age in Central Europe. Fibulae with interlinked chains, rattling pendants and small cymbals, various combinations of ring pendants (rings interlinked), fancifully created pendants with jingles and cage-like pellet bells, and bobbles with jingles belong to women's costume accessories of this period. When beaten against each other, their jingles and pendants create sounds. This sounding jewellery has been found in burials, in both cremation and inhumation graves. The Prehistoric Department of the Natural History Museum Vienna houses a large part of the excavated objects from the famous Hallstatt necropolis in Upper Austria in its collection and still is excavating the site (Grömer and Kern 2018). Although the first author of this article already investigated a large sample of the objects (Pomberger 2016: 112–41), there still remain some items to be examined and analysed. While cage-like pellet bells and bobbles are rather rare in Hallstatt Culture, several of these artefacts were found in tumuli in western Switzerland (Drack 1966/67). They are now in the collections of the Bern History Museum (Bachmann-Geiser 2001) and the *Archäologischer Dienst des Kantons Bern* (Ramstein and Cueni 2012). An ensemble of seven cage-like bobbles and house-shaped pendants, both with jingles, originate from the Býčí skála cave, an Iron Age sacrificial site near Brno, Czech Republic, and are now part of the collection of the Natural History Museum in Vienna (Parzinger et al. 1995). A large number of bells are known from the Roman period. The bells investigated in this project come from settlements and military camps along the Roman Limes at the Danube and its vicinity in Austria: Iuvavum/Salzburg, Ovilava/Wels, Vindobona/Vienna, Carnuntum/Petronell-Carnuntum and Bad Deutsch-Altenburg, and Savaria/Szombathely in Hungary. They are housed in the archaeological collections of the Salzburg Museums, the City Museum of Wels, the "Wien Museum", the "Stadtarchäologie Wien", the Museum Carnuntinum, and the Savaria Museum. The pellet bells

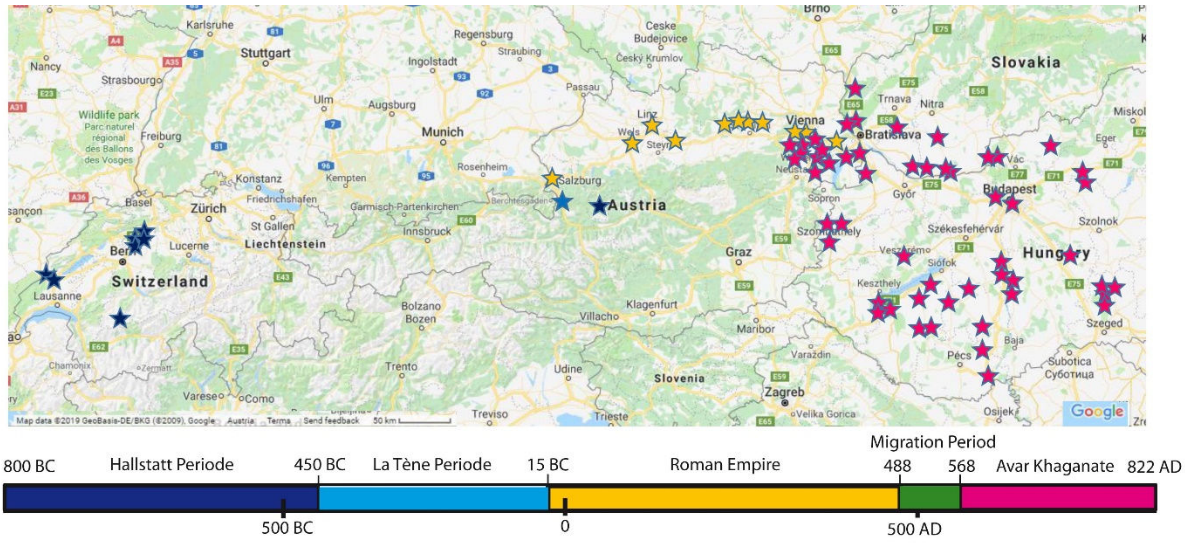

Figure 1: Map of sites with timeline. Map data: Google Earth/Google Maps; Design: B.M. Pomberger.

from the Early Middle Ages originate from the Avar period in Hungary, Slovakia, and East Austria. They are kept in the archaeological collections of the *Wien Museum*, the Slovak National Museums in Bratislava and Martin, the Danube Region Museum in Komárno, the Hungarian National Museum in Budapest, the Rippl-Rónai Museum in Kaposvár, and the Balaton Museum in Keszthely. In total there are more than 500 objects that fall under the purview of this article. We will present three case studies, one from each period, and then show an overview of all our acoustic and psychoacoustic results so far. However, it must be noted that sounds can only be studied as they can be produced and recorded today. Centuries of storage in the ground have corroded the objects. In the course of this process, the metals interact with their environment in a physicochemical way due to moisture and oxygen. Salts are deposited in the material, thus changing the chemical composition on the surface or throughout the entire body (Kaesche 1979). Although copper alloys form an oxygen-impermeable protective layer, this impairs the sound of the metal idiophones. Iron objects react so strongly that only in the rarest cases do they still sound. Corrosion not only changes the chemical composition but also the specific weight, which along with the shape of the sounding body plays an important role in the sound (Mühlhans et al. 2022; Mühlhans and Pomberger forthcoming). In addition to the above-mentioned investigations and aspects, we also examined textile residues that adhered to the sound objects in order to obtain information about their connection to the objects and the possible functions of the instruments, as well as the visual appearance (clothing) of people who carried the idiophones.

2 Research questions, methods, and terminology

When we were confronted with the plenitude of the different objects, several research questions arose, which we try to answer in our project. They can only be answered using interdisciplinary methods (see Figure 2) and we therefore created an interdisciplinary network with experts.

2.1 Research questions discussed in this paper

First, we wanted to find out what information could be obtained from the sound objects and the context of the finds that gave evidence about their function. Since we knew that we were dealing with sounds as they can be produced and recorded today, and because corrosion changes the material and thus the sounds, we needed to determine what information we could gain from the recorded sounds about frequency ranges, sound levels, and psychoacoustic parameters, as well as which metal alloys were used to produce the objects, and what their individual chemical compositions were. In addition, we investigated the influence of the materials on the produced sounds. Some pellet bells had textile residues adhered on their surfaces, so we wanted to determine their composition and the relation of this material to the pellet bells (Pomberger et al. 2021a). Finally, we investigated the possibility that the sound objects had any additional meaning.

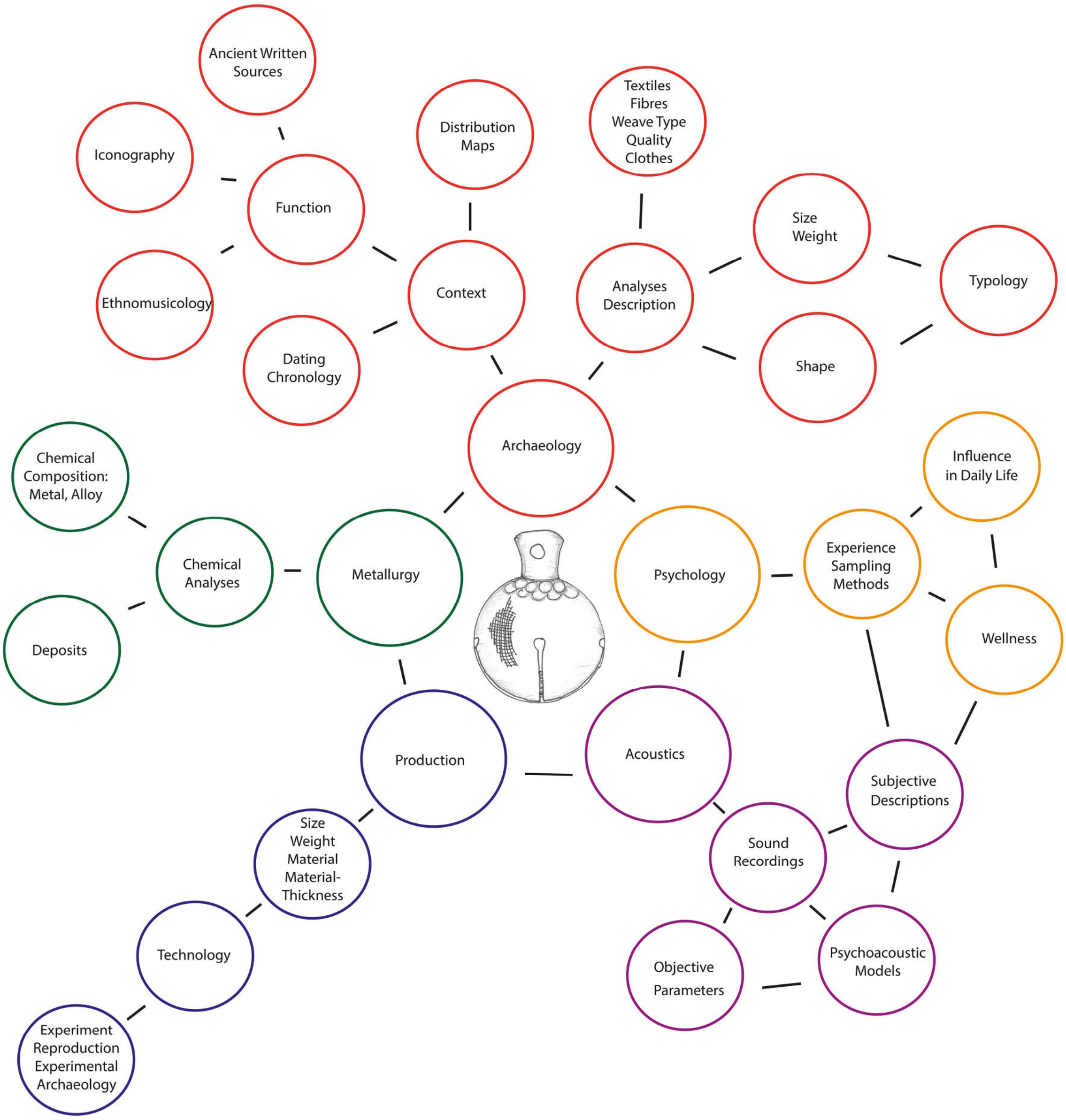

Figure 2: Model of the interdisciplinary research project. Design: B.M. Pomberger.

2.2 Methods

First, contextual analyses, measurements of the sizes and weights of the objects, classifications into types, and statistics regarding the quantitative occurrence within a site were carried out. Drawings and photos of the objects were made and extensive databases were created. Furthermore, distribution maps of the objects within the settlements and cemeteries were created and compared. In order to collect more information about the function of the idiophones in early history, ancient written and iconographic sources were studied (Pomberger et al. 2022a; Hackl and Pomberger 2022) and ethnological sources were likewise consulted. The chemical compositions of the idiophones were analysed by using X-ray fluorescence analysis and electron scanning microscopy. In order to determine the influence of metals and metal alloys on the sound, selected idiophones of the same size but made of different materials were produced and analysed (Mühlhans et al. 2022; Mühlhans and Pomberger forthcoming). Standardised analytical methods of textile archaeology comprise the analysis of weaving type, technical details about the textile qualities, and the fibre type. The sound recordings of the original idiophones were recorded in a specially designed portable recording studio with a damping of 20 mm, which was constructed for recordings in the various collections and museums. Even though the insulation cannot protect recordings from very low frequency noise, it is still quite sufficient for mid and high frequencies with a dampening effect of 21.4 dB on average (Pomberger and Mühlhans 2022). The sound recordings are analysed using Adobe Audition 2022. More complex analyses consist of a variety of audio features such as MFCCs35, which measures pitch strength[1] or impulsiveness[2], and are done using a variety of software packages within MATLAB or Python. Psychoacoustic parameters are calculated using HEAD ArtemiSuite (see also Pomberger et al. 2021b; Pomberger et al. 2020).

2.3 Terminology and definitions of acoustics and psychoacoustics

The sounds of idiophones have certain physical properties that clearly distinguish them from other types of sounds (e.g. aerophones or chordophones). Vibrating strings or air columns (e.g. in flutes, whistles, etc.) always have a fundamental and overtones or partials that are integer multiples of the fundamental, meaning from a physical point of view a harmonic oscillation or a sound. This is not the case with idiophones (formerly also often called "autophones"). In bodies that vibrate when they are excited, e.g. by striking, several partial oscillations are formed. These partial oscillations produce frequencies that are not integer multiples of a fundamental. Since the harmonic structure is missing, we speak physically of a "mixture of tones" rather than a sound. In physics/acoustics, a "tone" is only a single sinusoidal oscillation. What we describe using the language of music as a tone is – from the point of view of the physical world – a sound. The harmonic structure also plays an important role in the perception of pitch. In idiophones this is not clearly or only weakly pronounced.

Psychoacoustics is part of psychophysics and deals with the correlations between human auditory perception and the physical acoustic properties of sounds. The discipline explores which are the proportion of measurable acoustic parameters – such as fundamental frequency, partials, spectral parameters, temporal fluctuation, etc. – as well as subjective sound characteristics such as loudness, brightness, sharpness, roughness, etc. Psychoacoustic parameters are modelled by considering the properties of the human ear (e.g. critical bandwidths, see Fastl and Zwicker 2007: 149). This enables sounds and noises to be calculated by a computer and compared directly with each other.

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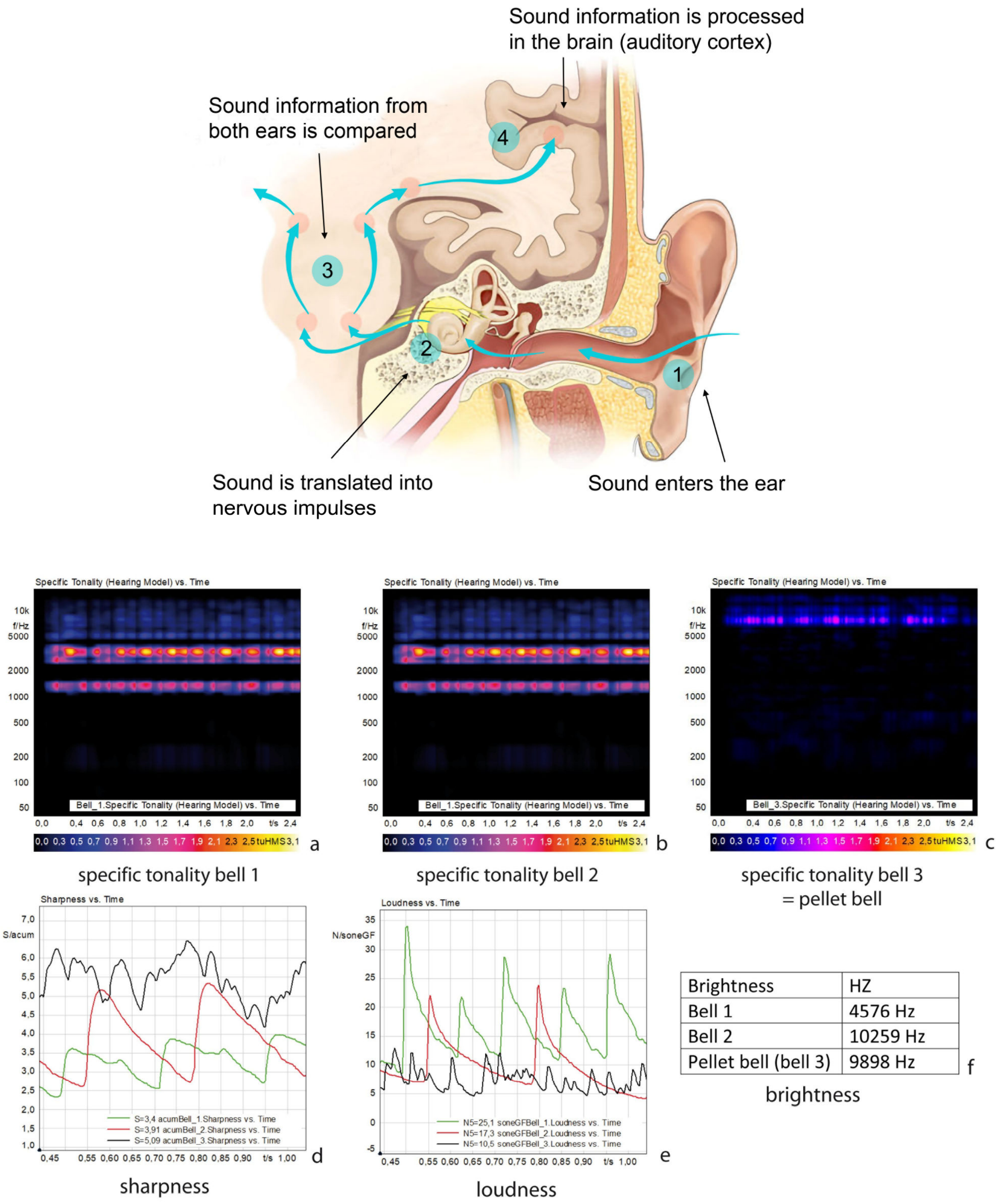
[1] MFCC stands for 'mel frequency cepstral coefficients' and is commonly used to calculate spectral similarities in sounds.

[2] Pitch perception is subjective but depends mainly on the harmonic structure of a sound, and thus can be predicted with pitch strength.

In 1984, Wolfgang Aures wrote in his publication that the "sensory euphony […] is influenced by roughness, sharpness, loudness and sonority" (Aures 1984: 735). These parameters also play a central role in today's psychoacoustic research and are used for calculating the measurement of the sound objects at hand. Loudness (German: *Lautheit*) describes the subjective perception of the objectively measurable intensity of a sound event. The physical unit that measures this objective intensity is sound pressure (Pa, pascals) or sound pressure level (SPL, decibels). This measure, if given in decibels, is commonly referred to as level (German: *Pegel*). If talking about the perceived intensity, which is called loudness, the units sone (German: *Lautheit*) or phon (German: *Lautstärkepegel*) are commonly used. The distinction in the German language does not exist in English. Both units are well defined in research resulting from various psychoacoustic experiments, and thus can be called psychoacoustic parameters. Volume (German: *Lautstärke*) and other terms often found on the knobs of audio equipment, are not clearly defined, have no scientific unit of measurement and can therefore not be used in a scientific context.

Loudness depends, among other things, on the sound pressure or sound pressure level, but must not be equated with it. Especially in the frequency range of the sound objects to be examined, for example between 2 and 5 kHz, the human ear is particularly sensitive (Gelfand 2010: 166). Therefore, the sound pressure level can lead to the subjective impression of high loudness/volume. Heinrich Barkhausen introduced the unit phon as a measure of loudness level in 1926, where 0 phon represents the human hearing threshold and 1 phon represents the smallest perceptible change in magnitude. In 1933, the curves of equal loudness levels were defined by Fletcher and Munson (Fletcher and Munson 1933: 91). In 1958, Eberhart Zwicker introduced the unit sone as a measure of loudness (Völz 1999: 51). At 1 kHz, a sound pressure level of 40 dB corresponds to a loudness level of 40 phon or a loudness of 1 sone. For the phon, an increase of 10 corresponds to a doubling (40 → 50 → 60 → 70 …), for the sone a doubling of the number itself (1 → 2 → 4 → 8 …). Sharpness is a parameter that depends predominantly on the spectral density and envelope, and again, the range in which the human ear is sensitive plays an essential role. The unit for sharpness is acum. A band noise with a critical bandwidth and a centre frequency of 1 kHz at 60 dB sound pressure level is defined as 1 acum. The following also applies to sharpness: doubling of the unit corresponds to a doubling of the perceived sharpness. In contrast to sharpness, which depends exclusively on spectral properties, roughness is determined exclusively by amplitude modulation (AM) – i.e. temporal fluctuation.

With a slow amplitude modulation up to about 15 Hz, the impression of a beat is created. Between 15 and 300 Hz AM, the impression of roughness is created, peaking at 70 Hz AM. From 150 Hz AM, the ear begins to perceive two separate tones. Roughness is indicated with the unit asper according to DIN (Deutsches Institut für Normung/German Institute for Standardisation) 45631 / A1. Tonal content (formerly called 'tonality') describes the perception of tonal substance in the spectrum without considering the noise components. Brightness is the psychoacoustic parameter that is most strongly correlated with an acoustic parameter, namely the spectral centroid (SC) frequency (Pomberger et al. 2020: 225–26).



specific tonality bell 1

specific tonality bell 2

specific tonality bell 3
= pellet bell

sharpness

loudness

Brightness	HZ
Bell 1	4576 Hz
Bell 2	10259 Hz
Pellet bell (bell 3)	9898 Hz

brightness

Figure 3: Path of the human audio perception from the outer (1), middle and inner (2) ear, over the auditory pathway (3) to the auditory cortex (4) in the brain. Single spectrograms (a-c) of three objects, sharpness over time in acum (d) and loudness over time in sone (e) for all three combined and table of brightness as the spectral centroid in Hertz (f). Design: J. Mühlhans.

3 Case studies and results

For the case studies presented in this article we chose idiophones from three sites, one dating to each period: the sounding Hallstatt Culture jewellery from the Býčí skála Cave near Brno (CZ), the bells from Roman period Vindobona/Vienna (AT), and the Avar pellet bells from Keszthely in Vas County (HU).

3.1 Sounding costume jewellery from the Býčí skála Cave, Czech Republic

The Hallstatt culture was the dominant culture in Central Europe during the Early Iron Age, being named after the famous site in Hallstatt-Hochtal in Upper Austria. This period is characterised by a great amount of various sounding bronze jewellery, such as fibulae, pectorals, multiple bracelets worn on arms and feet, belts with jingles, and even diadems with jingles (Kromer 1959; Kern et al. 2008; Grömer and Kern 2018; Urban 2000: 225–82).

The Býčí skála Cave (Bull Rock Cave) near Brno, Czech Republic, dating to 800 – 400 BCE, is one of the well-known archaeological sites in Moravia. It is located in the Moravian Karst near the village Josefov and together with the cave Rudické propadání it forms the second largest cave system of the Czech Republic. The 320-metre-long entrance area and the side entrance were used again and again in prehistory. The Czech prehistorian and speleologist Heinrich Wankel excavated the site during the second half of the nineteenth century. He excavated more than 40 human skeletons, two burnt offering sites, and a large number of precious artefacts, like the famous bronze bull sculpture, a parade carriage, weapons, animal bones, vessels, textile implements, organic fragments, tools, and bronze jewellery (Wankel 1882). The site is interpreted as a cultic or sacrificial site. The artefacts date from Ha C1 to Lt A2 (Parzinger et al. 1995).

Among the many finds, we encounter seven house-shaped pendants and seven bobbles, all jingles. They are all cast in copper alloy and, due to their equal number, might belong to a larger ornamental combination of jewellery. The house-shaped pendants are perforated vertically in a lattice-like manner and have a round eyelet at each corner. Two trapezoidal rattle sheets are hooked onto each on the two lower eyelets. The upper parts of the “houses” are decorated with three concentric circles. The pendants have a height of 10 cm in total and weigh from 26 g to 31 g. The bodies of the bobbles are composed of nine longitudinal bars that converge at the top and bottom. They are held together in the middle by a transverse bar. One round eyelet is at the top and one at the bottom. Two trapezoidal rattle sheets are interlinked in the bottom eyelet. Six bobbles have a long-oval body and one is spherical. There are no rattle bodies inside the bobbles. One bobble composition is 10.5 cm long and weighs from 27 g up to 39 g. The trapezoidal rattle sheets are decorated with small punched dots. All pendants together have a total weight of 425 g.

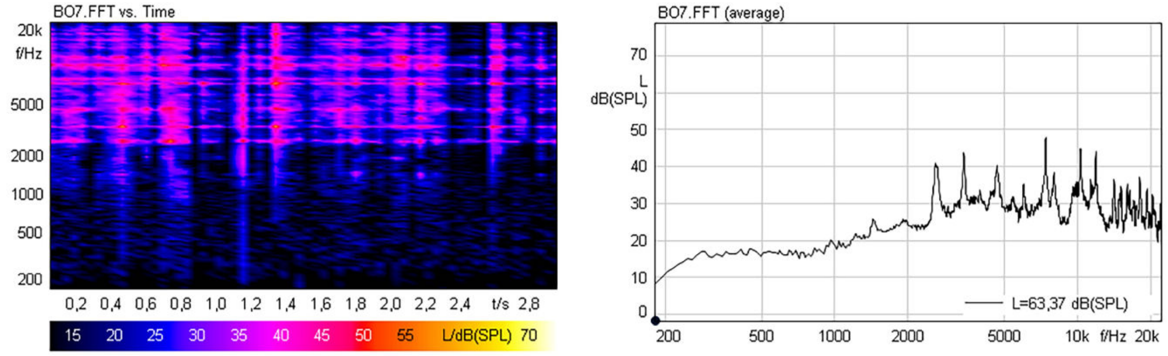
The cast parts are manufactured in lost wax technique. The sheets are forged by hand. Each object is unique. Local chemical EDS analysis (scanning electron microscopy) carried out in the Central Research Laboratories of the Natural History Museum Vienna, proved that the cast parts are made of high-quality bronze: they contain 70 – 95 % Cu, 7 – 24 % Sn and only little Pb, whereas the sheets contain much more Pb (Pomberger et al. 2020: 219–22).

Figure 4: The seven bobbles and seven house-shaped pendants with rattle sheets from the sacrificial site Býčí skála Cave, CZ © Naturhistorisches Museum Wien; Photo: A. Schumacher.

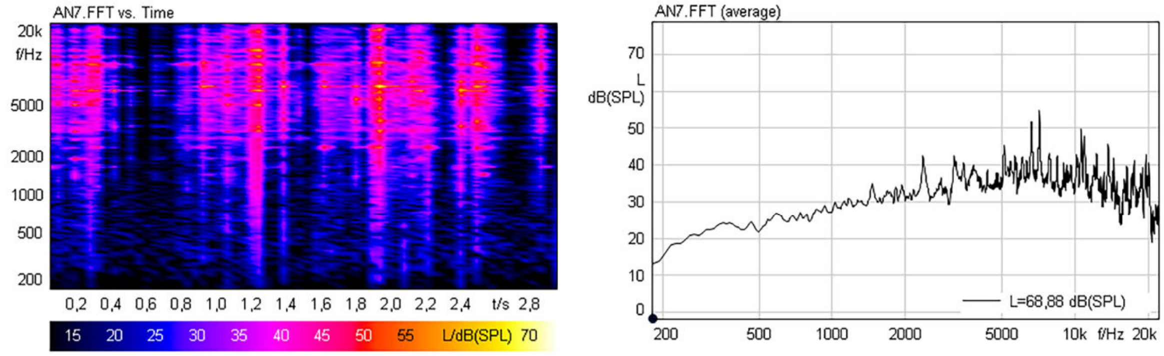
The pendants are classified as idiophones/indirectly struck idiophones/shaken idiophones or rattles according to the classification of musical instruments by Hornbostel and Sachs (1914: 565: system number 112.1; cf. MIMO 2011: 5).

The sounds are created by the individual rattle sheets or cast parts (depending on their arrangement) beating together. The pendants could have been worn on a belt, on a cloak, as a pectoral, or on another garment. The movement of the wearer causes the rattle objects to beat against each other and create sounds. The bobbles' rattle sheets create partials between 1.8 kHz and 20 kHz, while the bobbles beaten against each other have partials between 1.3 kHz and 16 kHz. The house-shaped pendants' sheets sound between 1.6 kHz and 19.3 kHz and the pendants have partials between 1.7 kHz and 16 kHz. A bobble and a pendant shaken together create partials from 1.4 kHz up to 11.3 kHz, and if all objects are shaken together they produce partials from 2 kHz up to 15.2 kHz. First, we have to mention that the analyses carried out show individual conditions, which can be completely different the next time they rattle, i.e. they are subject to greater fluctuations. Although, due to the similarity of the bobbles and pendants with rattle sheets, one would assume that they hardly differ in sound, clear differences are evident – especially in the brightness. The brightness of the sounds depends on the spectral distribution of partial tones and noise components, and strongly influences the perception of the timbre. Bobbles and pendants show clear differences between themselves here, but also differences in combination (Figure 5a – f).

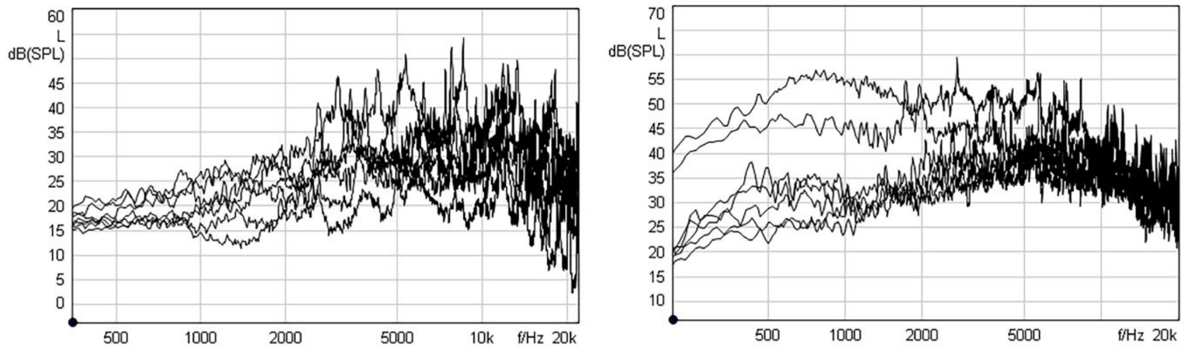
In total, the lowest partial tones of the bobbles are just in the frequency range in which the ear is particularly sensitive. The strongest partials are found between 5 and about 12 kHz, with some specimens producing partial tones up to almost 18 kHz. However, these high components contribute little to the brightness of the sound. The pendants clearly show less tonal components.



Bobble 7 a b



Pendant 7 c d



Bobbles e Pendants f

Figure 5: Acoustic analyses on bobble 7 and pendant 7 from the Býčí Skála Cave: a) and c) spectrograms, b) and d) measurements with the Fast Fourier Transformation. Energy distribution of partial tones and noise components in the spectrum: e) bobbles, f) pendants. Design: J. Mühlhans.

Noisy parts between 300 Hz and 2.5 kHz can be observed. Some pendants, however, can produce distinct partial tones. If bobbles or pendants sound at the same time, the level increases and so too does the loudness and spectral density. The decay time measured is below 1 msec.

The sound pressure level was calculated within a distance of 10 cm. The bobbles have the lowest sound pressure level with an average of 62.2 dB. If two or more bobbles are combined, the level increases to an average of 69.7 dB. A single pendant has a level of 70.2 dB on average. This increases to 73.4 dB when several are combined. Combining one bobble and one pendant together, the maximum level is 74.7 dB. Since the spectral distributions resemble one another, similar rankings can also be found in the loudness as in the level. With 10.1 / 17.1 sone (single/combined), the bobbles are the quietest. Single pendants have an average of 21.9 / 23.9 sone and together, 24.2 sone. Due to the acoustic properties of the sound objects, roughness is in all variants very low, averaging 0.06–0.09 asper. Slightly larger differences and generally higher values are reflected in sharpness. Individually, both types average 4 acum, and combined about 5 acum, which is a high value in comparison. Therefore, the sound objects may generally be considered to be sharp, but not rough. Due to the same excitation mechanisms and similar size of the objects, there are hardly any observed differences in impulsiveness. On the other hand, the bobbles are with an average of 6.6 / 8.3 dB slightly higher than the pendants with 4.2 / 5.4 dB. Sound pressure level, loudness, sharpness, and tonality increase when several sound objects are excited together. Roughness and impulsiveness are mostly the result of general sound properties and hardly change when more sound objects are added (Pomberger et al. 2020: 222–29).

Caged bobbles and pellet bells are of the same origin. The oldest known objects were found in the Iranian plateau in Tepe Giyan in grave 105, dating to the first part of the second millennium BCE (Contenau and Girsham 1935: 38). During the second half of the second millennium BCE, the objects spread over to the Caspian Sea, the Caucasus regions, and the Black Sea. They were detected mainly in burials near the hips or the neck and served as jewellery. Sometimes they were connected with a horse bridle (Castellucca and Dan 2014). Caucasian women of the Pre-Scythian period wore caged bobbles and pellet bells on their necklaces (e.g. Ateshi Gadirova 2014; Kadieva et al. 2020; Reinhold 2007). We can find caged bronzes in Greece (Kilian-Dirlmeier 1979) and the Balkan region (e.g. Bouzek 1974; Bouzek 2006; Bouzek 2012; Pomberger 2017), dating to the first millennium BCE. In the Hallstatt Culture, there are only a few known caged objects. Two of them originate from Hallstatt-Hochtal, burial 196 and burial 3/1875 (Kromer 1959: 68, pl. 22/12; Barth 2020). Both single pellet bells and bobbles, as well as combinations of two or more caged pendants, were found in Western Switzerland (Drack 1966/1967) and precious combinations of cast pectorals with pellet bells and bobbles were unearthed in eastern France, in the Jura Mountains (Wamser 1975; Ramstein and Cueni 2012; Piningre and Ganard 2004: 85–88). All these caged objects were found only in women's burials, dating from Ha C – Ha D1/800 – 600 BCE. They lay on the chest of the skeletons or were fastened on ribbons hanging from belts. Pellet bells and bobbles show the shapes of aggregate fruits like pomegranates, poppy pods, or rose hips. These fruits contain many seeds and thus symbolise fertility, abundance, magic power, love, passion, death and resurrection, and mental and spiritual fertility. They are also believed to be antidemonic (Pomberger forthcoming). Pellet bells and bobbles are rather rare finds in Hallstatt culture, which is important because rare finds can often be markers for both prestige and social status (Schumann 2015: 23–43). They were worn on the body and thus indirectly produced sounds with every movement of the wearer. The persons so adorned thus created sound fields, each with a unique profile. Clothing, costumes, personal ornaments, and sounds enabled direct non-verbal communication between people (Grömer and Pomberger 2023). We have created two videos, one describing the form, history and likely use of the original sound objects from the Býčí Skála Cave ("Bronze Pendants from the Býčí skála Cave in

Moravia")[3] and one dance video with the reconstructed jewellery ("Imagination of Dance in Hallstatt Culture").[4]

3.2 Roman bells from Vindobona/Vienna, Austria

Bells, mostly unnoticed in music archaeology and archaeology, played an important role in the Roman period. Bells are, in fact, the largest group of music archaeological finds from this period. 23 bells are known from ancient Vindobona, located near the ancient path of the river Danube. It was first founded as a military camp in the late first century CE, around which the *canabae legionis* developed. The civil town was built at the beginning of the second century CE. The Limes road along the Danube and a road to Scarbantia (Sopron), starting from the *Via Decumana*, connected Vindobona with important traffic routes of the Roman Empire. The legionary camp existed from the end of the first to the middle of the fifth century, but the civil settlement flourished with promotion to municipium only from the first to the third century CE (Kronberger and Mosser 2018). The borders of the Roman legionary camp in Vienna's inner city can still be seen today in the following streets and alleys: Tiefer Graben-Naglergasse/Graben-Rotenturmstraße/Stephansplatz and Gonzagagasse/Schwedenplatz. Like every Roman legionary camp, Vindobona was dominated by rectangular main streets, the *via principalis* and the *via decumana*. The *principia* was located at the junction of both streets. In the northern part of the camp facing the Danube were the buildings of the *tribunes*, the *thermae*, and the *valetudinarium*, in the south-western part – the *praetorium*, the barracks and the *fabricae* (Kronberger and Mosser 2018: Fig. 152). Nine bells and one clapper were found in the military camp. Two were unearthed within the area of the ancient *praetorium* at Judenplatz 7 and Parisergasse/Schulhof, and another one from the barracks at the Judenplatz, which is at the former Lazen- und Dreifaltigkeitshof (Bauernmarkt 22–24/Fleischmarkt 4 and 6). Furthermore, we know about two iron bells from this place, where a centurions' quarter may have stood (Mosser 2016; 2017). Unfortunately, they have been removed from the Wien Museum's collection. Three bells were found at the *fabricae* and barracks at 'Am Hof'. The clapper was discovered in the area of the main room ('*papilio*') of a *contubernium* of the southwestern barracks. The last bell was excavated in the area of the *intervallum* above the sewer of the *via sagularis*. The *canabae legionis* of Vindobona extends around the legionary camp to the west, south, and east, and is located within today's Ringstrasse and the Landesgerichtsstrasse. The living quarters of craftsmen, traders, businessmen, and the soldiers' families were located here. The Limes road today runs through Freyung, Herrengasse, Michaelerplatz, and Augustinerstraße, crossed by the southern road at the Michaelerplatz, which lead from the *porta decumana* of the military camp to Scarbantia/Sopron. One bell was found at the Freyung, where craftsmen carried out their work. Two bells were excavated at former metal workshops, at the Michaelerplatz, where objects were made of iron and non-ferrous metals (Donat et al. 2003; Donat et al. 2005). In the area of today's Stallburg, where in Roman times

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[3] https://www.youtube.com/watch?v=tX5tDQGrSNQ.

[4] https://www.youtube.com/watch?v=PN5b1OWACPc.

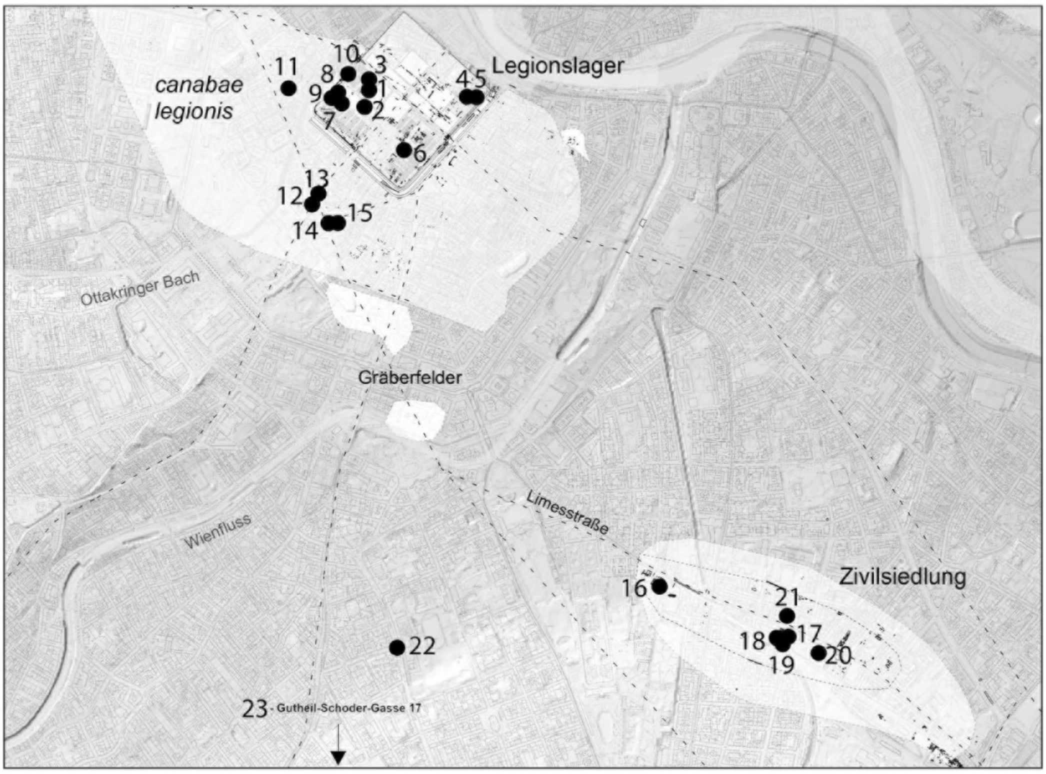

Figure 6: Distribution map of bells in Vindobona. Design: M. Mosser, Stadtarchäologie Wien © Stadtarchäologie Wien.

a small arterial road ran along the camp wall to the Limes road, two small bells were found. The civil settlement developed as early as the first century with houses along the Limes road, today the Rennweg in the third district of Vienna. Six bells from four sites are known from the settlement. One comes from the Botanischer Garten/Rennweg 14, where a building with 19 rooms was excavated. The small bell was found in a paved courtyard (Chinelli et al. 2001; Kenner 1904: 165). At Rennweg 44, where a residential, trading, and sales area was located in Roman times, three bells were found in a work pit, a storage pit, and a well (Müller et al. 2018).

One bell was discovered at Rennweg 52 in a pit backfill (Mosser 2017). Another bell from the site Rennweg 57/Schützengasse 24 comes from a residential and farm building with a courtyard and kilns.

From the junction of the Limes road into the civil settlement, a connection led to the street in the direction of Aquae (Baden). The course of this cross-connection can probably still be found today in Mayerhofgasse in the fourth district and crossed today's Favoritenstraße. Opposite today's Theresianum, a bell was found in the area of Favoritenstraße without any further known find context. Another bell was recovered at Gutheil-Schoder-Gasse 17, in the immediate vicinity of a road station (see distribution map Figure 6 and Figure 7; cf. Pomberger et al. 2022d).

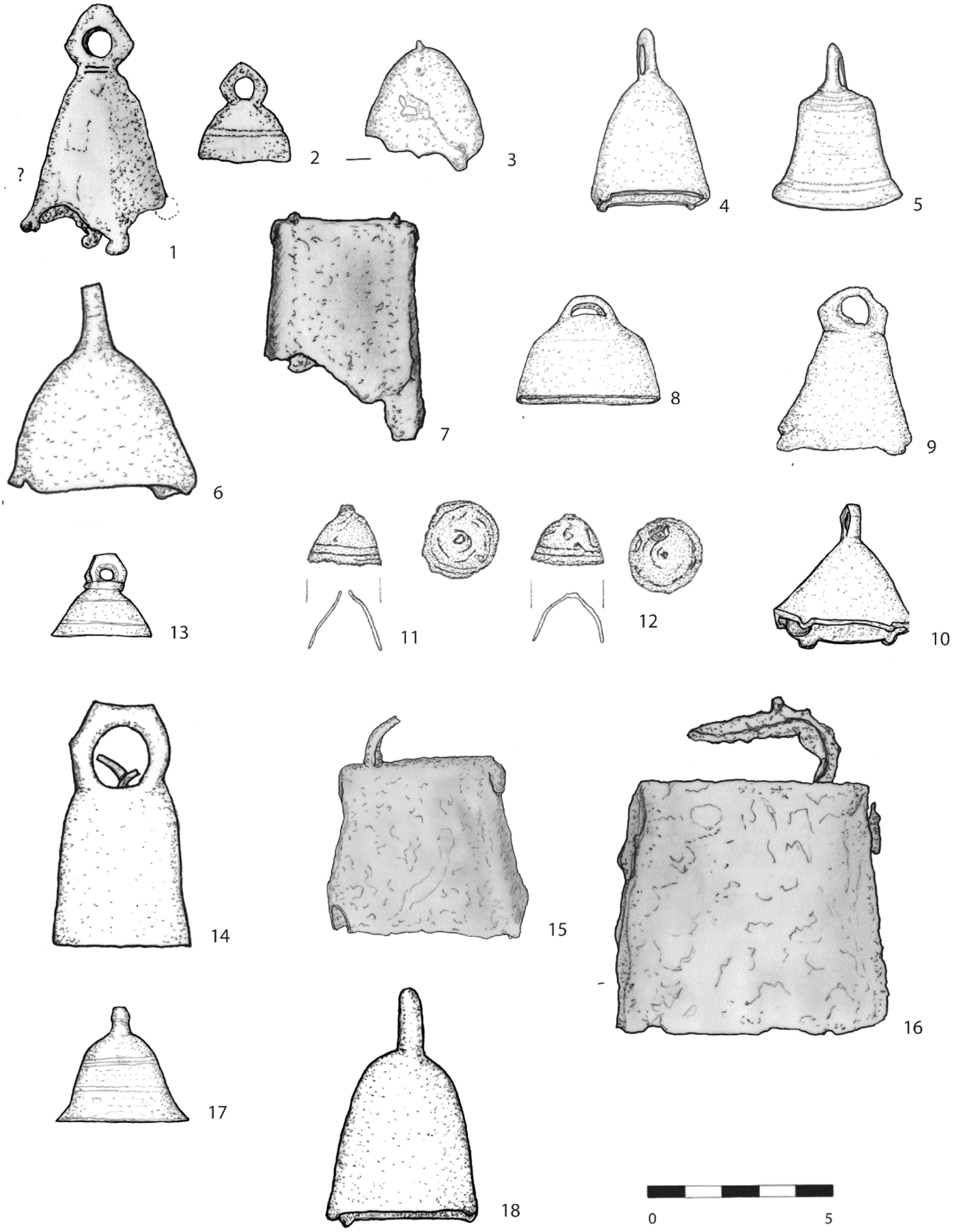

Figure 7: Bells from Vindobona. Military camp: 1 – 3/Judenplatz; 4 –5 Am Hof; 6 – 7/Bauernmarkt; *canabae legionis*: 8 – 9/Michaelerplatz; Freyung; 11 – 12/Stallburg; civil town: 13/Rennweg 14; 14 – 16/Rennweg 44; 17/Favoritenstraße; 18/Gutheil-Schodergasse 17. Design: B.M. Pomberger.

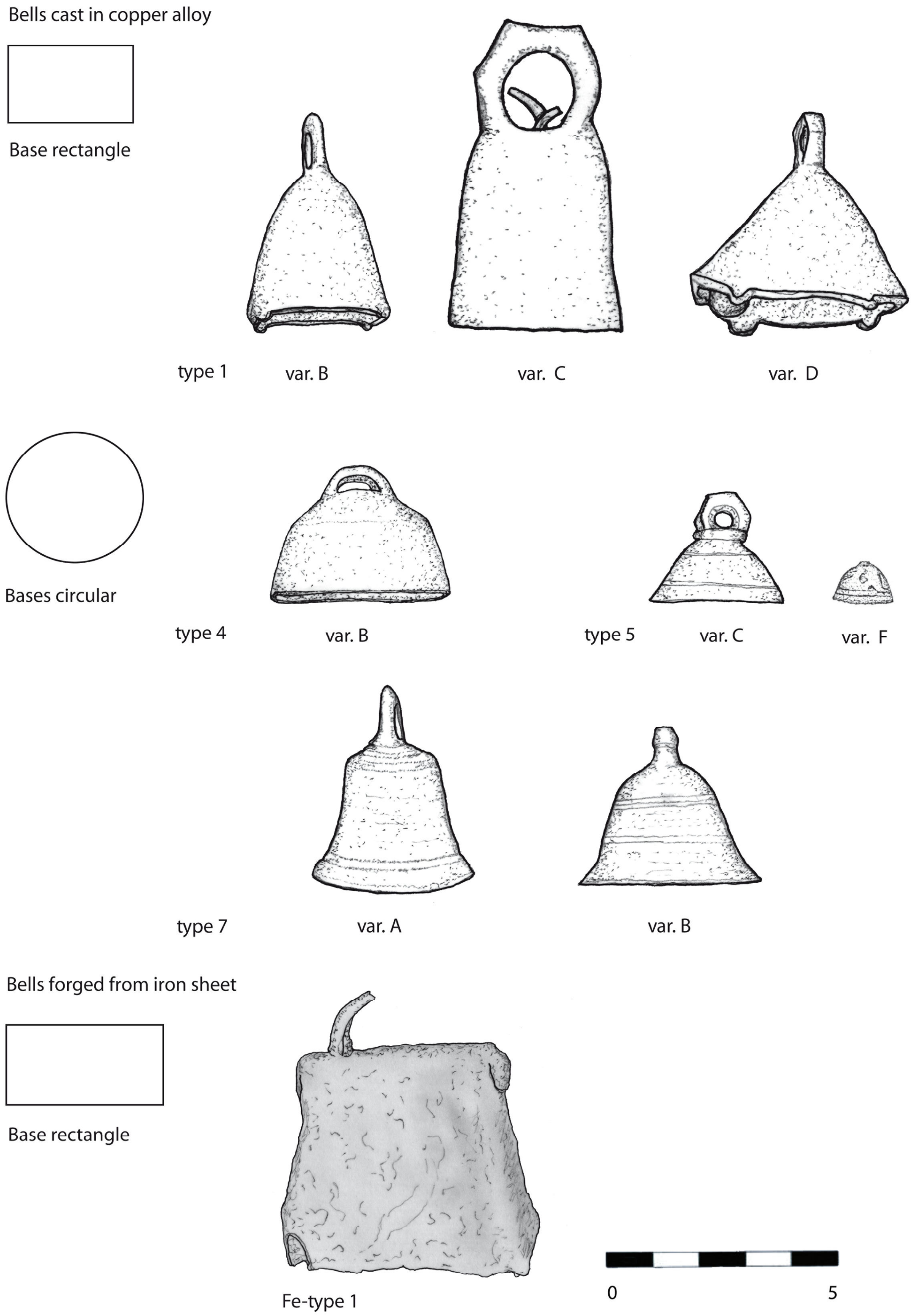

Figure 8: Types of bells from Vindobona. Design: B.M. Pomberger.

Of the Viennese bells, 18 were investigated. They have sizes between 7 mm and 91 mm and weights of 5.8 g up to 141.54 g. Three are forged from iron sheet and are classified to iron bell type 1.

site	object	Inv.Nr.	deepest partial (Hz)	highest partial (Hz)	strongest partial (Hz)
Am Hof 10/military camp	bell	MV 75/475/1	2091	20936	2091
Michaelerplatz/canabae legionis	bell	MV 25.169/1163	1981	21600	1981
Favoritenstraße	bell	MV 47.444	2706	17278	7586
Gutheil-Schodergasse 17	bell	MV 9.950/4	1593	20769	5051

Table 1: Frequency ranges from Vindobona bells.

The others are cast in various copper alloys. Eight of them have a rectangular base and are classified as Bell Type 1, Variants B, C, and D. The others have a circular base and belong to the Type 4/Variant B, Type 5/Variants C and F, and Type 7/Variants A and B (Figure 8). Compared to the bells from *Ovilava*/Wels, where 39 bells have been discovered, which can be divided into six types and several variants, the shapes of the Vindobona bells are not as varied (Pomberger et al. 2022a: 132, Figs. 4 and 5).

Ten bells were examined for their chemical composition using electron microscopy scanning by VIAS.[5] Four bells are cast in Cu-Sn-Pb bronze, (75–87 % Cu/11.6–14.3% Sn/1.2–10.7% Pb). One bell is cast in a copper-lead alloy (79% Cu/17.5% Pb) and the others are made from gunmetal (66.3–86.8 % Cu/3.7–14.3 % Sn/2.4–17% Zn/1.5–7.1% Pb) (Pomberger et al. 2022d: 375–76).

Idiophones do not have a harmonic overtone structure where all partials are integer multiples of a fundamental tone – as is the case with aerophones or chordophones. Instead, very different sound bodies produce very different partial oscillations, also called ‘modes’ (Winkler 1988: 119), which generate a multitude of partial tones, the frequency of which is not in any fixed relationship to one another.

Only four bells are intact and therefore able to have their sounds recorded today. Since the original iron clappers are corroded, we used reconstructed clappers for striking. Our analyses showed that bell Am Hof 10 has a range from 2 kHz – 20.9 kHz with a peak frequency of 2.09 Hz. The bell from the Michaelerplatz has a range from 1.98 kHz up to 21.6 kHz. The strongest partial is at 1.98 kHz. The frequencies of the bell from the Favoritenstraße range from 2.7 kHz up to 17.2 kHz with a peak frequency of 7.5 kHz and the last bell from the Gutheil-Schodergasse shows partials between 15.9 kHz and 20.7 kHz with a most developed partial at 5 kHz. Since the ear is very sensitive in the 2 kHz – 5 kHz range and can perceive even low levels, this characteristic gives the objects an average good audibility even with moderate noise (see Figure 9).

The timbre is determined primarily by the number, the spectral position, and the amplitude of partial tones. Bells have more pronounced partials, as well as less noise, therefore, they are often described as ‘clear’ or ‘pure’. This is not always the case with historical objects, as the extent of corrosion plays a significant role. Superficial corrosion only moderately dampens the vibration; however, it is not known how exactly the amount of corrosion is related to the vibration behaviour.

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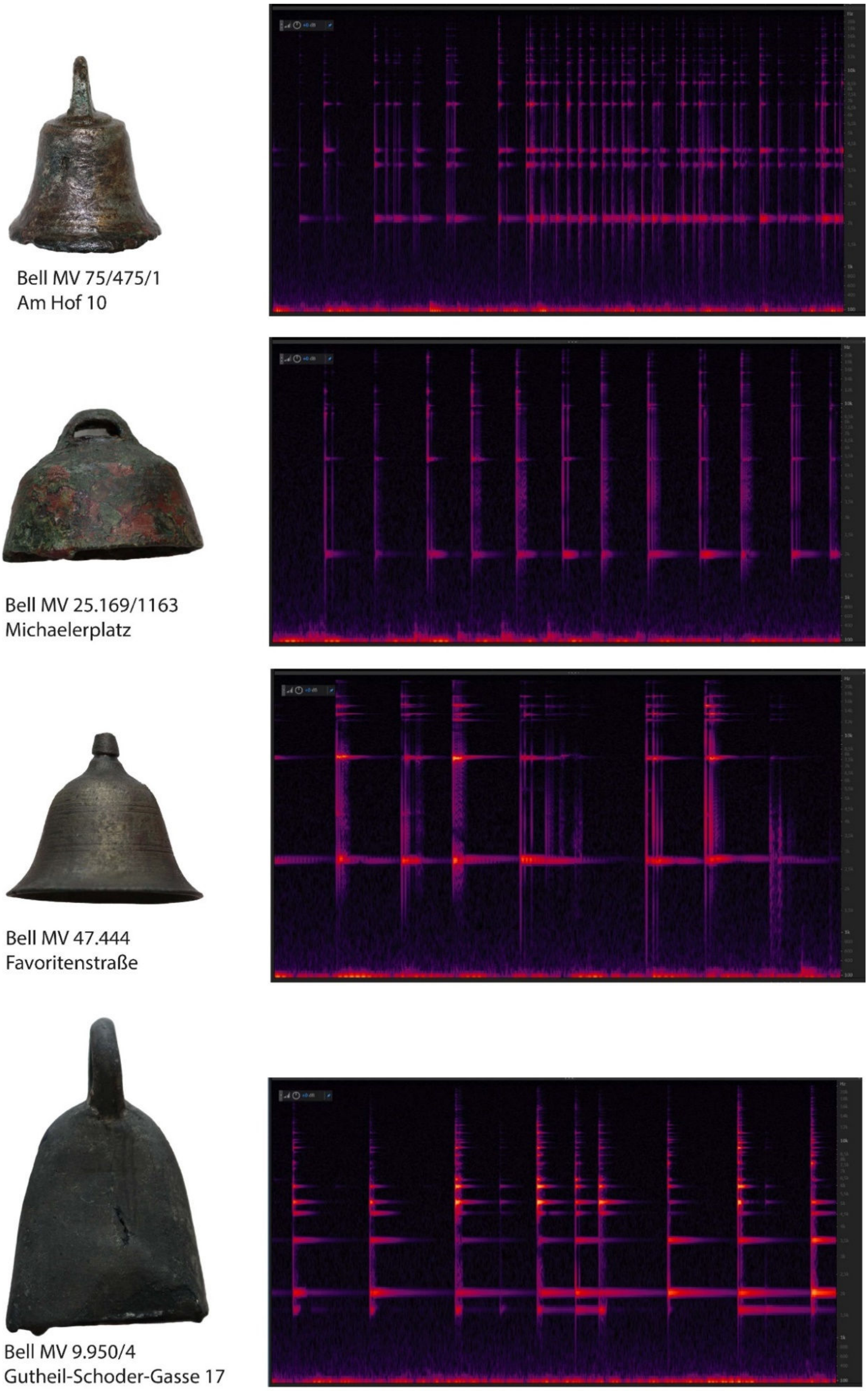
[5] Vienna Institute for Archaeological Science.



Bell MV 75/475/1
Am Hof 10

Bell MV 25.169/1163
Michaelerplatz

Bell MV 47.444
Favoritenstraße

Bell MV 9.950/4
Gutheil-Schoder-Gasse 17

Figure 9. Sonograms of the four bells from Vindobona. Design and photos: B.M. Pomberger, © Wien Museum.

site	object	Inv.Nr.	soundpresure level	loudness	sharpness	roughness	impulsiveness	tonality (DIN45681)	brightness SC
			kalib, dB re p0	sone	acum	asper	IU	dB	Hz
Am Hof 10/military camp	bell	MV 75/475/1	63.69	13.3	3.58	0.0449	2.4	17.24	5059
Michaelerplatz/canabae legionis	bell	MV 25.169/1163	58.44	8.31	2.79	0.0321	2.48	13.67	6937
Favoritenstraße	bell	MV 47.444	72.86	16	3.87	0.0545	1.91	24.5	8034
Gutheil-Schodergasse 17	bell	MV 9.950/4	78.86	31.6	3.83	0.0514	2.65	16.97	4625

Table 2: Psychoacoustic parameters of Vindobona bells.

The four bells have a sound pressure level of 70.6 dB or a loudness of 18.1 sone. This can be attributed to their percentage of copper (average 73.1 %). Their sharpness is on average 3.51 acum, while roughness is on average 0.05 asper. This means that their sound is sharp but not rough. Impulsiveness is on average 2.3 iu (impulsiveness units, see 4.5 below) and tonality on average TNR 18.1. Both values are related to excitation. Some statistical correlations between material and tonal properties could be determined. Content of copper correlates positively with loudness and sharpness, but negatively with spectral centroid. This shows that bells with a higher copper content are louder and sharper, but lower in brightness. Peak frequency correlates negatively with the tin content. The t-test did not show any significant differences in mean values between the gunmetal and tin-lead-bronze objects (Pomberger et al. 2022d: 377–80).

Bells fulfilled various functions in ancient times. First, they were sound tools and signal instruments (Haid 2004) and thus had many functions in daily life. Their ringing announced the opening and closing times of markets and baths (Plut. *Quaest. conv.* 4.42 = 668a e.g.; Plin. *Nat.* preface 6; Mart. 14.163) and the watering times of the streets (Sext. Emp. *Math.* 8.193). Bells also tolled when fire broke out.

Their sounds served as acoustic signals for the night watchmen (Cass. Dio 54.4) and were used as acoustic weapons in acts of war (Eur. *Rhes.* 379–85; 300–10). Even when bells were mounted on shields – like in Aeschylus' *Seven against Thebes*, in which he dramatizes the mythological battle of Oedipus' sons, the brothers Eteocles and Polyneikes (Aesch. *Sept.* 380–400) – they fulfil the apotropaic role of acoustic weapons, because loud and metallic sounds create fear and terror. Weapons and objects made of metal produce overtone-rich, 'metallic' sounds when struck against each other, which are perceived as hard, powerful, energetic, sharp, and defensive. Other acoustic descriptions of the sound of metals are booms and clangs. Noise and loud, penetrating music have always been a proven means of psychological warfare and torture to generate terror (Diederichsen and Schulze 2017; Grant et al. 2015) and to manipulate targeted crowds.

Executions and punishments of adulteresses – men were allowed to commit adultery with impunity – were announced by the tolling of bells (Cass. Dio 6.24; cf. Zonaras 7.21; Niemann 1997: 20; Kramer 2016: 27; Socr. *Hist. eccl.* 5.18). Slaves were awakened by bell sounds (Lucian *Merc. Cond.* 24) and bells played a role in banquets and feasts (Petron. 47.8.5). However, bells were mostly considered apotropaic objects (Crummy 2010) and thus were used to protect home, children, and animals. Several of the bells found in houses may indicate this use (Pomberger et al. 2022a). They served to ward off evil, were supposed to bring good luck and reinforce positive qualities. In people's minds, the inherent powers and qualities attributed to them were enabling. These properties and forces are also attributed to their materials – the metals (e.g. Quast and Wolf 2010; Bächtold-Stäubli and Hoffmann-Krayer 1987a: 207–10; 1987c: 718; 1987b: 836–37; Sartori 1932). In children's graves, bells are often found attached to a bracelet or necklace (e.g. Eckardt and Williams 2018; Ruprechtsberger 1996; Ubl 1997: 300; Villing 2002).

Pets, such as dogs, sometimes wore bells on collars (Authengrüber-Thüry 2021). Pack animals, as well as mounts and pasture animals, could have bells fastened around their necks (Phaedr. 2.7.1–8; Rost and Wilbers–Rost 2010; Himmelmann 1980; Furger and Schneider 1993; Mandl 2000; Mocchi 2018; Nicolay 2007). Even chariots of emperors were decorated with bells as sounding status objects and status symbols to attract attention. A status symbol or status object is a sign which advertises someone's elevated status/belonging to a society (Duden 2001: 946).

Sixty-four bells hanging from Alexander the Great's hearse tolled when being moved through his empire (Diod. 18.27.5).

Bells hanging from temples, *villae urbanae*, and *villae rusticae* sounded to avert misfortune and announce the status of the owners (Suet. *Augustus, Caes.* 91.2.5; Casaulta 2017; Tortoli 2017). Bells tolled during cultic rituals and processions and banished demons during eclipses of the sun. But bells were also musical instruments (Isid. *Orig.* 3.22.13) and sounded to dances and at feasts – for example, at the *bacchanalia* in Sardinia (Pesce 1957).[6]

The great challenge for archaeologists is to determine the function of a bell based on its find position in settlements. For the most part, we can only theorise about its function on the basis of its size. Small bells were certainly used as apotropaic sound jewellery for humans and pets. *Tintinnabula* were composed of several bells measuring between 2 cm und 3.5 cm. Bells with sizes from 6 cm up to more than 10 cm probably hung from buildings, cult pillars, and statues. Very large bells – 20 cm and larger – were worn by herd animals. Bells were not only sound tools, signal instruments, and apotropaic objects, but they also seem to have been objects of prestige and social status.

Etymologically, both words, *status* and *prestige* derive from the Latin language, but are terms with two different meanings. The word status goes back to Latin *status*, "existence, prosperity, position, rank, situation, condition, circumstances" (Stowasser 1969: 942). In German, 'Status' means as much as situation, position within a society, state, condition (Duden 1989: 1456) – an actual state. A status symbol is a sign or object that serves to demonstrate someone's elevated status or belonging within a society (Duden 2001: 946). Prestige, on the other hand, means dazzle, magic, prestige, validity (Duden 2001: 803) and is derived from the late Latin word *praestigiae* (Duden 1989: 1178),

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[6] For more detailed information, see Pomberger et al. 2022a; Maria Hackl created a list of ancient literature mentioning metal idiophones and assigned them to their functions. She was able to determine the function of the idiophones in 78 citations by 46 ancient authors (Hackl and Pomberger 2022).

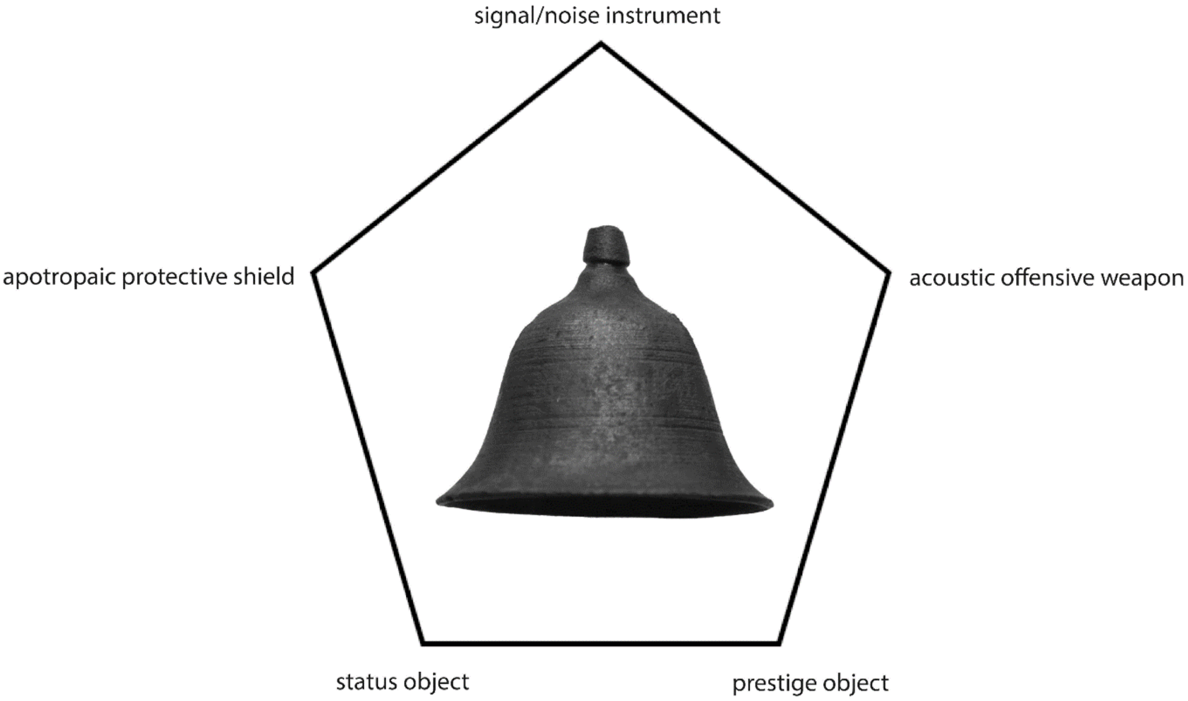

Figure 10: Diagram of bell functions. Design: B.M. Pomberger.

which in turn means dazzle and jugglery (Stowasser 1969: 796). Prestige could be described as a 'would-be state'. Prestige objects are special goods that are used to assert social prestige and to elevate oneself. They usually come from distant regions or are made of extraordinary material. Status, on the other hand, indicates a person's social origin and position within a culture, and a status symbol is an expression of power and social status (Schumann 2015: 35). In a diagram we try to show the different functions of the bells (Figure 10), however the discussion is not yet finished.

3.3 Early Middle Ages – Avar Khaganate

3.3.1 Avar pellet bells from the Migration Period collection of the Hungarian National Museum

Pellet bells appeared in the Avar Khaganate during the middle of the seventh century CE. They were probably imported from regions around the Black and the Caspian Sea, where they are common since the second millennium BCE (Contenau and Girsham 1935; Castellucca and Dan 2014; Ateshi Gadirova 2014; Kadieva et al. 2020; Reinhold 2007). The Hungarian National Museum houses 43 pellet bells from the Avar period originating from 17 sites – all cemeteries – in Hungary (Table 3).

The sites are Cikó, with 600 burials (Kiss and Somogyi 1984; Szentpéteri 2002; Hampl 1905) and two pellet bells, and Gerjen with 185 burials (Kiss and Somogyi 1984; Szentpéteri 2002) and one pellet bell, in the county Tolna. The necropolis of Halimba Belátó-domb, in county of Veszprém, consists of 489 burials (Török 1998; Szentpéteri 2002) and 13 pellet bells were found there. Two cemeteries with finds of pellet bells are known from the county of Jász-Nagykun-Szolnok, namely Jánoshida with 265 burials and 3 pellet bells (Erdélyi 1958) and Jászalsószentgyörgy with two burials and one pellet bell (Madaras 1995b). From the cemetery in Kiskőrös Vágóhídi-dűlő, in Bács-

Country	site	burials total	burials with idiophones	pellet bells	child	woman	man	sex?	iron	copper-alloy	gold
HU	Cikó	600	2	1		1		1		1	
AT	Edelstal = Nemesvölgy*	257	3	1	1	1	1		1	2	1
HU	Gerjen	185	1	1		1				1	
HU	Halimba Belátó domb	489	8	13	6	2			13		
HU	Janoshida	256	3	3	3				1	2	1
HU	Jászalsószentgyörgy	2	1	1						1	
HU	Kiskörös - Vágóhídi-dűlő	75	6	1	1					1	
HU	Kölked Feketekapu A	687	6	1	1				1		
HU	Mosonszentjánoss-Jánossomorja	316	1	1	1				1		
HU	Pilismarót-Öregek-dűlő	122	1	1	1				1		
HU	Pilismarót-Basaharc	197	9	7	5		1		4	3	
HU	Solymár	130	1	1	1					1	
HU	Szebény cemetery I	401	4	3	3				1	3	
HU	Szob Homokok-dűlő	140	2	2	2				2		
HU	Újhartyán (Kom. Pest)	?	1	1				1		1	
HU	unknown	?	?	6						6	

Table 3: Pellet bells from the Avar-Period/Migration-Period Collection of the Hungarian National Museum in Budapest.

Kiskun County, 75 burials are known, however only one contained a pellet bell (László 1955). The site Kölked Feketekapu A, Baranya County, consists of 687 burials, but only one pellet bell is known from this cemetery (Kiss 1996). Also, one pellet bell originates form the site Mosonszentjános Kavicsbánya, county Győr-Moson-Sopron, with 316 burials (Fettich 1927). In Pilismarót, county Komárom-Esztergom, two Avar period sites are excavated: the cemeteries Pilismarót Öregek-dűlő with 122 burials and one pellet bell (Szabó 1975) and Pilismarót Basaharc with 197 burials and seven pellet bells (Fettich 1965). One pellet bell was found in the cemetery of Solymár, Pest county, near Dinnye-hegy, Téglagyár with 130 burials (Török 1994). Two further pellet bells originate from the cemetery Szob Homokok-dűlő, Pest County, which consists of 140 burials (Kovrig 1975). The Szebény cemetery I, Baranya county, with 401 burials, contained three pellet bells (Garam 1975) and from Újhartyán, Pest County another pellet bell is known. One pellet bell from the cemetery in Edelstal 'Herrschaftsjoch' (Nemesvölgy) in Burgenland, Austria – a cemetery of 257 burials – is part of the Great Migration collection of the Hungarian National Museum (Lobinger 2016). Additionally, the collection keeps six Avar pellet bells from unknown sites. Furthermore, bells were excavated in eight of the cemeteries, but they are not the subject of this article (Pomberger et al. 2022b). The pellet bells were located near the hands, the hips and legs, and sometimes near the necks of the deceased. They were parts of the garments, served as sounding apotropaic amulets, thus influenced the appearance of the person wearing it.

When all graves of the cemeteries listed here are added together, there are a sum total of 3856 burials, but pellet bells were discovered in only 27 graves, a surprisingly small percentage at 0.7%. This fact shows that pellet bells were not at all common, but rather extremely uncommon in Avar

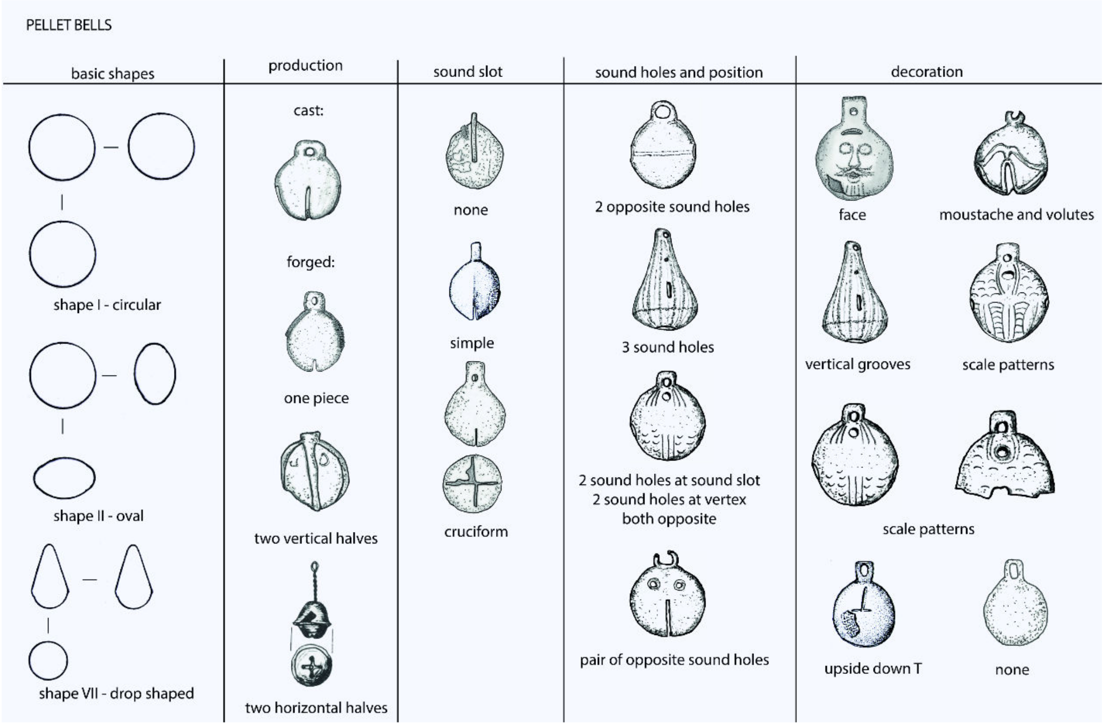

Figure 11: Shapes and decorations of Avar pellet bells form Hungary. Design: B.M. Pomberger.

communities. We are also not sure if they were imported products or were made in local workshops. 22 pellet bells are made from copper alloys and 25 are forged from iron sheet. The following copper alloys could be detected: Cu-Sn, Cu-Sn-Pb, Cu-Sn-Zn-Pb, Cu-Zn-Pb, and Cu-Pb. Some alloys show an astonishingly large amount of lead. Riita Rainio also mentions a large variety of copper alloys in her study on Finnish Iron Age pellet bells (Rainio 2008).

Two of the Hungarian sheet metal pellet bells are gilded (Pomberger et al. 2022b: 65, tab. 1). The sizes vary from 27 mm up to 46 mm with handle and the preserved weights from 5 g up to 37 g. Small pebbles, lumps of cinder, and bronze balls serve as pellets. Figure 11 shows the variety of shapes and decoration of these pellet bells. Furthermore, we must also mention that in the early Avar period burial bells were found. They are similar to Roman bell types and most probably from the Roman period.

The frequencies of the pellet bells are between 1.1 kHz and 20 kHz and range from 3–28 sone. Depending on background noise levels, the pellet bells can be heard from a distance of 1 m to a maximum of 12–15 metres. Noise content has more effect in lower frequencies, therefore pellet bells are usually lower in brightness (3.5–5 kHz). They have values between 0.02 and 0.1 asper as well as 2.5 and 4.5 acum and can be described as not at all rough, but instead quite sharp. With 4–8 dB they have barely more tonal than noise components (Pomberger et al. 2022b). Some original pellet bell sounds are published in our video “Pellet bells and bells from the Avar Period in the Hungarian National Museum in Budapest”.[7]

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[7] https://www.youtube.com/watch?v=nrMvHKKIjAM.

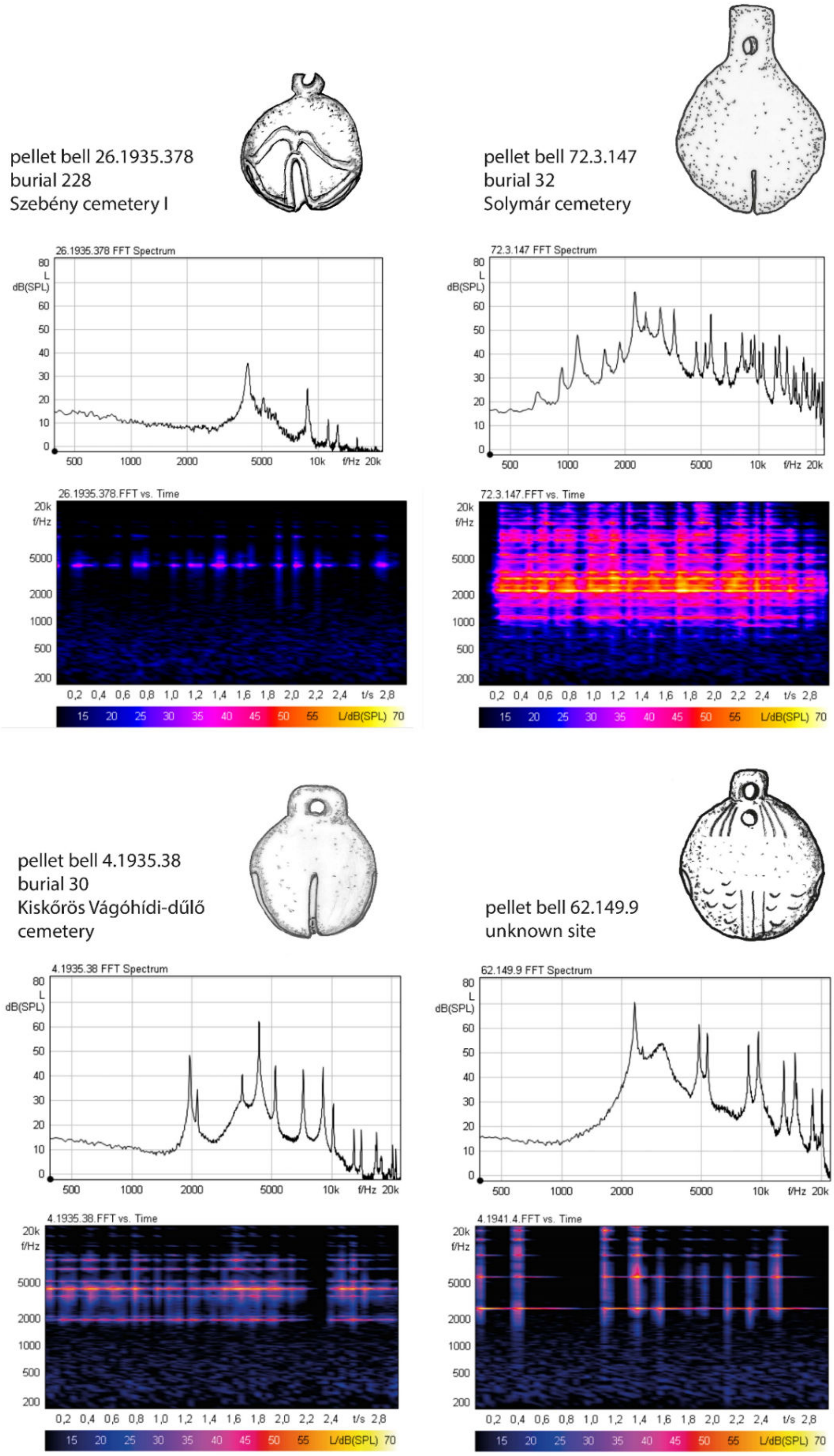

Figure 12: Sonograms and spectrograms of the pellet bells MNM 26.1935.378/burial 228/Szebény I; MNM 72.3.147/Burial 32/Solymár; MNM 4.1935/Kiskőrös Vágóhídi-dűlő and MNM 62.149.9/unknown site. 4096 window size, 85% overlap Hanning. Design: J. Mühlhans and B.M. Pomberger.

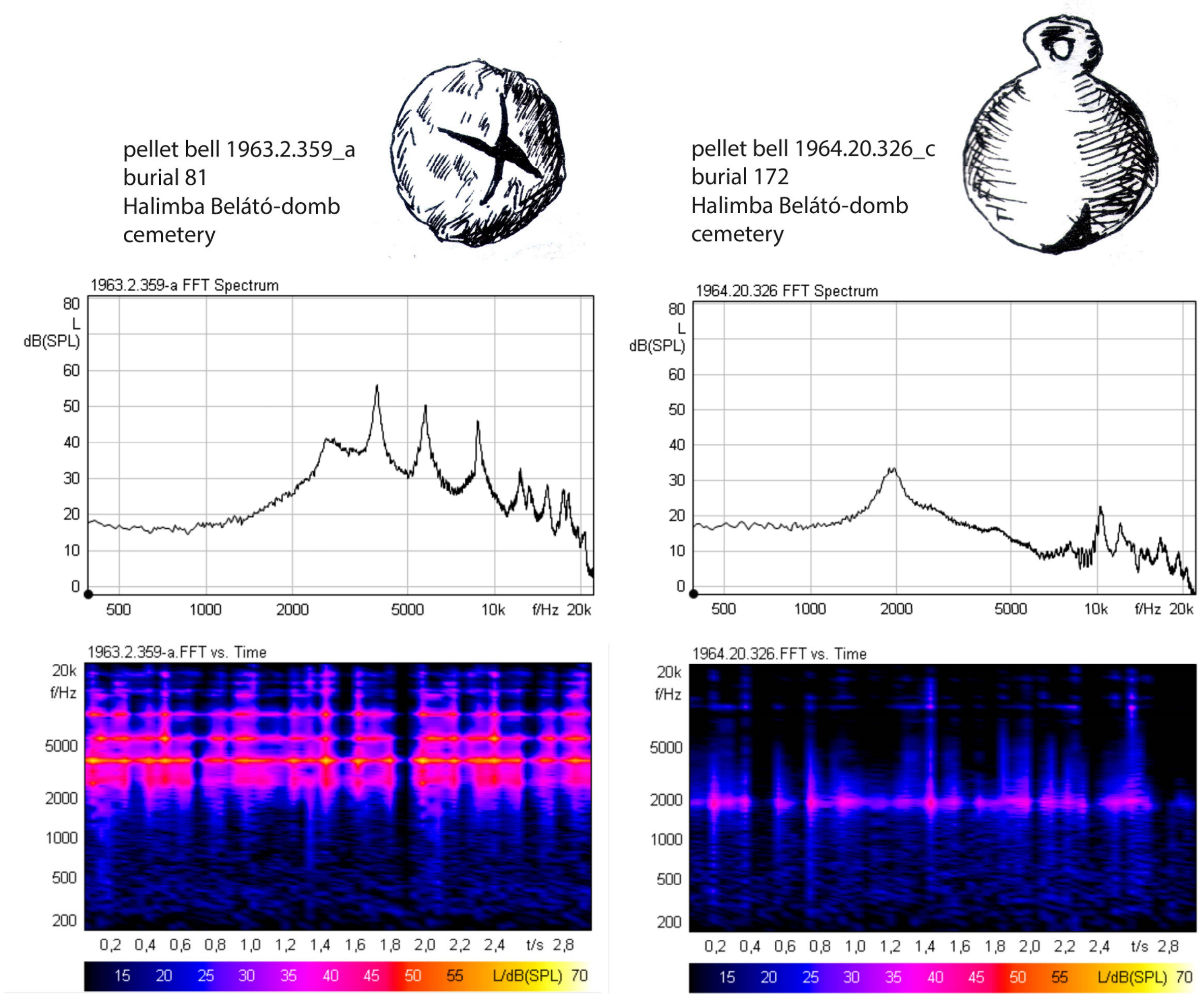

Figure 13: Sonograms and spectrograms of the pellet bells MNM 1963.2.359a/burial 81/Halimba Belátó-domb; MNM 1964.20.326c/burial 172/Halimba Belátó-domb. 4096 window size, 85% overlap Hanning. Design: J. Mühlhans and B.M. Pomberger.

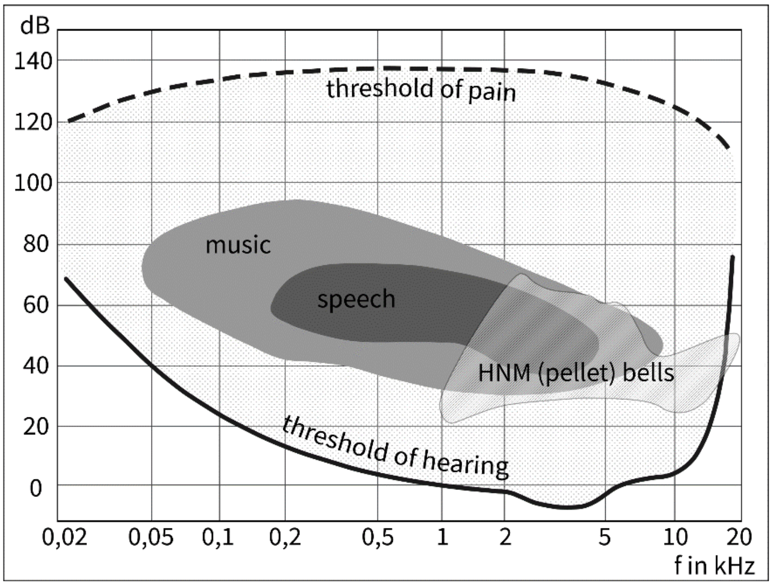

Figure 14: Human auditory thresholds and pellet bells from Hungarian sites. Design: J. Mühlhans.

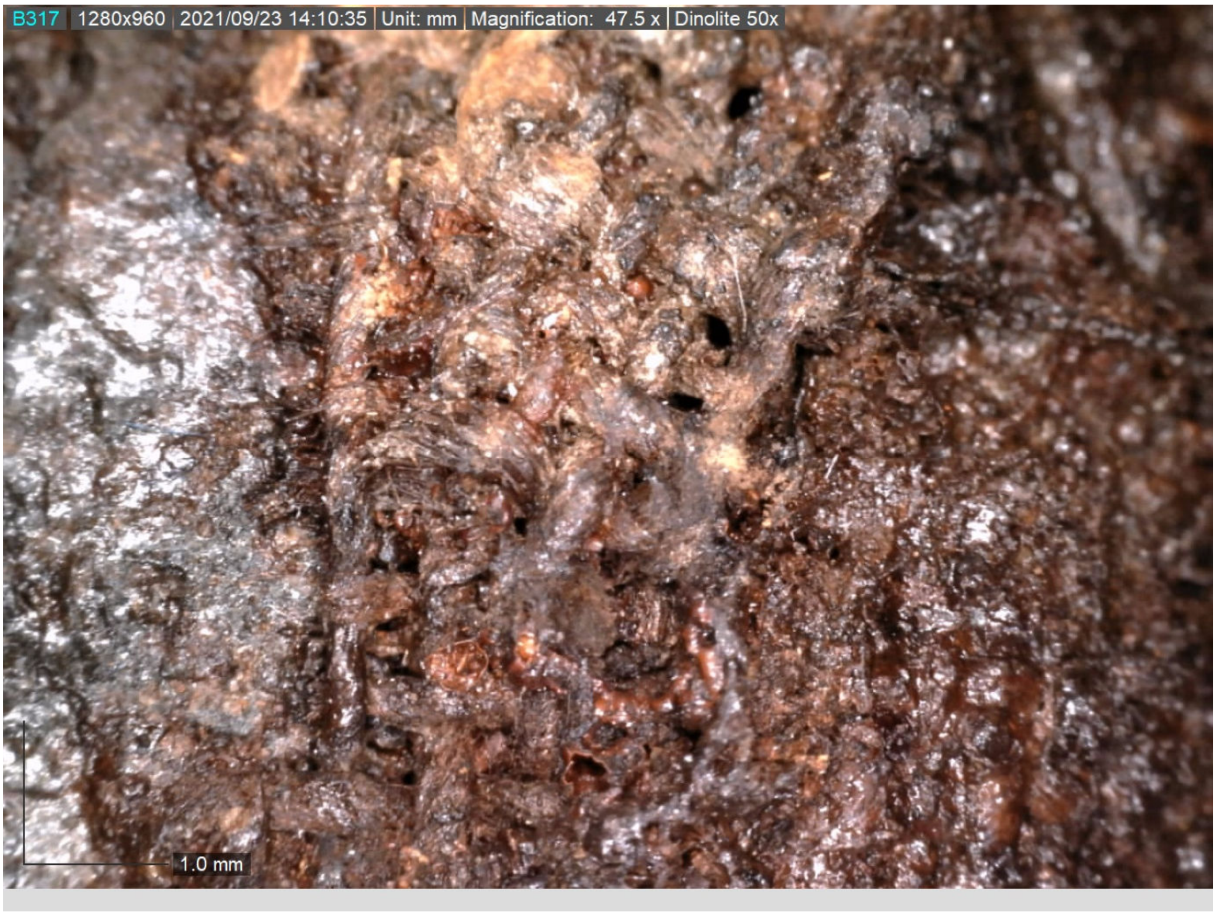

Figure 15: Textile fragments on an iron pellet bell from burial 17, Halimba-Belátó-domb, DinoLite_50x-Taxtile A_6. Photo: K. Saunderson.

3.3.2 Textiles on Avar pellet bells

Pellet bells were worn as parts of clothing, either on a necklace, on a bracelet on the wrist, or on a long hanging strap such as a ribbon or chain. They influenced not only the acoustic profile but also the visual appearance of the wearer.

Textiles found on the bells and pellet bells in question are therefore considered in the project, since they can offer further information on their function. These textiles were identified during their primary typological analysis and then analysed using a DinoLite digital microscope, measureing the thread diameters, densities, and twist angles, as well as identifying spin directions, weave types, layers, and special features.

These small fragments of textiles remained as mineralised pseudomorphs. Those analysed – from Devínska Nová Ves and Komárno (Slovakia); Gyenes/Gyenesdiás, Halimba-Belátó-domb, Jánoshida, Keszthely, Kölked-Feketekapu, Pilismarot-Öregek-dűlő, and Szob (Hungary); and Zillingtal (Austria) – fit well into the known spectrum of textiles from the Avar period (Hundt 1984; Dolejšová 1987; Scharrer-Liška and Klatz 2010; Grömer 2015; Grömer and Rapan Papeša 2015), mainly consisting of plant fibres (probably flax), and tabby-woven, z-spun, or single-ply yarn with most thread diameters being 0.3 – 0.4 mm. The function of the textile remains on pellet bells is difficult to determine. Fine, creased fabrics might derive from clothing, such as the fragments on an iron pellet bell from burial 17, Halimba-Belátó-domb (Figure 15), which lay in the area of the woman's knee, perhaps belonging to a loosely cut and gathered dress.

Generally, burial shrouds, wrappings, and burial linings can be suggested for many finds. Especially for a textile with extraordinarily thick threads (up to 1.6 cm) from burial A-342 of Kölked-Feketekapu, we must consider that the small child interred there might have been wrapped in a blanket together with the pellet bell (Pomberger et al. 2022b). A more secure finding derives from a textile on a pellet bell from burial 63 of Gyenes/Gyenesdiás, near Lake Balaton, which strongly suggests that the object was placed in a small bag or wrapped in a piece of fabric, which can be seen by the orientation of the threads, which are preserved all around the pellet bell (Pomberger et al. 2023). This emphasises the symbolic meaning of the pellet bell, at least in the context of a burial, since the sounding of the instrument would have been quite restricted when wrapped in fabric. It must be noted, though, that the wrapping of burial goods seems to be a general custom in this period.

Unfortunately, little is known about the clothing of the Avars, as no complete garments have been found due to the preservation conditions for textiles. Some literary evidence derives from (pseudo-)Maurikios' sixth/seventh-century Byzantine *Strategikon*, where Avar clothing is mentioned as wide-fitting tunics with wide sleeves of linen, goat's fur, or coarse fabric, which covered the knees while on horseback (Dennis and Gamillscheg 1981: 81). Although it must be noted that the author is describing clothing in military contexts, the description partially corresponds with the pictorial and textile archaeological evidence, though these are also sparse. For textile clothing, an antler object from Nosza (Serbia, seventh to ninth century) (Bugarski 2016: 86–88; Vida 2017: 93, Fig. 67.3) is most interesting, as it seems to depict two people with horses wearing a caftan, which covers most of the legs. As described above, archaeological textile finds also indicate a popular use of plant fibres (linen), though it is not always possible to determine if the fabric derives from clothing, and the frequently occurring folds could point to loosely fitting garments. Nevertheless, the information on the textiles and clothing (including the other accessories) can be used for visualisations and acoustic demonstrations of how the pellet bells might have been worn in reconstructions, which is useful for public communication of the research. Still, it must always be stressed that due to the lack of direct evidence, such reconstructions are speculative and involve a lot of interpretation. Three costumed dolls were recreated in order to physically visualise how the pellet bells might have been worn. The cuts of the clothing were based on the complete finds from the Moshchevaja Balka burials in the North Caucasus (Ierusalimskaja 1996: 33–58; 143–60; 307–16). These date to the eighth to ninth century and although they are associated with the Alanic period, they serve as a useful comparison for Avar textiles, as caftans – depicted on the Avar object from Nosza, as mentioned – were also worn by men and also because linen and tabby weaves were quite common. The other clothing components were based on typical Avar period finds: decorated men's belts, more simple women's belts, and bead necklaces. For the man and the woman, the pellet bells were hung from a string on the belt. The young child wears the bell on a band on its wrist. Figure

Figure 16: Avar costumes with pellet bells. Reconstruction: K. Saunderson. Photo: B.M. Pomberger.

16 shows dolls in Avar clothing that has been reconstructed based on the best evidence currently available, and wearing pellet bells.

4 Acoustics of metallic Idiophones

The spectral and temporal sound properties of (pellet) bells and other similar objects mainly depends on shape, size, material/alloy, wall thickness, and mode of excitation. In bells, a clapper hits the inner surface at the mouth/lip, creating approximately 5 to 12 single impulses per second when rung constantly. Inside the pellet bells an encapsulated stone or metal ball bounces against the inner surface, also creating single impulses, up to 50 per second. Bells produce a higher number and more pronounced partial frequencies, are louder and have a longer decay time than pellet bells, which gives the typical sound more tonal components and a clearer pitch, while pellet bells contain less partials, more noise components and hardly evoke any pitch perception. Neither sound is harmonic, however, multiple so-called *natural modes* (oscillations) create a variety of partial frequencies (Hall 1980: 158–62).

To gain an overview of all currently investigated idiophones, recordings of the following items were analysed: 14 pendants from the site Býčí skála cave, seven bells from Vindobona, 15 bells from

Ovilava, ten bells and two pellet bells from Savaria, six Avar pellet bells and two Roman-Avar bells from the Hungarian National Museum, Great Migration collection, eight Avar pellet bells and five Roman bells from the Slovak National Museum Bratislava, seven Avar pellet bells from the Danube Region Museum in Komárno and seven Avar pellet bells and seven Roman-Avar bells from the Wien Museum, in total 83 idiophones and 83 recordings.

4.1 Analysis of the sample

In this study, 83 recordings of metallic idiophones have been compared, consisting of bells (39), pellet bells (30), and other rattling pendants (14). All recordings were made inside of a mobile noise absorbing chamber, which was constructed for this project (Pomberger and Mühlhans 2022). For further low frequency noise reduction, a 500 Hz lowpass filter (Bessel, 5th order) was applied prior to analyses.

Sounds can be described physically and objectively, using acoustic parameters such as sound pressure level, amplitudes of partials, spectral shape/energy and the like, which were calculated using Audition and Praat for this study. Subjective descriptions mostly use contrasting pairs of adjectives like bright/dark, sharp/dull, simple/complex and the like. Psychoacoustics, being a part of psychophysics, seeks to find the connection between subjective impressions of a stimulus and its physical properties in order to model prediction parameters such as loudness, sharpness, roughness, tonality, brightness, and harmonicity (Fastl and Zwicker 2007), which were calculated using HEAD ArtemiS SUITE (HEAD acoustics GmbH 2022). JASP was used for statistical analyses of all known parameters.

4.2 Spectral and temporal features

In general, the objects from this sample produce partials roughly between 2 and 20 kHz, with only few exceptions reaching as low as 1 kHz. Figure 17a shows the spectra of all 39 bells, which are exclusively from the Roman period, Figure 17b shows the spectra of 30 pellet bells, almost exclusively from the Avar period. The bells clearly show more pronounced partials and higher amplitudes, but particularly more spectral energy in the frequency range above 5 kHz, rendering them brighter in perception. Both share a certain amount of spectral energy in the 2–4 kHz range, where the human ear is particularly sensitive, so they can be heard even at very low levels.

Figure 17a shows the temporal structure of an average Roman bell from the sample (Vindobona Cat. 23), with a decay time of about 300 ms, compared to Figure 17b with that of an average Avar pellet bell (Vindobona Cat. 35) at about 35 ms.[8]

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[8] Pomberger 2022.

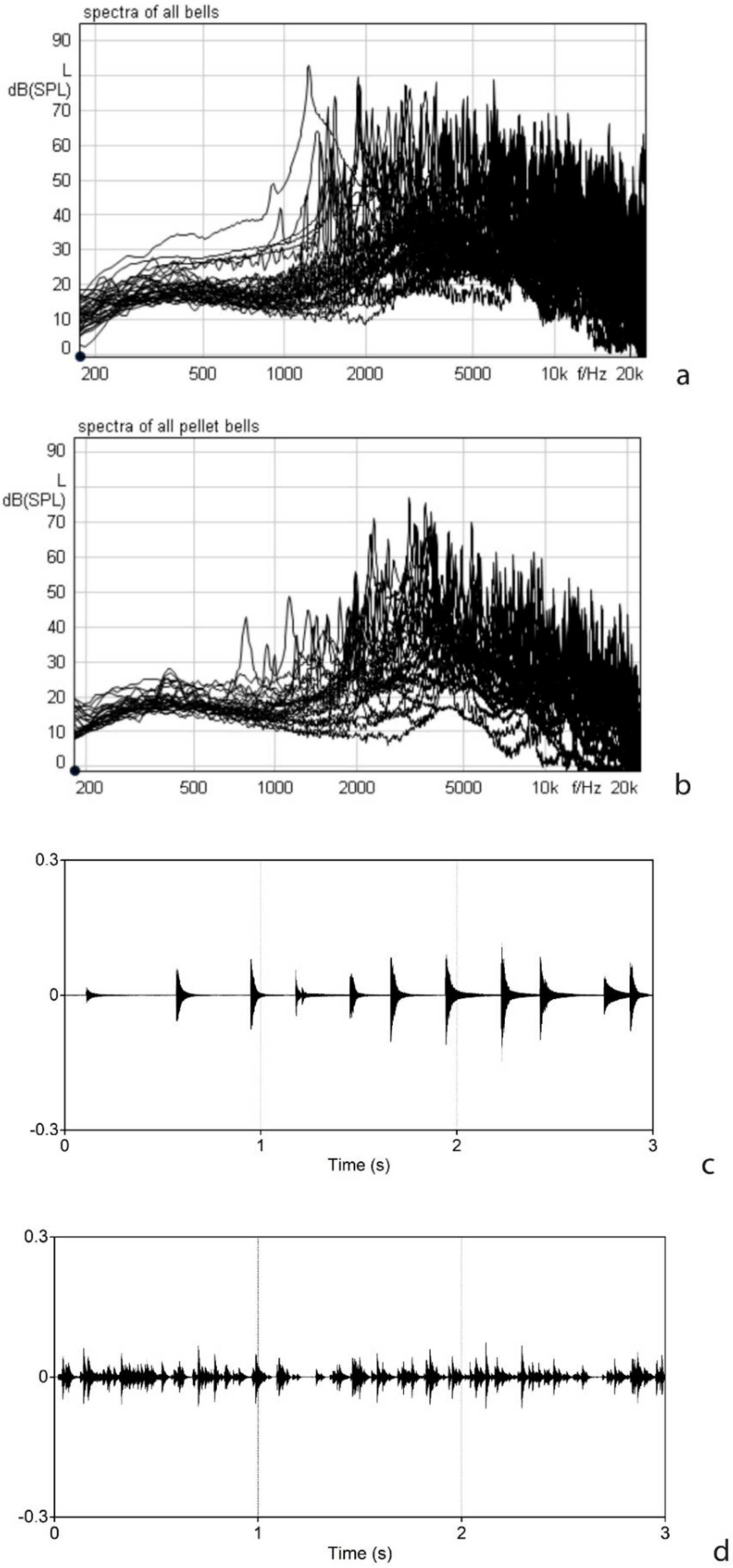

Figure 17: a: Spectra (4096, 85%, HAN) of all 39 bells from the sample;
b: Spectra (4096, 85%, HAN) of all 30 pellet bells from the sample;
c: Waveform of an average Roman bell (Vindobona Cat. 25);
d: Waveform of an average Avar pellet bell (Vindobona Cat. 35). Design: J. Mühlhans.

4.3 *Sound pressure level and loudness*

Loudness, measured in phon or sone (Fastl and Zwicker 2007: 203–5), is not to be confused with the level given in dB re p_0,[9] but instead depends on it, thus a correlation of r=0.95*** can be observed.[10] On average, bells are louder (73.5 dB, 23.5 sone, 83.5 phon) than pellet bells (69.1 dB, 18.8 sone, 80.5 phon), but with only a medium effect size[11] of about d=0.4*. Unsurprisingly, heavier/larger objects are also louder, with a correlation between weight and level of r=0.67***. Also, the amount of copper in the alloy (known for 45 objects) correlates with level/loudness at r=0.39**, which could also be observed in prior measurements, but with a too small sample.

4.4 *Sharpness, brightness, and roughness*

Sharpness is influenced by spectral shape and density and is inversely related to pleasantness (Fastl and Zwicker 2007: 239–40). Brightness is highly correlated with the spectral centroid (Schubert and Wolfe 2006). Roughness is a sensation evoked by the modulation of tonal components (Sottek 2009). All three parameters show large effects in a t-test between Roman bells and Avar pellet bells, with the former showing higher mean values for brightness (d=0.86***), but lower values for sharpness (d=-0.81***) and roughness (d=-0.75**). However, while both types can be classified as bright and sharp sounds, despite the group differences, they are not rough at all. Again, the amount of copper is highly correlated with sharpness (r=0.47***), but not at all with the remaining two parameters. Sharpness is also weakly correlated with level (r=0.47***) and loudness (r=0.37**).

4.5 *Impulsiveness and tonality*

Impulsiveness depends on the energy of the onsets in a sound which adds to the dynamic sensation in a stimulus (Sottek et al. 1995) and is calculated in the ArtemiS software in *impulsiveness units* (iu) using the Sottek Hearing Model. Tonality is calculated as the simple ratio between tonal and noise components in the signal in dB. The Roman bells are slightly more tonal (d=0.55*) with a mean value of 18.6 dB compared to 15.0 in the Avar pellet bells. In terms of impulsiveness, no difference between the groups can be seen, since more impulses per time unit also create less energy, which evens out the parameter between the types. Nevertheless, tonality is negatively correlated with impulsiveness itself at r=-0.52***. In this calculation, only a minor trend could be found for the amount of copper in the alloy for tonality r=0.23, p<.067.[12] Tonality is negatively correlated with roughness (r=-0.62***) and positively with impulsiveness (r=0.81***).

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[9] p_0 = 20 µPa (Micropascals) is the commonly used reference sound pressure.

[10] Here *r* describes the correlation coefficient that can range from 0 (no correlation at all) to positive 1 (strict linear correlation) or negative 1 (inverse linear correlation). The level of significance, which depends on the sample size, is often marked with asterisks, * for a p<.05, ** for p<.01 and *** for p<.001. The more asterisks, the higher the significance.

[11] The effect size between two means is expressed as *Cohen's d*, 0.2 = small, 0.5 = medium, and 0.8 = large effects.

[12] If a p-value is close to significance (in this case p<.05), it is sometimes referred to as a *trend* or *tendency* that could undergo further examination.

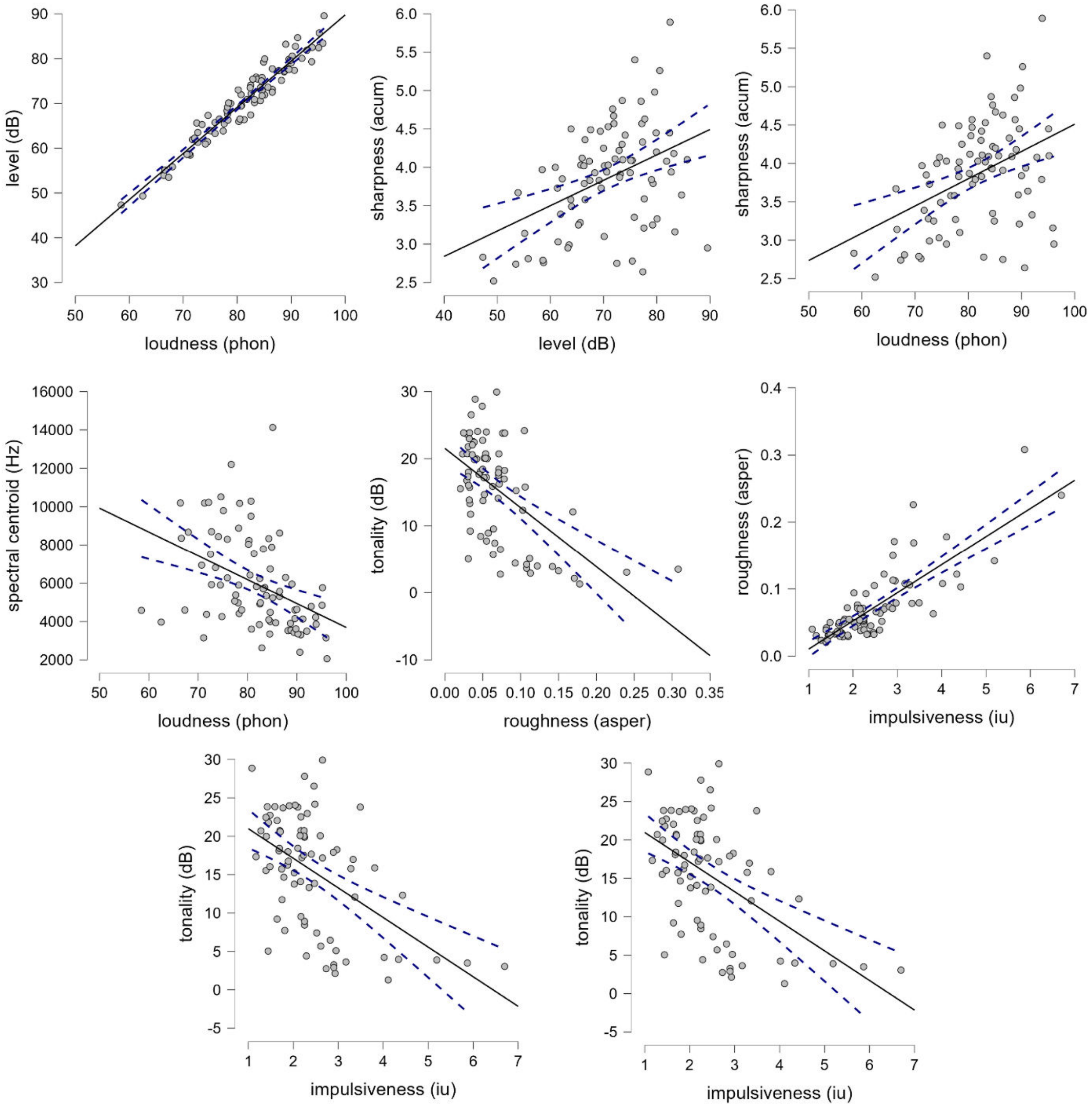


Figure 18: Scatterplots for the eight highly significant correlations between two parameters ($p<.001$) with 95% confidence interval (dashed blue line). Design: J. Mühlhans.

4.6 *Peak frequency and lowest partial*

The peak frequency is the strongest partial in amplitude over the measurement and is likely to influence pitch perception, which is not obvious from the spectral components (Benade 1976: 56). The lowest partial or *fundamental* in bells depends on thickness and diameter and is a result of the axial mode [2,0] (Fletcher and Rossing 1991: 578). Peak frequency is correlated with brightness (r=0.72***), but the lowest partial only shows very weak negative effects with loudness (r=-0.26*).

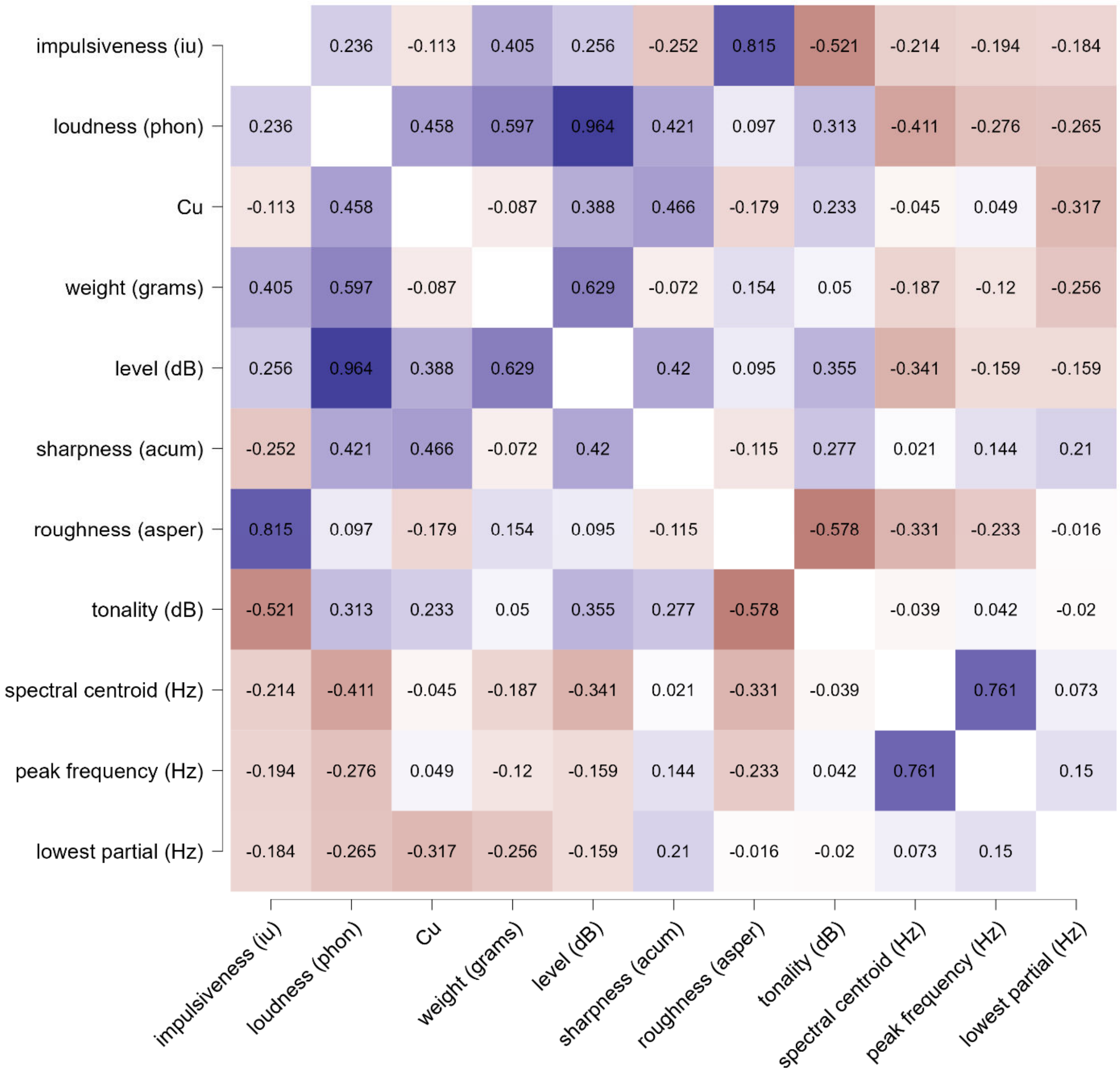
Variable		level (dB)	loudness (phon)	sharpness (acum)	roughness (asper)	tonality (dB)	impulsiveness (iu)	spectral centroid (Hz)	peak frequency (Hz)	lowest partial (Hz)	Cu
2. loudness (phon)	n	83	—								
	r	0.964 ***	—								
	p	< .001	—								
3. sharpness (acum)	n	83	83	—							
	r	0.420 ***	0.421 ***	—							
	p	< .001	< .001	—							
4. roughness (asper)	n	83	83	83	—						
	r	0.095	0.097	-0.115	—						
	p	0.394	0.384	0.301	—						
5. tonality (dB)	n	79	79	79	79	—					
	r	0.355 **	0.313 **	0.277 *	-0.578 ***	—					
	p	0.001	0.005	0.013	< .001	—					
6. impulsiveness (iu)	n	83	83	83	83	79	—				
	r	0.256 *	0.236 *	-0.252 *	0.815 ***	-0.521 ***	—				
	p	0.019	0.032	0.021	< .001	< .001	—				
7. spectral centroid (Hz)	n	83	83	83	83	79	83	—			
	r	-0.341 **	-0.411 ***	0.021	-0.331 **	-0.039	-0.214	—			
	p	0.002	< .001	0.852	0.002	0.733	0.053	—			
8. peak frequency (Hz)	n	83	83	83	83	79	83	83	—		
	r	-0.159	-0.276 *	0.144	-0.233 *	0.042	-0.194	0.761 ***	—		
	p	0.151	0.012	0.193	0.034	0.715	0.078	< .001	—		
9. lowest partial (Hz)	n	82	82	82	82	78	82	82	82	—	
	r	-0.159	-0.265 *	0.210	-0.016	-0.020	-0.184	0.073	0.150	—	
	p	0.153	0.016	0.059	0.884	0.859	0.099	0.515	0.177	—	
10. Cu	n	45	45	45	45	43	45	45	45	45	—
	r	0.388 **	0.458 **	0.466 **	-0.179	0.233	-0.113	-0.045	0.049	-0.317 *	—
	p	0.009	0.002	0.001	0.239	0.133	0.459	0.771	0.747	0.034	—

Table 4: Pearson's correlations for all calculated parameters with sample size (n), correlation coefficient (r) and significance (p). * p < .05, ** p < .01, *** p < .001.

The statistical calculations above are mainly a result of comparing only 69 objects from the sample for a direct comparison of Roman bells and (mostly) Avar pellet bells. Some statistical values change slightly when the 14 remaining objects from the Iron Age are considered, e.g., r-value from weight-loudness changes from 0.67*** to 0.62*** and roughness-impulsiveness from 0.81*** to 0.82***. Table 4 gives an overview of the correlations between all parameters for the entirety of the sample.

5 Conclusion/Discussion

Investigating metallic idiophones over a time span of 1600 years demonstrates their various uses and functions, their diversity of material and chemical compositions, and their influence on their



	impulsiveness (iu)	loudness (phon)	Cu	weight (grams)	level (dB)	sharpness (acum)	roughness (asper)	tonality (dB)	spectral centroid (Hz)	peak frequency (Hz)	lowest partial (Hz)
impulsiveness (iu)		0.236	-0.113	0.405	0.256	-0.252	0.815	-0.521	-0.214	-0.194	-0.184
loudness (phon)	0.236		0.458	0.597	0.964	0.421	0.097	0.313	-0.411	-0.276	-0.265
Cu	-0.113	0.458		-0.087	0.388	0.466	-0.179	0.233	-0.045	0.049	-0.317
weight (grams)	0.405	0.597	-0.087		0.629	-0.072	0.154	0.05	-0.187	-0.12	-0.256
level (dB)	0.256	0.964	0.388	0.629		0.42	0.095	0.355	-0.341	-0.159	-0.159
sharpness (acum)	-0.252	0.421	0.466	-0.072	0.42		-0.115	0.277	0.021	0.144	0.21
roughness (asper)	0.815	0.097	-0.179	0.154	0.095	-0.115		-0.578	-0.331	-0.233	-0.016
tonality (dB)	-0.521	0.313	0.233	0.05	0.355	0.277	-0.578		-0.039	0.042	-0.02
spectral centroid (Hz)	-0.214	-0.411	-0.045	-0.187	-0.341	0.021	-0.331	-0.039		0.761	0.073
peak frequency (Hz)	-0.194	-0.276	0.049	-0.12	-0.159	0.144	-0.233	0.042	0.761		0.15
lowest partial (Hz)	-0.184	-0.265	-0.317	-0.256	-0.159	0.21	-0.016	-0.02	0.073	0.15	

Table 5: Heatmap with Pearson's correlations of all calculated parameters, coefficients (r) shown as numbers, negative correlations marked in red, positive ones in blue. Design: J. Mühlhans.

acoustic surroundings. The fourteen pendants from the Býčí skála Cave, Hallstatt culture, very probably were sacrificial offerings of a woman. Cage shaped pendants (here the bobbles) have their origin in the regions of the Black Sea and the Caspian Sea. Bobbles and pellet bells imitating pomegranates or poppy seeds can be interpreted as symbols and amulets for fertility, luck, and abundance. Their material is bronze with some amounts of lead. The sounding jewellery is quite heavy and produces sounds/noises with frequencies between 1.3 kHz and 20 kHz. They are quite sharp, but not rough or loud and can be described as pleasant.

The Roman bells of Vindobona were cast from three different copper alloys and forged from iron sheets. The materials, types, and average sizes are very common in the Roman imperial period. Their analysed sounds are in the upper human auditory range, show more tonal components than noise character, and would be perceived as sharp but not rough. Bells are multifunctional sound objects that could serve many purposes. Their basic functions were as noise and signal objects, acoustically-perceived offensive weapons, perceived apotropaic protective sound shields, and, furthermore, objects of status and prestige. Ancient authors inform us about their use in daily life, revealing uses both profane and sacral. Given the range of uses, precise statements about a given bell's function is thus highly dependent on the context in which it was found. This means that bells in specific find contexts, for example, in graves, in connection with animal skeletons, or attached to chariots, allow for more precise statements than bells discovered in buildings, roads, or ditches.

During the Early Middle Ages (Avar period), bells seem to lose their important role. Only a few (of Roman origin) were found in burials. Pellet bells appear in the Carpathian base again in the middle of the seventh century and are similarly excavated in burials, mainly of children. They probably spread from the Black Sea region and the Caspian Sea back to Central Europe. Each object is unique and of different metallurgic quality. Shapes and ornaments are manifold. Pebbles, bronze balls, and lumps of cinder serve as rattle bodies. Textile fragments of various quality as well as their find positions in the graves demonstrate that they could have been worn on the body or placed in a small bag or wrapping. Some horse bridles might have been decorated with pellet bells. They are made from various copper alloys and iron. Their sounds are rather high, with partials located between 1 kHz and 20 kHz. They would thus be perceived as sharp but not rough. We do not know for certain if the Avar people really believed that pellet bells served an apotropaic purpose, as has been suggested in many publications, or whether other imaginations and ideas lay behind their inclusion in burial contexts. In any case, it is strange that they appear in such conspicuously small numbers.

This article examined a total of 83 objects (83 recordings) for a variety of (psycho-)acoustic parameters. 39 bells stemming exclusively from the Roman period were compared to 30 pellet bells mainly from the Avar period. These two groups showed the greatest differences in the acoustic parameters. 14 Iron Age objects consisting of other types of metallic idiophones were also calculated in to provide context for the overall correlations. The results were as follows: Roman bells consistently ranked higher in weight, level/loudness, tonality, brightness, and peak frequency. The Avar pellet bells ranked higher in the amount of copper in the alloy, sharpness, and roughness. Other parameters, such as impulsiveness and lowest partial frequency, were approximately similar between the two groups. In statistically precise terms, large effect sizes could be observed between the groups in terms of weight, sharpness, roughness, and brightness, with a Cohen's d>0.75. Medium and therefore less significant effects could be seen in level and tonality with a Cohen's d>0.5. Other differences were either small in effect size or not significant in the t-test. Since the corpus of parameters in the project grew larger with time, an exploratory factor analysis was done to determine if the complexity of data could be reduced. The results were positive but mixed. If only bells and pellet bells are calculated, reducing the single parameters to two factors can cumulatively explain about 55% of the variance. Adding a third factor explains up to 67%. This is still not satisfying, and indicates that many parameters have a high value in uniqueness and thus are needed for a detailed understanding of the differences among the tested metallic idiophones.

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Some Notes on Woodwind Instruments in al-Fārābī's *Kitāb al-Mūsīqī al-kabīr*

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Abstract

Al-Fārābī (d. 950 CE), the so-called 'Second Master' (Aristotle being the First Master), is known for his influential works on philosophy, especially his commentaries on Aristotle, as well as for his works on logic, physics and metaphysics, ethics, and politics. It was on behalf of al-Karḫī, Caliph ar-Rāḍī's (r. 934–940 CE) *wazīr*, that al-Fārābī wrote his *Grand Book on Music*, explaining musical concepts such as rhythm and melody to the *wazīr*. As a logician and practicing musician, he combined and improved upon different sources, such as Greek musical theory, as well as on the Arabic authors and musicians al-Kindī (d. after 870 CE) and Isḥāq al-Mawṣilī (d. 850 CE).

In this paper, I discuss several issues related to woodwind instruments mentioned in al-Fārābī's *Grand Book on Music*. Al-Fārābī expounds on their interconnections with the tonal production of other instruments, specifying their tone system in terms of finger positions on the fretboard of the ʿ*ūd*.

Further questions address the relation between theory and practice, as well as some considerations about the modes that seem to be common on woodwinds.

Keywords

Arabic music theory – Al-Fārābī – Woodwinds – Mediaeval music

Al-Fārābī, the exceptional Muslim scholar known to the Latin Middle Ages as Alfarabius or Avennasser, used to be referred to in the Islamic world simply as the 'Second Master', the first being Aristotle, whose writings are the primary basis of al-Fārābī's vast work.

Born around 257 AH/870 CE, Abū Naṣr Muḥammad b. Muḥammad b. Ṭarḫān al-Fārābī died in Damascus in the year 339 AH/950 CE. According to his *nisba*, or attribution, he or at least his family originated from Khurasan or Transoxania – both regions included settlements called by the name of al-Fārāb. Little is known about his life. In his youth, he moved to Baghdad, and then in 331 AH/943 CE on to Syria, a keystone region for the transmission of Greek literature to the Arabic-writing community.[1] His supremely influential philosophical works comprise original writings and commentaries on Aristotle's books on logic, physics and metaphysics, ethics, and politics. Introduced to philosophy primarily by the Christian Yuḥannā b. Ḥaylān, al-Fārābī also seems to have had contact with the school of Christian Aristotelians in Baghdad, especially with the famous translator Abū Bišr Mattā b. Yūnus (d. 329 AH/940 CE).[2] Since music was an integral part of the canon of knowledge known as the quadrivium, it was natural that al-Fārābī would write about music theory as well, all the more so because he may have been a practising musician himself.[3]

His *Grand Book on Music* (*Kitāb al-Mūsīqī al-kabīr*) was composed on behalf of al-Karḫī, Caliph ar-Rāḍī's (r. 297–322 AH/934–940 CE) *wazīr*, to whom he explains musical concepts ranging from the basics of harmonic theory up to questions of rhythm and melodic composition.[4] The only existing full translation of the book into a European language was published in French by Rodolphe d'Erlanger between 1930 and 1935, notably before the Arabic text had even been edited for the first time. More recently, George Dimitri Sawa translated the two chapters about rhythm, while Alison Laywine is currently preparing an English translation of the entire work.[5]

Apart from the *Grand Book*, seven other works by al-Fārābī are known to have dealt with music. Only three of these, however, seem to have survived, including a short chapter in the *Iḥsāʾ al-ʿulūm* ("Classification of the sciences"), which was known in Latin translation in Europe, the *Kitāb al-Īqāʿāt* ("Book on rhythms") and the *Kitāb Iḥsāʾ al-Īqāʿāt* ("Book for the basic comprehension of rhythms"). The latter have both been translated into English by Sawa and into German by Eckhard Neubauer, together with editions of the texts.[6] None of these texts comes anywhere close to the comprehensiveness of the *Kitāb al-Mūsīqī al-kabīr* and its richness of sources regarding harmonic theory and melody. In contrast, al-Fārābī's two other works on rhythm are crucial for understanding his conception of rhythm, being revisions of the comparatively opaque explanations in the corresponding chapters of the *Grand Book*.[7]

Al-Kindī (d. after 870) had already used Greek sources to some extent, but it was not until al-Fārābī's times that a greater number of Greek works bearing on music – such as Aristotle's *De anima*, works by Aristoxenus, Euclid, Nicomachus and Ptolemy – had been translated into Arabic.

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[1] Janos 2015; Druart 2016.

[2] Janos 2015 mentions Abū Bišr as "possibly" one who "shaped" al-Fārābī's philosophical thought. For al-Fārābī's connection to the Greek Philosophical School of Alexandria, cf. Vallat 2004; Watt 2008; cf. also Lameer 1997; Endreß 2003; D'Ancona 2017.

[3] Sawa 2015a.

[4] Sawa 2015a.

[5] Druart 2016.

[6] Sawa 2015a.

[7] Cf. Sawa 2009.

Al-Fārābī combined different sources and improved on them. For example, he drew on Greek musical theory as well as on the Arabic authors and musicians al-Kindī, Isḥāq al-Mawṣilī[8] (d. 850) and Ibn al-Munağğim[9] (d. 913). Al-Fārābī's double approach of scientific description and evaluation, as well as of considerations concerning musical practice, make his book a veritable treasure trove of Arabic music theory.

An important part of this treasure is formed by the chapter on musical instruments. Although its section on the *ʿūd* is naturally the biggest, due to the importance of this instrument as the model for displaying harmonic structures, al-Fārābī also pays considerable attention to woodwinds.

Here this investigation will concern itself with the scales and tonal range of these instruments. How does he describe the notes they play? Does he refer to different sizes of instruments with different ranges? Does he differentiate between notes in different octaves? Between modes? Pursuing these questions will also put us in a better position to assess al-Fārābī's understanding of the relationship between theory and practice. Neubauer's[10] and especially Sawa's[11] works on rhythm have opened an important field of music theory. With this article on tonal material of musical instruments and al-Fārābī's attempts to transfer the lute-based pitches to the fingerholes of the woodwind instruments, I hope to further our understanding of the *Kitāb al-Mūsīqī al-kabīr* in its entire musicological context, filling in another lacuna in the development of Arabic music theory.

After reflecting on theoretical issues and various ratios, al-Fārābī starts his chapter on woodwinds by detailing the general conditions that would affect the pitches of these instruments. Subsequently, he presents four different woodwind instruments of his time, specifying their respective pitch ranges: these instruments are the *mizmār muzdawiğ murakkab* (Arabic: "composite double *mizmār*"), the "most common *mizmār*", the *surnāy* (Persian: "festive flute"), and the *mizmār muzāwağ* (Arabic: "paired *mizmār*"), which is also known as *mizmār muṯannā* (Arabic: "doubled *mizmār*") or *dūnāy* (Persian: "two flutes").

The first of these instruments, the *mizmār muzdawiğ murakkab*, consists of two pipes that are connected to a third, into which the player blows. From the central pipe two or more connections lead to the left and right pipes. Al-Fārābī states that it is difficult to predict the precise pitches because it would be impossible to determine the proportions of air going into the different pipes. Therefore, he says, the ratios of the notes at the bridges do not always correspond to the ratios that one might predict on the basis of the fingerhole positions. Consequently, these instruments were built according to the makers' experience and the model of existing pipes. From al-Fārābī's description of the *surnāy*, where he stresses the pipes' conical nature, we may guess that the pipes of this instrument were mostly cylindrical, although he does not expressly state this.

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[8] Cf. al-Fārābī, *K. al-Mūsīqī al-kabīr*, 58 Ḫašaba.

[9] Cf. al-Fārābī, *K. al-Mūsīqī al-kabīr*, 102 Ḫašaba.

[10] Neubauer 1968–9; Neubauer 1994.

[11] Sawa 2009; Sawa 1989: 35–70.

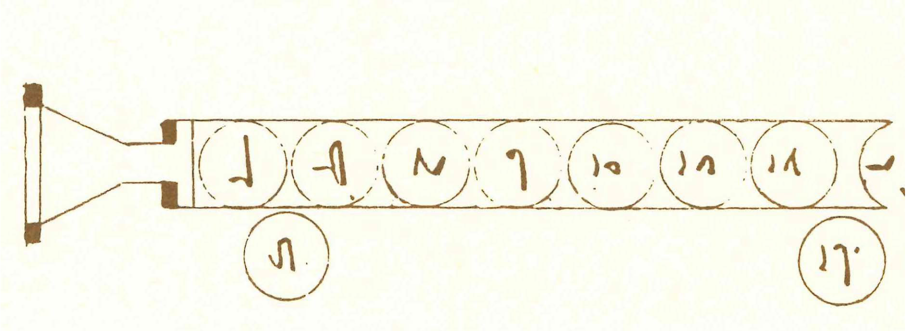

Figure 1: Sketch of the "most common *mizmār*", including its mouthpiece, Ms. Istanbul, Köprülü, 953, facs. ed., 296 (courtesy of Eckhard Neubauer).

Al-Fārābī does not detail the nature of the mouthpieces of any woodwind instrument. However, all six extant manuscripts[12] include drawings of the *mizmār muzdawiǧ murakkab*, the "most common *mizmār*" and the *mizmār muzāwaǧ* (but not the *surnāy*), which show trapezoid mouthpieces. The drawings of Ms. 953, Köprülü (Istanbul) pp. 294, 296, 303, which represent these with protecting caps on their ends, especially suggest a double-reed. On the other hand, these drawings, although doubtless deriving from a common archetype, may not go back to the author's autograph. There is therefore a chance that they derive from some copyist's contemporary understanding that does not necessarily reflect what al-Fārābī had in mind. Similarly, the trapezoidal shape might also have spread from one illustration to others by mistaken generalisation. Other 'wrong' details, such as hugely oversized fingerholes, shed further doubt on the accuracy of the extant copies, not to mention serious problems with the representation of a double reed on the *mizmār muzdawiǧ murakkab* – a topic we cannot further pursue here.

The second instrument is what al-Fārābī calls the "most common *mizmār*", whose notes correspond to the ones on the *ʿūd*. Its single pipe must also have been cylindrical, both externally and internally. It has seven finger holes of similar diameter aligned on the upside, one thumbhole on the back, and one additional lateral hole close to the lower end. In his discussion, al-Fārābī identifies the individual holes by assigning letters of the traditional *abǧad* alphabet to them. In this way, the finger holes are labelled with ascending pitch as **Ǧ**, **D**, **H**, **Z**, **Ḥ**, **Ṭ**, **Y**, the alphabetical series being continued with **K** for the thumb hole. The initial **A** is reserved for the end of the bore at the bottom of the pipe; accordingly, **B** is assigned to the hole between **A** and **Ǧ**.

The next instrument is the *surnāy*, variants of which appear still to be played in Turkey (*zurna*), in the Balkans, in Iran, India and elsewhere, all equipped with double reeds. Al-Fārābī describes this instrument as having a conical corpus, which confirms the assumption of not only linguistic, but genuine organological continuity with modern zurna-type instruments. Its side holes are once more associated with letters. Eight are aligned on the upside (from the highest hole downwards: **A**, **B**, **Ǧ**, **D**, **H**, **Z**, **Ḥ**, **Ṭ**), supplemented by one on the left (**N**) and one on the right hand (**M**) close to

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[12] Ms. 953, Köprülü (Istanbul): 294, 296, 303; Ms. 876, Rağıp Paşa (Istanbul): ff. 118v, 120r, 122r; Ms. or. 651 (Leiden): ff. 77v, 78r, 81r; Ms. res. 241 (Madrid): 116, 117, 122; Ms. C 40 inf. (Ambrosiana): ff. 126r, 127v, 130v.; Ms. 220b, Garrett (Princeton): ff. 65r, 66r, no image of the *mizmār muzāwaǧ*.

the exit. Once more, the thumbhole (**K**) comes last in the alphabetic series, preceded by the exit of the main bore at the bottom of the instrument (**Y**). As for the pitch of this instrument, al-Fārābī states that it is an octave above that of the others.

Finally, another double instrument is presented: the *mizmār muzāwaǧ*, for which the author also gives the alternative names of *mizmār muṯannā* and *dūnāy*. The illustration in the manuscript Ms. 953, Köprülü (Istanbul) 303, suggests that it consisted of two double-reed pipes, like the *aulos* of antiquity. However, we should probably not rule out the possibility that they may in fact have rather been single-reed instruments, similar to reedpipes still found in Egypt, North Africa, and the Levant under the names such as *miǧwiz* or *zummāra*. On the other hand, in contrast to the tubes of the *mizmār muzāwaǧ*, those of the modern instruments either play in unison, pairs of matching holes being operated by a single finger positioned across the entire instrument, or, in the case of the modern *arġūl*, consist of one drone pipe and one melody pipe. In any case, al-Fārābī does not clarify the nature of this instrument's mouthpiece in the text any more than those of the other instruments.

In contrast to the first of the four woodwinds, its two tubes are only tied together in parallel or at an acute angle, meaning that there are no internal connections between them, and the player must blow into both at the same time. When naming the holes by means of the *abǧad* alphabet, al-Fārābī remains once more reticent about the absolute or relative placing of the holes, so the drawings of the Köprülü manuscript with their huge holes do not reflect anything that is said in the text. The *mizmār muzāwaǧ* has no thumbholes, but four and five holes respectively on the upper side. Al-Fārābī describes them as follows: the bores at the end of the tubes are called **A** and **B**, tube **A** has five holes, labelled, from **A** upwards, as **Ǧ**, **D**, **H**, **Z**, and **Ḥ**, and tube **B** has only four holes, from **B** upwards, **L**, **K**, **Y** and **Ṭ**.

Considering the labelling of the holes on the three instruments, to the holes of which labels are attached at all, the variety is striking. The *abǧad* starts like this: **A**, **B**, **Ǧ**, **D**, **H**, **W** (which al-Fārābī always omits), **Z**, **Ḥ**, **Ṭ**, **Y**, **K**, **L**, **M**, **N**... For the "most common *mizmār*", this series starts from the lowest pitch. The opposite is true for the *surnāy*, where a descending series starts from the letter **A** for the finger hole next to the mouthpiece, while the last letters **K**, **M** and **N** are assigned to the additional holes. The labelling of the *mizmār muzāwaǧ* is more complex: the tubes are named **A** and **B**, but otherwise, the tube of **A** is labelled upwards, that of **B** downwards. Evidently, the letters merely follow his line of reasoning in the text.

But how does al-Fārābī refer to available notes? Given his intimacy with ancient Greek music theory, one might expect to find the Greek terms of the Greater Perfect System, or a loan translation, perhaps including a description of the intervals between the individual notes. Indeed, he equates the Greek designations with the Arabic *abǧad* earlier in his book, when regarding the theoretical basis of music theory.[13]

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[13] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 506 Ḫašaba.

أ	A	lowest-pitched open string: *bamm*
ب	B	(two *leîmmata* (*baqiyyatān*) or half a tone (*niṣf ṭanīnī*) lower than the index finger on the *bamm*), omitted in Figure 2 for reasons explained in the text
ج	Ǧ	index finger on the *bamm*
د	D	Zalzalian middle finger on the *bamm*
ه	H	third highest open string (*maṯlaṯ*)
ز	Z	index finger on the *maṯlaṯ*
ح	Ḥ	Zalzalian middle finger on the *maṯlaṯ*
ط	Ṭ	second highest open string (*maṯnā*) or little finger on the *maṯlaṯ*
ك	K	above (*muğannab*) the index finger of the *maṯnā*
ي	Y	index finger on the *maṯnā*

Table 1: Pitches played on the “most common *mizmār*”

However, in describing existing musical instruments, al-Fārābī chooses a different method. Further exploring a path that had been laid out by earlier theorists, he uses finger positions on the fretboard of the *ʿūd* to specify both relative pitches and range of the woodwinds. Like many modern lutes, the Early Islamic lute was tuned in fourths,[14] as we already know from al-Kindī’s description, which predates al-Fārābī. The same author also details fret positions, all derived from a framework of pure fifths and fourths. So the index finger fret plays a note a whole tone above the open string (9/8), the middle finger fret a minor third (32/27), the ring finger fret a major third (81/64), and the small finger fret a fourth (4/3), coinciding in pitch with the next higher open string.[15] In the passage under scrutiny, al-Fārābī also stresses several times that the position of the small finger is equal to the next open string, which offers further evidence that his strings are still tuned in fourths. For the instrument called *mizmār muzdawiğ murakkab*, al-Fārābī cannot give any note equivalents in terms of finger positions, but he does do so for the other three.

Here the focus will be on only two of these instruments : the “most common *mizmār*” and the *mizmār muzāwağ*, the first giving an example of how al-Fārābī specifies pitches, and the second illustrating al-Fārābī’s use of elements of Greek music theory.

1 The “most common *mizmār*”

Al-Fārābī warns the reader that one cannot predict the pitches of the “most common *mizmār*” on the basis of its physical properties, in the ways he had described in the opening paragraphs of his section on woodwinds. While the instruments would thus not play the desired scales straightforwardly, because of unavoidable imprecisions of construction, the required notes are nevertheless elicited by the players by careful manipulation (e.g., by means of embouchure?). Being interested in the musical uses of the instruments, al-Fārābī details the pitches actually played, providing their equivalents on the *ʿūd*, as indicated in Table 1, Figure 2, and Figure 3. Instead of the diatonic middle-finger fret described above, al-Fārābī here refers to an alternative fret position, the “Zalzalian

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[14] Söhne 1994: 366; cf. Neubauer 1993.

[15] Söhne 1994: 365.

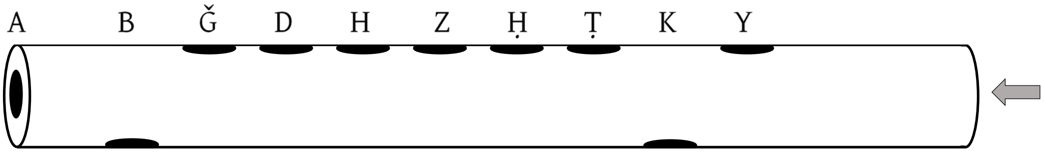


Figure 2: The "most common *mizmār*". The exit end of the pipe, sounding the bass note, is on the left.

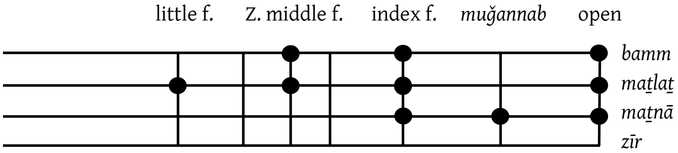
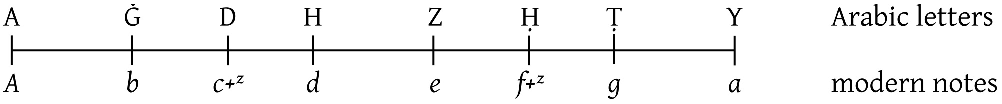
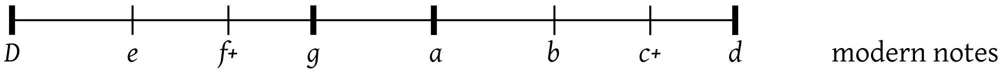


Figure 3: The equivalents of the notes of the "most common *mizmār*" as fret positions on the *ʿūd*

middle finger". Earlier, he had defined this position as lying halfway between the ring-finger fret and the "Persian middle-finger fret". The latter in turn sits halfway between the index and ring finger frets. [16] As a result, the Zalzalian fret creates a neutral third with its open string (and with the index fret on the next higher string).[17] In terms of intervals, al-Fārābī therefore describes a scale of tone, three-quartertone interval, another three-quartertone interval, tone, three-quartertone interval, another three-quartertone interval, tone – if we omit the somewhat strange pitches of **B** and **K** for the moment:



The scale thus includes what later theory describes as tetrachords of the *rāst* type. Currently, a *rāst* octave scale is usually conceptualised as comprising, in rising direction, two disjunct 'tetrachords' (*aǧnās*, Sg. *ǧins*), each consisting of a tone, a three-quartertone interval, and another three-quartertone interval:



In terms of Greek music theory, in contrast, nominal tetrachords always have their smaller intervals at the lower end. On this basis, the same scale cannot be described as an octave falling nicely within tetrachord boundaries; instead, the highest interval of the higher tetrachord would appear transferred to the lower end of the octave (resulting in a 'Phrygian' octave species):

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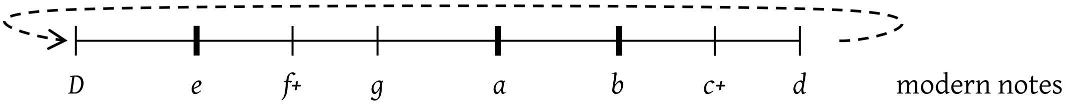
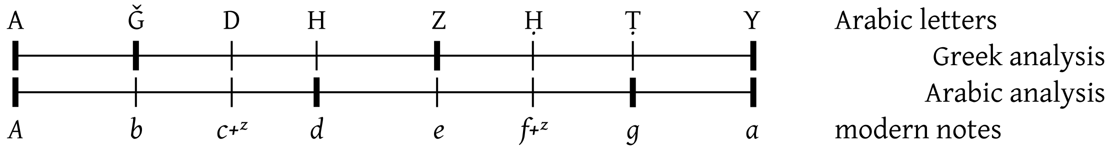
[16] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 511 Ḫašaba.

[17] Ideally, the third below calculates as 354.5 cents (27:22), slightly more than an equally tempered neutral third of 350 cents. Conversely, the third above would amount to 347.4 cents (11:9).



Al-Fārābī's *rāst*-like octave, however, is of a different composition, so that it happens to fit well within both the Greek and the later Arabic paradigm. In the Greek view, two conjunct tetrachords (such as *hýpaton* and *méson*), each consisting of two three-quartertone intervals followed by a tone are complemented by a tone beneath (*proslambanómenos*),[18] in the shape of a 'Hypodorian' octave species. The 'Arabic' analysis, in contrast, would posit two conjunct tetrachords that have their whole tones at their lower ends, below the additional tone:



Regarding the second note (**B**) and the seventh note (**K**), at first glance they seem to be what al-Fārābī describes as alteration of the index finger on the *ʿūd*. As such they might serve as an embellishment called *tabdīl* ('replacement'). Sawa translates al-Fārābī's explanation of *tabdīl*[19] as follows:

> "(a) Those [ornamental notes] which replace some of the fundamental notes are, in order of preference, the octave, then the fifth, and the octave + fifth, then sometimes the fourth; (b) then the neighbouring notes which are mixed in a group such as [a note produced] by the anteriors to the index finger to replace the index finger; (c) the most successful replacements are those which occur in the middle of a piece." (Sawa 1989: 97)

Our concern here is the second type of *tabdīl* (b), the replacement of fundamental notes by means of their neighbouring notes. This may be what the scale of the "most common *mizmār*" tells us: Instead of the index finger, one of its *muǧannab* (neighbouring) positions is used, but only at the beginning of the scale (**B**) and at the end (**K**). In the middle (**Z**) the fifth stays unaltered. As the linking point between the two tetrachords, it seems that it must not lose its function by means of alteration. But this applies only if the use of eight fingers plus one thumb to grasp all the finger holes is assumed.

But this is exactly the crux of the problem: al-Fārābī describes the position of note **B** as "between [the end of the bore at the bottom of the pipe (**A**)] and the holes on the back of the instrument",[20] so – like the thumb hole **K** – opposite of the other finger holes. This means, unless the player uses his knee, **B** cannot be fingered! Al-Fārābī has only temporarily stated that the note sounding from hole **B** is heard either two *leîmmata* (*baqiyyatān*) or half a tone (*niṣf ṭanīnī*) lower than the index finger on the *bamm*. Later, however, he writes verbosely about **B** as a kind of overflow hole that regulates the air supply by redirecting the surplus of air not needed for the pitch of

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[18] Cf. Hagel 2018: 452–53.

[19] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 1060–61 Ḫašaba.

[20] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 781 Ḫašaba.

note **A**. Only by reducing the air coming out of hole **A** by means of hole **B**, can note **A** be heard as the fundamental note, namely as the equivalent of the open *bamm*. This means that hole **B** stays open most of the time, “unless in case of exception or *tašbīʿ*”,[21] the latter being a kind of embellishment of the melody.[22] This is a strange claim, however, since the hole is not accessible to any finger. At the end of the corresponding paragraph, al-Fārābī adds that some *mazāmīr* do not need the additional hole **B** because there is no air surplus. This statement can be taken as a hint to the construction of the instrument. If it is well planned, no additional hole **B** will be needed. Otherwise, hole **B** is apparently required for adjusting the tuning, curtailing the air column of the deepest note (and not for any embellishment).

أ	A	open *bamm*
ب	B	tuning adjustment, therefore omitted in Figure 4
ج	Ğ	index finger on the *bamm*
د	D	Zalzalian middle finger on the *bamm*?
ه	H	ring finger on the *bamm*
ز	Z	open *maṯlaṯ*
ح	Ḥ	index finger on the *maṯlaṯ*
ط	Ṭ	little finger on the *maṯlaṯ* or the open *maṯnā*
ك	K	above (*muǧannab*) the index finger of the *maṯnā*
ي	Y	index finger on the *maṯnā*

Table 2: First alternative scale of the “most common *mizmār*”

Al-Fārābī also offers two alternative tunings, the first of which utilises both the Zalzalian middle finger and the ring finger (a major third above the respective open string), which is rather unusual, since middle-finger and ring-finger notes of the same string are normally mutually exclusive (Table 2 and Figure 4).

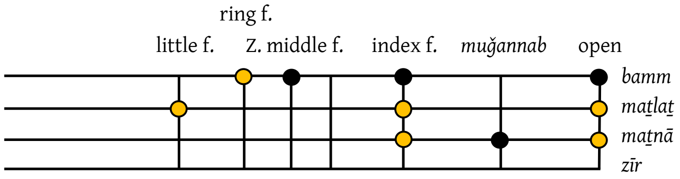
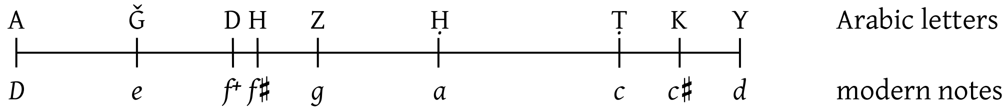


Figure 4: First alternative scale of the “most common *mizmār*” as fret positions on the fretboard of the *ʿūd*. The changes indicated by al-Fārābī are coloured.

Leaving aside the original positions, the alternative notes by themselves form the intervals of a semi-tone, a tone, a minor third, and a tone. This scale does not make much musical sense in terms of either Arabic or Greek music theory. When we supply the unchanged notes of the original scale, the scale looks like this:



In fact al-Fārābī explains that usually *mizmār* players do not use the note of the middle finger position on the *ʿūd* together with that of the ring finger on the *ʿūd*.[23] This restriction to one mode within a composition is known, for example, in Ibn al-Munaǧǧim’s (d. 913) *Kitāb an-Naġam*,[24] who,

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[21] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 786–787 Ḫašaba.

[22] Sawa 2015b: 225–26.

[23] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 784 Ḫašaba.

[24] Wright 1966: 28–29; Neubauer 1995–6: 266–67; 310–13.

أ	A	open *bamm*
ب	B	actually for tuning adjustment, therefore omitted in Figure 5
ج	Ǧ	index finger on the *bamm*
د	D	ring finger on the *bamm*
ه	H	little finger on the *bamm*
ز	Z	index finger on the *maṯlaṯ*
ح	Ḥ	ring finger on the *maṯlaṯ*
ط	Ṭ	open *maṯnā*
ك	K	above (*muǧannab*) the index finger of the *maṯnā*
ي	Y	index finger on the *maṯnā*

Table 3: Second alternative scale on the "most common *mizmār*"

however, asserts that there are also songs using eight, nine or ten notes, i.e., obviously transcending a single mode.[25] Accordingly, the first tetrachord beginning from the open *bamm* may be diatonic with a Zalzalian middle finger or a ring finger (major third above open string). The second tetrachord is striking in that it features neither. This cannot be a lacuna in the manuscripts, particularly as there is no gap in the assignment of the notes to the letters of the *abǧad* alphabet.[26] Rather, there may be a hint as to musical practice here. By means of changes in lip tension the embouchure can be affected, so that the resulting pitch is raised or flattened.[27] In this case it would be possible to play a tetrachord of today's *ḥiǧāz*, consisting of a semi-tone, a three semi-tone interval (using the *muǧannab*-position of the thumbhole **K**), and a semitone, or a diatonic 'tetrachord' with a minor third above the open string.[28]

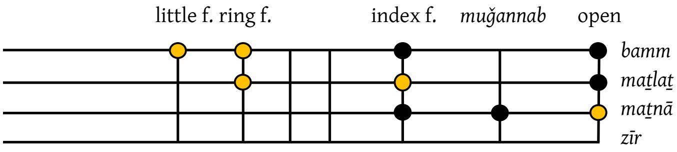

Figure 5: Second alternative scale of the "most common *mizmār*" as fret positions on the fretboard of the *ʿūd*. The changes indicated by al-Fārābī are coloured.

On the other hand, pitch manipulation by means of embouchure is possible for every note, so there is no need to have two different thirds that are as close to each other as are the Zalzalian middle finger and the ring finger in the first tetrachord. Another problem arises regarding instrument making: Is it possible to drill the two holes for these two notes sufficiently close to each other? Therefore, a textual corruption or perhaps a mistake by al-Fārābī is more probable.

Al-Fārābī's other alternative scale of the "most common *mizmār*" (Table 3 and Figure 5) features major thirds above the open strings; today one would describe it as comprising two conjunct tetrachords with an additional tone at the top (which is internally divided by the thumb hole,

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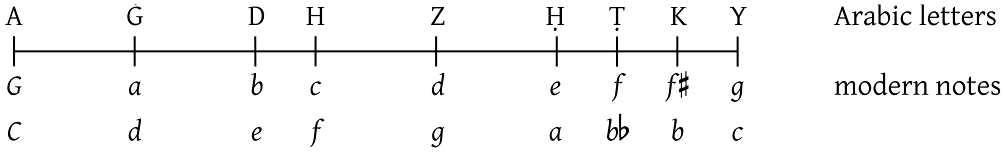
[25] Ibn al-Munaǧǧim, *Kitāb an-Naġam*, transl. by Neubauer 1995–6: 313–15. In his *Kitāb al-Aġānī*, 8.373–75 (= 8.25–27 Būlāq 1285), al-Iṣfahānī (d. 35 AH6/967 CE) gives examples for sophisticated composers who also used eight, nine, or ten notes, either by using the middle and ring finger notes in chromatic succession, allegedly with aesthetically questionable results, or by using these fingers in separate sections of the composition; cf. also 9.43–44; 59–61, 344–45 (= 8.46, 54, 197 Būlāq 1285) "*ḏikru l-aṣwāti llatī taǧmaʿu n-naġama l-ʿašar*" ("songs containing ten notes"). My thanks go to one of my reviewers for making me aware of this.

[26] All six manuscripts I was able to collate are unanimous in this respect: Ms. Istanbul, Köprülü, 953, facs. ed.: 298; Ms. Leiden, or. 651: f. 78b; Ms. Madrid, Res. 241: f. 66a; Ms. Princeton, Garrett, 1984: f. 90a; Ms. Mailand, Ambrosiana, C 40 inf.: ff. 127b–128a; Ms. Istanbul, Rağıp Paşa 876: ff. 120a–120b.

[27] Ibn Zayla, *al-Kāfī fī l-mūsīqī*, 78 Yūsuf, and al-Ḥasan al-Kātib, *Kitāb Kamāl adab al-ġināʾ*, 135 al-Ḥifnī (transl. in Shiloah 1964: 189), describe two ways of achieving notes falling in between the existing finger holes: by changing the blowing pressure, or by resorting to half opening the next higher finger hole.

[28] I do not dare claim that a major third can be achieved by change of lip tension without the possibility of empirical evidence.

which appears to provide a modulating note). These tetrachords consist, in ascending direction, of a tone, a tone, and a semitone; a structure that is nowadays known as *ǧins al-ʿaǧam*.[29] In terms of ancient Greek theory, this is simply a diatonic octave, though the tetrachord boundaries would once more be analysed quite differently.



2 The *mizmār muzāwaǧ*

Regarding the *mizmār muzāwaǧ* al-Fārābī again first names the holes of the two tubes, and then discusses the equivalent notes on the *ʿūd*. Here the octaves are interesting because al-Fārābī uses two different expressions when describing them.

> Both of the notes **B** and **Ḥ** of these *mazāmīr* form an octave (*bi-l-kull*). If we equate (*ǧaʿalnā... musāwiyan*) the *tamdīd* of note **B** (*tamdīd naġmat* **B**) with the *tamdīd* of the note of the open *maṯlaṯ*, or if we equate it *bi-l-quwwa* with the note of the open *maṯlaṯ*, then note **Ḥ** is the [note of the] index finger on the *zīr*.
>
> If we let note **B** correspond to (*sāwaqnā... bi...*) the note of the open *bamm*, note **Ḥ** is [the note] of the index finger on the *maṯnā*, and in general (*wa-bi-l-ǧumla*), if we let note **B** correspond to any note of any instrument, either by means of equation of *tamdīd* or *bi-l-quwwa*, then note **Ḥ** becomes equal to the upper octave (*musāwiyatan li-ṣiyāḥ*) of that note of that instrument. (al-Fārābī, *Kitāb al-Mūsīqī al-kabīr*, 796 Ḫašaba)

This text passage is striking because al-Fārābī uses a pair of terms here that are not immediately intelligible. The Arabic *tamdīd* is the *nomen verbi* of the verb *maddada* (II form), which means "to extend, to stretch out s. th., to spread, to elongate."[30] Since both the note of the *mizmār muzāwaǧ* and the note on the *ʿūd* have a *tamdīd*, from the context *tamdīd* may be thought of as the "position" of the fingers on the instrument. According to this meaning it is suggested that the term *tamdīd* may be derived from the vibration 'stretch' of a string, between bridge and fret. Then it might correspond to the Greek *thésis* in the music-theoretical sense of "position". But there is another possibility. Ancient authors in the Aristoxenian tradition use the same semantic concept for expressing pitch: Their term *tásis*, "tension", is obviously derived from the experience of tuning the strings of a lyre (or harp). Does *tamdīd* ("stretching, extension") translate this term, and if so, can this be concluded

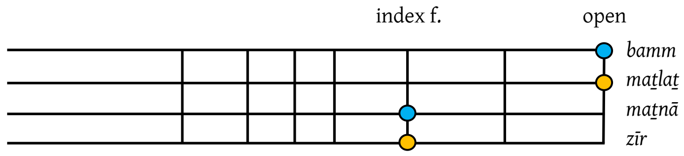


Figure 6: Two octaves on the *mizmār muzāwaǧ* as fret positons on the *ʿūd*

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[29] Cf. ʿAbd-al-ʿAẓīm 1992: 15.

[30] Wehr 1980: 896.

from al-Fārābī's book? Indeed, it can be; for he defines the term in his chapter on *ṭabaqāt* and *tamdīdāt*[31]:

> „The condition (*ḥāl*) of any note (*naġma*) in every single system (*ǧamᶜ*) of analogous systems (*al-ǧumūᶜ al-mutašābiha*) in heaviness or sharpness [=low and high pitch] – I mean the condition that it has in whatever heaviness or sharpness – is named *tamdīd*."
>
> (al-Fārābī, *K. al-Mūsīqī al-kabīr*, 365 Ḫašaba)

Here, al-Fārābī references the same idea as Cleonides, for example, who says: "A note (*phthóngos*) is the melodic dropping of the voice (*phōnē*) on a *tásis*."[32] This means that the voice can produce a great deal of sound, but if it is melodic (not just a noise) and drops on a *tásis*, (i.e. a certain pitch), then it is called "musical note" (*phthóngos*).

Before finishing the investigation of *tamdīd*, it is necessary to consider the other term used in explaining the octave of the *mizmār muzāwaǧ* : *bi-l-quwwa*. This is usually translated as "in potency, potentially, virtually". Therefore in this case, it would mean: If the positions on the *mizmār* are equated with the ones on the *ᶜūd,* either by playing the notes or just in potential, meaning they sound only in the imagination ("potentially"/ "virtually"), then the octave is produced. What does this mean? In this case, the translation as 'in potential' or 'potentially' is imprecise. How should one imagine a note? Unless the listener has absolute pitch, they must imagine notes in relation to others.

In his chapter on registers, al-Fārābī states that a composed melody sounds similar when transposed one octave lower or higher. That is, he says, because the functions of [the notes of] the melody are identical, if they are played one octave lower or higher. They are identical *bi-l-quwwa*, though, they are not in an absolute pitch.[33]

In the chapter on similar/analogue intervals (*al-abᶜād al-mutašābiha*), a similar issue occurs. Here, al-Fārābī refers to intervals whose lower note could be half or twice as low and whose higher note could be half or twice as high as the original one. Then, he says, one would call these two intervals "one [and the same] *bi-l-quwwa*" (*wāḥid bi-l-quwwa*), with the lower note of one of the intervals being "*bi-l-quwwa*" the lower note of the other one, and the higher note of one of the intervals being "*bi-l-quwwa*" the higher note of the other one.[34]

The expression *bi-l-quwwa* here cannot be translated as 'potentially' or 'virtually', because something more than just imagining another interval is meant. Rather, *bi-l-quwwa* should be translated in terms of function. If one transposes the two notes of an interval or every single note of a melody one or two octave/s higher or lower, the interval or the melody, respectively, will still be

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[31] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 365 Ḫašaba.

[32] Cleonides 1, 179 Jan: φθόγγος μὲν οὖν ἐστι φωνῆς πτῶσις ἐμμελὴς ἐπὶ μίαν τάσιν. Cf. Aristoxenus, *Harmonics* 1.15, 16 Da Rios.

[33] Cf. al-Fārābī, *K. al-Mūsīqī al-kabīr*, 115 Ḫašaba.

[34] Al-Fārābī, *K. al-Mūsīqī al-kabīr*, 357f. Ḫašaba.

heard as musically intact, and its notes will not lose their musical function within the interval or the melody. This conforms precisely to the musical meaning of Greek *dýnamis*.[35]

So far, al-Fārābī's examples deal only with transposition by octaves. The next paragraph of his chapter on similar/analogue intervals appears to refer to transpositions by less than an octave. There, al-Fārābī says, if one transposes an interval "a small or medium [interval]" higher or lower, then these intervals are called 'similar/analogue, but differing in their *quwwa*' (*al-mutašābihūn al-muḫtalifūn fī l-quwwa*). This is a significant meaning of *quwwa*. According to this statement, it seems to refer to transposition in octaves only. This implies that al-Fārābī sees musical function in an absolute sense and not in relation to other notes: Only the octave of a note has the same musical function as the original one, then. Transposition of other intervals than the octave still makes the intervals similar, nevertheless, they no longer have the same quality. They 'differ in function'.

⁂

Al-Fārābī's chapter on woodwinds is significant in several ways. It provides us with a more or less rudimentary description of four different woodwinds. Regarding their construction, al-Fārābī keeps us frequently in the dark. We fail to learn about their measurements, materials, the exact place and diameter of their finger holes. Were they arranged equidistantly? And with which kind of mouthpiece, if any, were they equipped? Most of these details would have been evident to al-Fārābī's original audience, while it can only be hoped that it is possible to collect relevant information from other sources, such as the much later Persian *Kanz at-tuḥaf*.[36]

One major interest of al-Fārābī is to determine and describe the tonality of instruments in terms of pitches and modes. However, though al-Fārābī employs *abǧad* letters for labelling finger holes and pipe exits, his labelling remains surprisingly unsystematic, although he uses Greek designations to equal the Arabic *abǧad* letters with musical functions (not pitches!) when presenting the theoretical basis of music theory.

Although al-Fārābī is familiar with the Greek Greater Perfect System and otherwise uses it both transcribing the Greek terms and giving Arabic translations, when it comes to describing the various musical pitches of contemporary music, he prefers to demonstrate their equivalents on the frets of the *ʿūd*, which are unambiguously defined by their association with a particular finger. The use of the *ʿūd* as model was doubtless prompted by its reputation and popularity; in this way, al-Fārābī's readers could easily assess his assertions, and on top of this, the relation of woodwind notes to lute fingering may well have formed part of the author's everyday musical experience as a performer.

When explaining musical concepts, however, al-Fārābī refers to Greek nomenclature and theory. He differentiates between note (*naġma = phthóngos*) and pitch (*tamdīd = tásis*), *tamdīd* ("extension", "stretching out", "elongation") apparently being a translation of the Greek term (*tásis* "tension"). Another important expression is *bi-l-quwwa*, which translates Greek *dynámei*, so important

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[35] Cf. Ptolemy, *Harmonics* 2.4.

[36] Cf. Tsuge 2013.

in Aristotelian philosophy, which normally refers to the concept of “potentiality”. In his book on music, however, al-Fārābī has obviously adopted its much more specific musical meaning, which features centrally in Aristoxenus’ musical thinking. Here *bi-l-quwwa* essentially describes the musical “function” (*dýnamis*) of a note (or a combination of notes) within its melodic environment. Following Aristoxenus’ and Ptolemy’s emphasis on the functional equivalence of notes an octave apart, the term becomes crucial for al-Fārābī’s description of octave relationships. Transposition by other intervals is of course possible but will not result in a melody remaining “identical *bi-l-quwwa*”, rather it will be “similar, though different *fī l-quwwa*”.

Al-Fārābī’s method in the chapter on wind instruments is systematic and theoretical insofar as he describes the instruments, discusses their susceptibility to a physical assessment of their relative pitches, labels their holes, and details the pitches resulting from them, referring to more than one way of instrument design where necessary. Notably, he does not endeavour to establish an overarching system of labelling finger holes yet, nor do his labels designate particular notes. He uses concepts of the ancient music theory of the Greeks alongside the Arabic use of the lute as reference for describing pitches.

On the other hand, al-Fārābī also considers practical issues. Although his emphasis is on notes and scales, he points to tuning customs and mentions that woodwind players did not care about theoretical aspects, but rather aimed “at improving the hole positions” without the help of theory.

Most importantly, while emphasising the theoretical relations between physical shape and pitch, al-Fārābī remains acutely aware of the inadequacies of available physical theory for predicting the pitches of many instruments. He does not hesitate to include a discussion of the *mizmār muzdawiǧ*, even though his means are unable to account for its tuning, and though he needs to acknowledge, if indirectly, that makers drilled finger holes that were at odds with theoretical prediction and performers compensated through their blowing technique.

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Kakui's *Hakase-Shi-Kuden-no-Koto* in Modern English Translation: A Window into the Workings of Thirteenth-Century Japanese Buddhist Neumes and a Step Forward for Comparative Liturgy

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Abstract

The present work is a modern English-language translation and annotation of Kakui's (1237-?) *Hakase-Shi-Kuden-no-Koto*, the earliest dated medieval Japanese manuscript to give specific details regarding the design and function of the *go-in bakase*, itself a system of diastematic neumes prevalent in Shingon-sect Japanese esoteric Buddhist circles from as early as the thirteenth century used for recording, as well as recalling, their hymnody. *Hakase-Shi-Kuden-no-Koto* has the secondary distinction of being the earliest dated treatise on Shingon-sect Shōmyō oral transmission of any kind, and it has the tertiary distinction of being, to the translator's knowledge, the only extant medieval Japanese manuscript to provide a comprehensive table of medieval Japanese neumes. The treatise has been preserved in a manuscript in the hand of the eighteenth-century Shingon priest Reizui (ca. 1756). Rezui's copy is currently housed at the Koyasan University Library in Wakayama prefecture, and it is upon this version of Kakui's text that the current translation is based. This translation is intended to provide both a point of entry into the world of Japanese, and indeed East Asian, neume studies for musicologists, and a point of reference in the necessarily collaborative endeavor of internationalizing the field of comparative liturgy. With that in mind, the footnotes include references to neumes from the notational systems of the Latin and Byzantine Christian churches of late antiquity and medieval times that are, to the translator, obvious graphic equivalents to neumes given by Kakui. This is done not to suggest any particular historical interpretation, but rather to identify phenomenological similarities that beckon to be explored for their historico-musicological significance.

Keywords

Japanese Music History – Buddhist Chant – Buddhist Music – Shomyo – Gagaku – Buddhist chant notation – Neume studies – Neumatic notations – Asiatic music historiography – Oriental music

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1 Introduction

It has been over a half century since Walter Kaufmann (1907–1984) first introduced readers of the English language to the neumatic musical notation system most prevalently used, from as early as the thirteenth century, to record, as well as to recall, the hymnody of Shingon-sect Japanese esoteric Buddhism.[1] That system was and is known as the *go-in bakase*[2]. Since Kaufmann's short article that appeared in the journal *Ethnomusicology* in 1967, very little has been written on the subject of the historical development of the *go-in bakase* system.[3]

That this should be the case for the English-language literature is perhaps unremarkable given the remoteness of this topic for most musicologists of whom that tongue is native, but the dearth of related historical studies in Japanese is striking, if not only because of the appearance of the *go-in bakase* system as a topic in many Japanese-language introductions to traditional Japanese music history and practice.[4]

In such introductory works, the Shingon priest Kakui (1237-?) is generally credited as the originator of the *go-in bakase* system. Little else is known about Kakui, and perhaps the lack of extant details pertaining to his life is a contributing factor to the aura of obscurity surrounding the origins of the fascinating system of musical notation that he supposedly devised and most assuredly championed. Be that as it may, Kakui did write a short treatise detailing many of the aesthetic and functional features of the *go-in bakase* system, and that treatise has been preserved in a manuscript in the hand of the eighteenth-century Shingon priest, Reizui (ca. 1756). The treatise in question is the *Hakase-shi-kuden-no-koto*, of which the present work is a translation.

2 Towards an internationalization of comparative liturgy

This translation is intended to provide a point of entry into the world of Japanese, and indeed East Asian, neume studies for musicologists. The diastematic *go-in bakase* system is considered both a

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[1] See Kaufmann 1967: 161–69.

[2] The initial consonant of the word '*bakase*' from the compound '*go-in bakase*' is voiced as a result of the rules of euphonic combination in the Japanese language, which dictate that the first syllable '*ha*' of the word '*hakase*', become voiced when following the nasal 'n', here the last mora of the compound '*go-in*'; thus '*go-in hakase*' becomes '*go-in bakase*'.

[3] By far, the most detailed account of the development of neumatic notations for Japanese Buddhist chant can be found in Arai 1996. In this article, in both its Japanese and English (translated by Steven G. Nelson) versions, an historical account is given for the development of the various types of neumatic notations used in the Shingon and Tendai sects of Japanese Buddhism, but an in-depth look at the individual neumes and specific melodic types represented by them is not attempted. An excellent introduction to the *go-in bakase* system can be found in Nelson 1998: 458–503.The *go-in bakase* system is also described in Malm 2000: 279–81 and Harich-Schneider 1973: 329. These two authors, though referencing the *go-in bakase* system, give few details about its historical development. Finally, an interesting theory for an Indian origin of the various Buddhist notational systems of Japan, Nepal, and Tibet, is given in Ellingson 1986: 302–42.

[4] See, for example, Sawada 2008: 126.

functional and aesthetic development of the older, cursive, adiastemtaic, and strictly graphic *fushihakase* notations.[5] That the latter have continental origins was demonstrated in 1993, when graphically equivalent neumatic notations were discovered affixed to the Chinese text of a *gāthā*, as preserved in a tenth-century manuscript fragment from Dunhuang secured by Aurel Stein (1862–1943) and currently housed in the British library.[6] Chinese precedent for the *fushihakase* notations had already been hypothesized by Kaufmann who, having also noted significant graphic similarities between the neumes of Tibetan Buddhist chant and those of the Syriac, Byzantine, Armenian, and Latin Christian churches, suggested that such graphic similarities were ultimately the result of interactions between Buddhists and Christians on the Silk Road.[7]

To Kaufmann's point, there were ample opportunities for exchange between, at the very least, Nestorian Christian missionaries from Persia and Tibetan and Chinese Buddhists in Central Asia. Beginning in the late seventh century, the Tarim Basin was the centre of territorial disputes between the Tibetan empire and Tang Dynasty China, and the existence of neumatic notations with links to the Nestorian church in this area was confirmed in the early twentieth century with the discovery, among the Turfan manuscripts, of Sogdian-language Manichean hymns furnished with ekphonetic signs of the kind devised around the year 500 by the Nestorian hymnographer Joseph Hûzâjâ.[8]

Interestingly, the Nestorian neumes very much resemble the diacritical marks used to indicate the tones of Middle Chinese, known as *sìshēng* in modern Chinese and *shisei* in Sino-Japanese, which are themselves a feature of Buddhist chant scores in both the ancient Chinese and Sino-Japanese traditions.[9] For example, in Japanese scores dating from as early as the eleventh century, such tone

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[5] See Arai 1996a.

[6] See Kobayashi 2014: 173–76. The word 'gāthā' here refers to a verse portion of a Buddhist text. The text in question is the so-called Lotus Sutra (Skt. *Saddharma-puṇḍarīka-sūtram*, Ch. *Miàofǎ-Liánhuá-jīng*, Jp. *Myōhō-Renge-Kyō*) and in particular, its twenty-fifth chapter, "The Universal Gateway of Avalokiteśvara Bodhisattva" (Ch. *guānshìyīn-púsà-pǔmén-pǐn,* Jp. *kanzeon-bosatsu-fumon-bon*). This chapter is often recited separately from the larger text in East Asian Buddhism, in which case it is known by a contraction of its longer title as the 'Avalokiteśvara sutra' (Ch. *guānyīn-jīng*, Jp. *kannon-kyō*). The manuscript fragment in question is S.5556 from the Stein collection at the British Library. The discovery of the Dunhuang neumes was followed, in 2000, by the discovery of neumes affixed to a Buddhist treatise in the hand of the Korean monk Wonhyo (元暁, 617–686). This treatise, the *Hanpiryōron* in Japanese or *Panbilyanglon* in Korean (判比量論), was imported to Japan in the eighth century from the Korean kingdom of Silla, a vassal state of Tang Dynasty China. From this time it was in the possession of the Japanese Empress Kōmyō (光明皇后, 701–760).

[7] See Kaufmann 1967: 360. Although the earliest extant Tibetan Buddhist chant part books with graphic notations date from the late eighteenth century, a thirteenth-century treatise on music by the renowned Tibetan scholar Sakyapandita (1182–1251) seems to describe, by way of simile, a number of signs for the notation of Buddhist chant. See Canzio 1978: 74–75.

[8] For a table of the Nestorian neumes, see Wellesz 1978a: 10. The neumes from the Manichean hymn unearthed in the Tarim Basin represent an early phase of Hûzâjâ's notational system. Also note that the Turfan manuscripts included Nestorian texts.

[9] Traditionally in China, the creation of the tone markings has been attributed to the great poet, musician, and statesman, Shěnyuē (沈約, 441–513), although the earliest extant specimens of the tone markings date to the late eighth and early ninth centuries. For more on this, see Ishizuka 1993: 30–50.

markings are used in conjunction with the *fushihakase* in indicating melodic contour. [10] This convention can be shown to have continental origins, as is evidenced by the fact that the neumes from the aforementioned manuscript fragment from Dunhuang emanate from the spaces usually occupied by the tone markings. Hence, there seems to be a developmental relationship between such tone markings and the various neumatic notational systems of East Asia in medieval times. This relationship can be traced back to Dunhuang which, as the gateway from Central to East Asia and the nexus of the Silk Roads, was an area that would have been well traversed by missionaries of the Nestorian Church.

Just as there is, as demonstrated by Kaufmann, substantial overlap in the graphic forms assumed by neumes in the Tibetan Buddhist and various medieval Christian notational systems, there are also significant graphic correspondences between the early East Asian neumes and, for example, those of medieval Latin Christendom. Both the *fushihakase* and their Chinese precedents appear in straightened, upward bending, downward curving, and undulating varieties graphically identical to the prototypical forms of the Carolingian *virga*, *podatus*, *clivis*, and *torculus*, respectively. When one takes into account the East Asian tone markings, considering them to be, as they were, integral to the early East Asian neumatic notational systems, the total number of graphic forms in those systems comes to five, with the fifth sign being graphically equivalent to the Carolingian *punctum*. Hence, each member of the Carolingian system of neumes is represented by a graphically equivalent neume in the early East Asian neumatic notational systems.[11]

The Japanese *fushihakase*, along with the later diastematic *go-in bakase* system, shares with the notational systems of both contemporaneous Gregorian and Tibetan Buddhist chant the use of what might be called ligatures.[12] That is, a single text syllable may be furnished with a series of neumes. In the *go-in bakase* system, a single stroke of such a ligature is at times realized with an additional melismatic motif or melodic embellishment. These embellishments are left unnotated, and their intervallic content and timing have been passed down orally. This oral transmission has been aided by a descriptive manuscript tradition, to which Kakui's treatise belongs.

If indeed there are historical connections between the East Asian, Tibetan, and various Christian neumes of medieval times, then the melodic embellishments in the current traditions of Shingon-sect Buddhist chant, when considered in conjunction with their textual descriptions in the

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[10] For a description of the relevant Japanese manuscripts, see Numoto 1991: 45–74. In both the Chinese and Sino-Japanese traditions of transliterating Sanskrit with Chinese characters, the tone markings were also used to indicate the vowel lengths of the transliterated Sanskrit syllables. For more on this, see Numoto 2011: 3–18. The tone markings continue to appear, albeit superflously, in modern Japanese Buddhist chant scores utilizing the diastematic *go-in bakase* system. In this context, the departing tone, when it is indicated, is done so with a dot in the upper right-hand corner of the Chinese character in question, and this generally corresponds to a melodic ascent; this is mirrored in the Nestorian neumes, in which a dot in the top right-hand corner of a word likewise represents a melodic ascent. The dots of the Nestorian neumes are at times doubled or tripled; in similar fashion, the Sino-Japanese tone markings are doubled on occasion, and this typically indicates a voiced, as opposed to an unvoiced, initial consonant in the relative text syllable.

[11] See Appendix I.

[12] See Canzio 1978: 61–64. The thirteenth-century Tibetan neumes, of which we have only textual descriptions, seem to have been used singularly as well as in compound.

manuscript tradition, may have the potential to inform our interpretation of certain functionally ambiguous neumes and to explain gaps between theory and practice in and between the differing systems.

Whether or not the various notational systems mentioned above at one time shared functional, in addition to their conspicuous graphic, similarities, there can be no doubt that a better understanding of Kakui's neumes and the melodic features they represent will improve our understanding of East Asian neumatic notational systems overall. Aside from Kakui's treatise, the author knows of no other ancient or medieval Japanese manuscript that gives a comprehensive table of the medieval Japanese neumes in either their curved or straightened forms, and the table of neumes provided by Kakui in the section of the present translation entitled "A List of *Hakase* Graphs" will be an indispensable point of reference in the necessarily collaborative endeavour of internationalizing the field of comparative liturgy. Contributing to such internationalization is, then, the *raison d'être* of the present work.[13]

With that in mind, the footnotes include references to neumes from the notational systems of the Latin and Byzantine Christian churches of late antiquity and medieval times that are, to the translator, obvious graphic equivalents to neumes given by Kakui. This is done not to suggest any particular historical interpretation, but rather to identify phenomenological similarities that beckon to be explored for their historico-musicological significance.[14]

3 Primary materials and their accessibility

The esoteric nature of Shingon Buddhism is often cited as a significant impediment to research on its musical practices, but the assumed insuperability of this barrier is quite contrary to the author's experience, who has been asked to comment on how the closed-off nature of the sect in question has affected the compiling of the present translation.

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[13] Both the Tibetan and Japanese Shingon traditions belong to the Mahāyāna Buddhist tradition. To the author's knowledge, the earliest description of anything resembling a liturgical form in the Mahāyāna Buddhist context can be found in the *Dharmasaṃgraha*, an ancient collection of Buddhist technical terms attributed to Nāgārjuna (150–250). Here, the ceremony known as the "Seven Supreme Offerings" (Skt. *Saptavidhānuttara-pūjā*) is introduced. Its component parts are the *vandanā* (worshipping), *pūjanā* (honoring), *pāpadeśanā* (confessing), *anumodanā* (rejoicing), *adhyeṣaṇā* (requesting instruction), *bodhicittotpāda* (generating a mind set on awakening), and *pariṇāmanā* (developing the mind set on awakening). A truncated version of the *Dharmasaṃgraha* in a Chinese translation (*Fúshuō-fǎjí-míngshù-jīng*) by the Indian monk Dānapāla (d. 1017) was known in East Asia. Some of Dānapāla's terms for the component parts of the "Seven Supreme Offerings" (七種最上供養, Ch. *qī-zhǒng-zuìshàng-gòngyǎng*, Jp. *shichi-shū-saijō-kuyō*) appear as piece titles in the repertoires of the Japanese Shingon and Tendai Sects. Especially notable in this regard is the 'suite' of confessional pieces known, in both sects, as the *gokai* (五悔). The titles of four out of five of the Shingon *gokai* pieces , namely, the *sange* (懺悔), *zuiki* (随喜), *kanjō* (勧請), and *ekō* (回向), match terms used by Dānapāla to translate *pāpadeśanā, anumodanā*, *adhyeṣaṇā*, and *pariṇāmanā* respectively. All four of these appear in the Tendai *gokai* where a fifth piece, the *hatsugan* (發願), corresponds to Dānapāla's translation of *bodhicittotpāda*.

[14] For a comparison of the Tibetan Buddhist and various Christian neumes, the reader is enthusiastically referred to Kaufmann 1967: 410–13.

Indeed, being a true ‘practitioner’ of Shingon Buddhism is to have been entered into holy orders; lay believers are simply not given access to the full spectrum of ritual practices. The injunction against divulging ritual secrets in the Shingon tradition is an ancient one that can be traced back to seventh century India. The *Vajraśekhara Sūtra*, for example, includes the following description of a rite designed to ensure the mystical and spontaneous death of a disciple upon their breaking of trust.[15]

“[Then] the Adamantine Ācārya (Teacher) should himself bind the *sattva-vajrī* seal, which he places facing downward on the disciple’s head, making the following pronouncement: ‘this is the *samaya-vajra* (pledge-*vajra*). It will split your head [if you talk about this to others, so] you must not speak of it.’”

Despite the thus attested severity of repercussions incurred for divulging secret matters in the esoteric Buddhist traditions of ancient times, a substantial portion of the chant repertoire of today’s Shingon sect is accessible in Japan through commercially available recordings. Also, medieval notation manuals are extant and increasingly accessible to local and foreign researchers alike. This is in no small part due to the noble archival and publication efforts of scholars such as Professor Steven G. Nelson and the late Kazuo Fukushima, both of the now disbanded Research Institute for Japanese Music Historiography at Ueno Gakuen University. Recent digitization efforts in Japan are also contributing to the publication of materials germane to this field, though these continue to proceed at an unhurried pace.[16]

The interpretation of notational manuals, many of which have been published in facsimile form, is greatly informed by consulting the contemporaneous oral-transmission manuscripts (Jp. *kudensho*, 口伝書). A number of these are held by the Koyasan University Library and date from as early as the eigtheenth century with colophons indicating textual origins in as early as the thirteenth century, as in the case of the manuscript used in the present translation. Being affiliated with a university in Japan is helpful in gaining access to such primary source materials, but not necessary, especially if one has obtained the proper recommendation. Finally, compilations of modern notations published in conjunction with audio recordings, though mostly out of production, are available on the old books market in Japan.[17]

As such, examination of the relationships between the current chanting practices of the Shingon sect and their corresponding contemporary, as well as forbearing medieval, musical notations, is well within the grasp of any sufficiently motivated musicologist whose level of interest and leisure is commensurate with that required for gaining facility in classical Japanese, classical Chinese, and Sanskrit, and for spending some time in Japan to identify, peruse, and allocate materials. All

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[15] Giebel 2001: 76. In the Japanese Shingon and Tendai traditions, this sutra is known as the “Adamantine Pinnacle Sutra” (Jp. Kongōchō-kyō 金剛頂経, Skt. *Vajraśekhara Sūtra*), and its contents are equivalent to those of what in the continental esoteric Buddhist traditions was the first chapter of the much longer “Compendium of Principles of All the Tathāgatas” (Skt. *Sarvatathāgatatattvasaṃgraha*).

[16] For an extensive account of recent digitization projects of musicological significance in Japan, see Tsukahara 2022: 669–79.

[17] See for example, Kuriyama and Koizumi 1998.

the better if one devotes a portion of said time to acquiring the relevant academic, if not clerical, connections in Japan. There is much work to be done in this field, and generating interest locally is as much of an endeavor as is generating it abroad. Having spent the good part of a decade doing the former, the author, with the present translation, seeks to make progress on the latter.

4 Regarding pitch and scales

Throughout this translation, the five pitches of the anhemitonic pentatonic scales used in Japanese Buddhist chant, or *shōmyō,* are given in their Sino-Japanese nomenclature.[18] The five scale degrees are 'kyū', 'shō', 'kaku', 'chi', and 'u'. Though pronunciation obscures the fact, these are nominally equivalent to the Chinese scale degrees 'gōng', 'shāng', 'jué', 'zhǐ', 'yǔ', written as they are using the same Chinese characters, but there is a crucial difference with regards as to how they are employed in the Japanese context. In the Chinese system, the basic scale can be systematically rotated such that the sequence begins on any of the five scale degrees, thus rendering five different versions of the anhemitonic pentatonic sequence. In the medieval Japanese tradition however, only two of these possible sequences were used, and these were and are referred to as the *ryo* and *ritsu* scales, respectively. In terms of the Chinese scales just previously mentioned, the *ryo* scale is equivalent to that beginning on the pitch 'gōng', and the *ritsu* scale to that beginning on the pitch 'zhǐ', but in Japanese practice both scales begin on the pitch 'kyū'. That is, both scales, despite their differing intervallic sequences, are expressed by the terms 'kyū', 'shō', 'kaku', 'chi', and 'u', in that order.

Both the *ryo* and *ritsu* scales are, in theory as well as in practice, transposable to any starting definite pitch, and as such may perhaps be most unambiguously expressed in terms of their pitch names separated by Arabic numerals representing the number of intervening half-steps between pitches. In doing so, the *ryo* scale comes to be represented as 'kyū' [2] 'shō' [2] 'kaku' [3] 'chi' [2] 'u', and the *ritsu* scale as 'kyū' [2] 'shō' [3] 'kaku' [2] 'chi' [2] 'u'. Note that the distance from a lower member 'u' to an upper member 'kyū' in both scales is three half-steps. This modal theory must be taken into account when working with the *go-in bakase* notational system, as the intervals represented by, say, a *hakase* graph indicating movement from 'shō' to 'kaku', or perhaps from 'kaku' to 'chi', will differ depending upon which of the scales, *ryo* or *ritsu*, is intended for the particular piece or section thereof in question.[19]

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[18] Until the late Heian period, the term *shōmyō* in Japan, as well as in China, referred not to Buddhist chant per se, but rather to one of the five ancient Indian sciences (Skt. *pañcavidyā*), namely, that one dedicated to the study of language and phonetics, *śabdavidyā*. It seems that Buddhist chant was covered in the rubric of *śabdavidyā* in such a way that is reminiscent of the way in which Vedic chant was central to the *śikṣa* literature, the study of phonetics in the Brahmanical tradition. Perhaps for this reason, overtime, *shōmyō* became a catch-all term for Buddhist chant in Japan, a convention that continues to the present.

[19] The *ritsu* or *ryo* status of any particular piece is not typically indicated in medieval scores of the Shingon sect, but it is so indicated in the contemporaneous *kudensho* literature. Also note that the specific mode intended for a particular piece may vary between the Shingon and Tendai sects, as do the actual melodies

5 Notes on the translation

Hakase-shi-kuden-no-koto is the earliest work to give specific details regarding the design and function of the *go-in bakase* system. In addition, it has the secondary distinction of being the earliest dated treatise on Shingon-sect Shōmyō oral transmission of any kind. [20] The manuscript itself is housed at the Kōyasan University Library in Wakayama prefecture, Japan, and a facsimile has been provided as an appendix to the present translator's own master's thesis, completed at the Tōkyō University of the Arts in 2017.[21]

The majority of Kakui's text is written in a classical Chinese that is annotated in such a way that it may be read aloud in the classical Japanese register. Such a style of writing would be known as *kanbun-kundoku* to students and specialists alike in the field of Japanese literature. The often terse nature of this writing style is one of the reasons that the present translator has avoided a too literal translation.

Another reason for the present translator's eschewing of a strictly word-for-word rendition is the highly contextualized nature of the text which concerns, by definition, a topic of an esoteric nature.[22] To help alleviate much of the guess work that would otherwise be involved in reading a too literal translation, contextualizing text has been added by the translator based on his personal knowledge of the Shōmyō *kudensho* literature ascertained by him from over a decade of working with that particular genre of texts in Japan.

There are exceptions to the generally liberal style of translation employed here. For example, the reader may at once detect a sense of awkwardness in the choice of the verb 'indicate' to refer to the action of affixing *hakase* graphs to texts. In fact, this word has been consciously selected to represent the Japanese word used by Kakui himself in referring to that very same action. The word in question is 'sasu', and it is written with the same Chinese character as is the Sino-Japanese word 'shi' from the text's title, *Hakase-shi-kuden-no-koto*.[23] This character, in both Japanese and Sino-Japanese contexts, refers to indication with the fingers, that is, to the act of pointing, and its use in the context of notating Buddhist chant may very well have its origins in the method of Sāmavedic cheironomy hypothesized by Kaufmann as being the predecessor to, if not only the inspiration for, the development of the *go-in bakase* graphs. For this reason, and to preserve a nuance latent with historical possibilities, the present translator has opted to use, in a quite literal fashion, the word 'indicate' throughout the body of the translation to substitute for the Japanese word 'sasu'.

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and notational systems employed to dictate those melodies. The present translation uses as its point of reference the Shingon repertoire.

[20] Treatises such as these are known in Japanese as *kudensho*, a term that literally means 'oral transmission text'. These texts, though befitting their collective appellation, do so not without a sense of irony in that they make a written record of what is, in principle, an oral transmission.

[21] Duran 2017.

[22] The topic is 'esoteric' in both the general sense of that word, in that its scholarly exploration requires specialized knowledge, and also in the technical sense, insofar as it concerns the ritual of a sect of Buddhism that emphasizes 'secret teachings' (Jp. *mikkyō* 密教) as opposed to open ones (Jp. *kengyō* 顕教).

[23] The character referred to is "指".

The manuscript used in this translation, dated to 1756, contains a number of notes by the priest Reizui, a man of whom, in similar fashion to Kakui, very little is known except that he gave himself quite thoroughly to the transmission of the teachings of the Nanzan-shinryū branch of Shingon-sect Shōmyō, as is evidenced by the proliferation of treatises, such as the present one, bearing his name as copyist. Reizui's notes have been excluded from the present translation, as are the treatise's accompanying appendices, which though elucidating certain topics covered in the body of the main text, were not penned by Kakui himself and are by all estimations a part of a much later tradition, perhaps even that of the eighteenth-century copyist. On the other hand, this translator has provided in the footnotes to this translation and in four of the five appendices that follow it information that will enhance the reader's understanding of principles discussed in the treatise.

Each section of the translation that follows is prefaced with a heading given in bold print. Some of these are translations of Kakui's own headings, but not all. A number of them have been penned by the present translator, and an even larger number are English translations of those given by Atsuko Sawada in her 1985 Japanese-language article which introduced the content of Kakui's treatise to readers of modern Japanese.[24] These same headings were used in the present author's own modern Japanese translation and annotation of Kakui's treatise, which to this translator's knowledge is, excepting the present work, the first and only complete translation of the treatise into any modern language to date.[25] Reizui was not the only priest to copy Kakui's text, and there is undoubtedly much to learn from a comparison of various copies of Kakui's treatise. However, Reizui's copy is a key source of Kakui's work and an excellent starting point for understanding his notational system.

6 Kakui's *Hakase-Shi-Kuden-no-Koto* in English translation

6.1 Regarding the arrangement of hakase graphs in the central vocal register[26]

Among the five pitches of the central vocal register, 'kaku' is central. The position of the *hakase* graph of 'kaku' determines that which is above and below, namely, the positions of the adjacent *hakase* graphs. Despite this, the *hakase* graphs representing the pitches 'u' and 'chi' should be indicated in a slightly sagging manner, and those representing 'kyū' and 'shō' in a slightly raised manner. A fitting example of this is the character 'ground' in the *Rishukyō*, from a section of text in which the characters are cramped.[27]

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[24] See Sawada 1985: 91–103. Sawada's article, though not including a modern Japanese translation of Kakui's text, does provide a transcription of the classical Japanese one, as well as some useful commentary.

[25] In retrospect, that translation is at places so free that it might be considered a simultaneous annotation and translation. The current translation is meant to supersede the former one in terms of its literality, but not in regards to its accompanying commentary, which differs in both focus and breadth.

[26] Those unfamiliar with the basic layout and method of reading the *go-in bakase* graphs are referred to Appendix II.

[27] "Ground" here refers to the character "地". For an example of this passage in notation, see Appendix III. Here, the second *hakase* graph, though indicating the pitch 'u' does not appear at a 90-degree angle as it

6.2 Regarding the arrangement of hakase graphs in the lower and upper vocal registers

There are times when a *hakase* graph must be indicated beyond what would be its usual position.[28] One of the best examples of this from the hymnal is the character 'life' from the compound word 'long life' in the piece *Ungabai*.[29] When the character 'life' is to be intoned on the pitch 'u', the *hakase* should be drawn as if to indicate the pitch 'kyū'. The reason for this is that the *hakase* graph for the character 'life', a character that is intoned in a prolonged and melismatic way, is very long; if it, that is, the pitch 'u', were indicated as would be expected with the *hakase* graph for 'u', that *hakase* graph would brush-up against the other characters.

Another example of when a *hakase* graph should be indicated in such a way that it extends beyond its usual position, this time in contrast with the previous example in a raised fashion, is the phrase "wondrous and unsurpassed flowers that are in the ten directions" from the piece *Bonnon*.[30] Here, the *hakase* graph that seemingly indicates the pitch 'u' and is affixed to the character 'are', is similar to the previous example in that it should be intoned at a different pitch than warranted by its position. This pertains to the pitch 'kyū' from the central vocal register.[31]

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theoretically should, but rather, it is tilted slightly to the left. Note, '*Rishukyō*' refers to the Chinese translation by the Samarkandian priest Amoghavajra (705–774) of the tantric Buddhist text known in Sanskrit as the *Prajñāpāramitā-naya-śatapañcaśatikā sūtra*. The text, in Amoghavajra's translation, is central to Shingon theology.

[28] The point here is that, for aesthetic and practical reasons, there are times when *hakase* graphs indicating the lower and upper vocal registers cannot be written in their theoretically standard positions; that is, the upper register cannot be indicated revolving upwards and clockwise around to the right of the character, and the lower register cannot be indicated revolving downward and counterclockwise, again around to the right of the character. Although so indicating the *hakase* graphs would be theoretically correct, the spatial limitations of a Buddhist hymnal (Jp. *shōmyōshū*, 声明集) requires that these *hakase* graphs be repositioned, for the most part being placed in what would normally be occupied by *hakase* graphs indicating the central vocal register. To get a sense of what is being discussed here, as well as in the following examples given by Kakui, please refer to Appendix IV.

[29] 'Ungabai' is a representative piece from a wider genre of pieces known as 'Bai'. The 'Bai' is but one in a group of four genres, the other three being the 'Sange', 'Bonnon', and 'Shakujō', that constitute the *Shikahōyō*, a four-part section of the Sino-Japanese Buddhist liturgy that fulfills an offertory function. A truncated version of this offertory section, and one excluding the latter two genres, is known as the *Nikahōyō*. Also note, this translator uses the word "hymnal" here to translate the word "Shōmyōshū", which might as well have been translated as "Compilation of Buddhist chant", but has not been so, on account of, and in preference for, the tone of familiarity invoked by the word 'hymnal'. Finally, the text "long life" here translates the Sino-Japanese "長寿", meaning 'longevity'. The translation "long life" has been opted for in order to distinguish the two characters of the original compound from each other, hence enabling, for explanatory purposes, the isolation of the character "寿", or 'life', of which the notation is being explained in the passage.

[30] The *Bonnon* is the third member of the group of four-pieces that taken together constitute the *shikahōyō* offertory section of the liturgy.

[31] The quoted text from the piece *Bonnon*, in the original, is as follows: "十方所有(勝妙華)". The clause-completing text in parentheses has been supplied by the translator after consulting the relevant piece in the 1472 Shōmyōshū as well as in the authoritative hymnal of the Nanzanshinryū branch of Shingon Shōmyō, the *Gyosan-taigai-shū*. Note that the characters "所" , meaning 'place', and "有" , meaning 'to possess', when used in compound, indicate possession, as well as often, location. For the purposes of explaining the distribution of the *hakase* graphs, a distinction between the two members of the compound has been made in the translation. Most importantly, the word "are" corresponds to the Chinese character "有" in the original text, of which the *hakase* graphs are being explained by Kakui in this passage.

When the upper and lower vocal registers are used, the *hakase* graphs should be indicated in the middle, that is, they should be written in the space usually allocated to the indication of the central vocal register. For example, the excerpt "pureland dwelling of the dharma king" from the piece *Monju-no-san* is an example of an upper vocal register *hakase* graph being indicated at a lower position than what would be theoretically warranted.[32] This is but one such example.

The excerpt *Namamaka* from the piece *Kongō-kai-Raibutsu* is an example of indicating a lower vocal register *hakase* graph at a lower [sic] position than standard.[33] Such examples are innumerable; as such, rather than attempting to memorize every particular instance, one must acquire a sense of the governing principle.[34]

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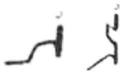
[32] According to the *Gyosantaigaishū*, the piece Monju-no-san modulates from the *ryo* to the *ritsu* scale beginning with the character '土'. In Shingon Shōmyō, a modulation from the *ryo* to *ritsu* scale is often synonymous with a modulation from a lower to higher vocal register. Here, though the piece moves to a higher vocal register, the *hakase* graphs, while maintaining the theoretically correct angles, are re-positioned to occupy the space theoretically reserved for indicating the central vocal register. Another point about this passage pertains to the translation of the title *Monju-no-san*. 'Monju' of "Monju-no-san" refers to the bodhisattva Mañjuśrī, and the character for the word "san" (讃) is used frequently in the Chinese Buddhist Canon to translate the Sanskrit word 'stotra'. For example, the *gaṇḍhī-stotra-ghātā*, a Sanskrit text attributed to the poet, dramatist, and orator Aśvaghoṣa (80–150) appears in Chinese translation in the 32nd volume of the Taishō Buddhist canon as "犍稚讃" (Ch. jiān-zhì-zàn, Jp. Kenchisan). For this reason, perhaps an acceptable Sanskrit translation of "Monju-no-san" would be '*Mañjuśrī-stotra*'. For now, however, this translator has been unable to source the text of this piece to even the Chinese Buddhist Canon, let alone to a source Sanskrit text, and one cannot preclude the possibility that this piece was composed, albeit in Classical Chinese, in Japan.

[33] This is likely a scribal error, as the excerpt *Namamaka* from the piece *Kongōkai-Raibutsu* is actually an example of indicating a lower vocal register *hakase* graph at a higher position than standard; this much can be determined from an analysis of the notations in the *Gyosantaigaishū* and the 1472 *Shōmyōshū*, in which the *hakase* graph for the first character of this excerpt, "南", though positioned, as it is, at a 180-degree angle as if it were indicating the pitch kaku from the central vocal register, appears at the lower left-hand corner of the character. Thus the affixer of *hakase* graphs seems to have been seeking to differentiate this pitch from 'kaku' of the central vocal register. Clearly, the pitch being indicated is that of 'chi' from the lower vocal register, but it is done so not below and wrapping counterclockwise around the character to the right, but rather, within the ambit of the space allocated theoretically to the indication of the central vocal register. Also regarding this passage, the word 'Namamaka' is a Sino-Japanese transliteration of the Sanskrit 'Namaḥ Mahā...', or 'salutations to the great...'); finally, "Kongōkai-Raibutsu" might be translated into English as 'Praise to the Buddha of the Diamond Realm'. For a facsimile of the *Gyosantaigaishū* see Chōe 1496 (1743), available online via the following link: https://www.dh-jac.net/db1/books/results-thum.php?f1=arcBK01–0091&f12=1&sortField1=f8&-max=40&enter=default&lang=en. For a facsimile of the 1472 *Shōmyōshū*, see Fukushima 2018: 7–50.

[34] With regards to that principle, when *hakase* graphs are indicated in positions differing from their theoretically correct ones, that is, with respect to their corresponding vocal registers, the theoretically correct angles of the *hakase* graphs are nonetheless maintained. So, for example, were the pitch shō from the upper register to be indicated, for practical and aesthetic reasons, in the central position, it would be done so at a 90 degree angle; it would, in notation manuals not utilizing the small dots that specify the starting points for the *hakase* graphs (more on this later), appear to be representing the pitch 'kaku' from the central vocal register.

6.3 *How to link the hakase graphs*

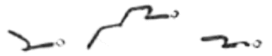
When moving, for example, from the pitch ‘kyū’ to the pitches ‘shō’ or ‘kaku’, the *hakase* graph of the second member in each case should emanate from the centre of the *hakase* graph of ‘kyū’. The indication of the melodic type ‘pierce and twist’ is more refined in its details, and it should appear as follows:[35]



This *hakase* graph should be indicated with the second member of each pair emanating from the centre of the first member.

In moving from the pitch ‘shō’ to another pitch, the *hakase* graph should, for the most part, be indicated as follows:

Here, the initial member ‘shō’ is thicker than that of the succeeding members. All other such cases abide by this rule. When moving from the pitch ‘kaku’, the succeeding *hakase* graphs for the most part are thinner than the initial ‘kaku’, as follows:

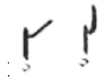


Additionally, a *hakase* graph succeeding that of ‘kaku’ should emanate from the latter’s final third portion and, as stated before, should be thinner.

For the most part, when moving from the pitch ‘chi’, the *hakase* graphs should be indicated as follows:

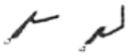
Here, the second members, just as in the previous examples, are thinner.

In moving from the pitch ‘u’, the *hakase* graph should, for the most part, be indicated as follows:



All other such cases follow this pattern.

When moving from the pitch ‘kyū’ of the upper vocal register, the *hakase* graphs should take the following form:



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[35] The images contained in the body of the present translation are screenshots taken from a digital facsimile of the eighteenth-century manuscript, published in this translator’s own master’s thesis: Duran 2017. The images as they appear here are not necessarily at scale with regards to the original or with respect to each other.

When moving from the pitch 'u' of the lower vocal register, the *hakase* graphs should, for the most part, take the following form:

6.4 Regarding the Lengths of Hakase Graphs

These are but some examples of the various lengths of *hakase* graphs:

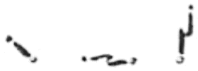
6.5 Regarding the thickness of hakase graphs

With regards to the matter of the thickness or thinness of *hakase* graphs, even in such instances when, for example, the pitch 'chi' is followed yet again by the same pitch 'chi', the second member is indicated thinly, as follows:

This rule is followed in all such similar instances employing the other four remaining pitch levels.

6.6 Regarding short hakase graphs

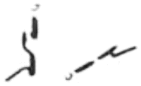
At times, a normal-sized *hakase* graph will be followed by a shorter one, for example:



Hakase graphs such as these are called 'continuing breath'.

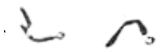
6.7 Regarding long hakase graphs

There are times when a *hakase* graph will be indicated slightly longer than usual, for example:



6.8 How to bend the hakase graphs

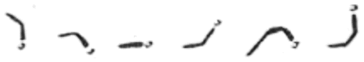
There are times when a *hakase* graph should be indicated in a twisting manner, for example:



In these two examples, though they both indicate, by way of the initial *hakase* graph in each example, the pitch 'chi', one of the 'chi' *hakase* graphs stands quite erect, while the other faces in a more downward direction. Though the norm is that the pitch 'kyū' be indicated facing directly downward, the pitches 'chi' and 'kaku' diagonally, and the pitch kaku horizontally at a 180 degree angle, the most fundamental principle of *hakase* graphs is their form, and as such, these forms are not necessarily standardized but rather should be adjusted for aesthetic and otherwise practical concerns.[36]

6.9 Regarding the positions of hakase graphs in the sutras

A point to be careful about with regards to the *hakase* graphs is as follows: in such cases as that of the Rishu-kyō and Amida-kyō, one must be cautious with the spatial relationships between the upper and lower members of vertically adjacent characters; the *hakase* graphs of those characters should all be of the same size, for example: [37]



Whether or not a column of characters is succeeded by yet another column or not, the length of the *hakase* graphs should not be extended; rather, the *hakase* graphs should be indicated directly below and in close proximity to their respective characters. An exception to this rule is the case in which the space between two adjacent characters is cramped; in such cases, and depending whether the column of characters in question is succeeded by yet another such column, one may use the additional space between the columns and indicate the *hakase* graphs in such a way that is larger than usual. One should know this principle well.

6.10 Regarding the positions of hakase graphs in the fukuyō

In the Fukuyō, one must be especially cautious with regards to indicating, with *hakase* graphs, pitches that follow the pitch 'kyū'.[38]

6.11 A list of hakase graphs[39]

This *hakase* graph is called 'continuing breath'.[40]

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[36] Here apparently, is the presence of a scribal error. The pitches typically indicated diagonally in the central vocal register are 'chi' and 'shō' , not 'chi' and 'kaku'.

[37] The *Amida-kyō* (*Fúshuō-āmítuó-jīng*) is the Chinese translation by the Kuchean monk and scholar Kumārajīva (344–413) of the Pureland-themed Buddhist text known in Sanskrit as the '*Sukhāvatī-vyūha sutra*'.

[38] *Fukuyō* (*Bùkōng-juànsuǒ-shénbiàn-zhēnyán-jīng*) is a short piece, the text of which is a mantra taken from the *Amoghapāśakalparāja sutra* by the Northern Indian Buddhist monk and translator Bodhiruci (ca. sixth century).

[39] In the notes for this section of Kakui's text, reference has been made to the neumes of the Latin and Byzantine Christian churches for the purposes of comparison with Kakui's neumes. For all references to the Latin neumes, the translator has consulted Floros 2011. For the Pale-Byzantine neumes, the author has consulted Wellesz 1978b: 14–52. Finally, for the Middle Byzantine neumes, the author has consulted Troelsgård 2011.

[40] The text here reads "ikitsuzuki" (息續). This neume resembles the Latin *punctum* and Paleo-Byzantine *kentema*, especially as when the latter appears in the Middle Byzantine system used in conjunction with *oligon*, in which case it represents an ascending third. In the Shingon tradition, this neume most often appears as a component of a compound of two or more neumes, and it represents simultaneously both a continuity of the breath and a cutting-off of the sound in the midst of a transition between two adjacent notes that share the same pitch and are intoned on the same syllable. Interestingly enough, the corresponding neume in the Middle Byzantine system is classified as a *pneumata*, which, in the case of the ancestral Alexandrian prosodic signs, refers to the group of diacritics that indicate the presence or absence of aspiration (Ltn. *spiritus*). In


Hakase graphs like this one are called 'pierce and twist'.[41]


This *hakase* graph is called 'pierce and overlap'.[42]


This *hakase* graph is the same as that above, namely, 'pierce and overlap'.


This *hakase* graph is called 'draw in'.[43]


This *hakase* graph is called 'rising sound'.[44]


This *hakase* graph is called 'receiving sound'.[45]


This *hakase* graph is called 'bend and suspend'.[46]


This *hakase* graph is called 'pierce and stop'.[47]


This *hakase* graph is called 'shake and descend'.[48]


This *hakase* graph is called 'shake and overlap'.[49]


This *hakase* graph is called 'shake and bend upward'.[50]


This *hakase* graph is called 'kaku, of which there is no bending upward'.[51]

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pieces with Chinese-character transliterated Sanskrit texts, the neume "ikitsuzuki" is often applied to text segments in which the underlying Sanskrit text features a double consonant. See Duran 2020:, 56.

[41] The text here reads "tsuki-mawasu" (突回).

[42] The text here reads "tsuki-kasane" (突重). This neume, as well as the one that follows it, resembles the Latin *porrectus* and Paleo-Byzantine *parakletike*. Like *porrectus*, 'tsuki-kasane' notates a three-pitch pattern. When 'tsuki-kasane' is drawn from left to right, as it is in Kakui's treatise, the three-pitch pattern is characterized by a fall and subsequent rise, just as the pitch pattern indicated by *porrectus*. In such cases that 'tsuki-kasane' is drawn from right to left, the direction of the pitch inflection is often reversed, becoming a rise and subsequent fall. In either case, the precise interval associated with the movement from the first to the second members of the three-pitch pattern represented by 'tsuki-kasane' varies between pieces, sub-sects, and performers. In some cases, the second member of the three-pitch pattern is distinguished not by a change in pitch per se, but rather, by way of decreased volume and a change in tone color.

[43] The text here reads "hiki-komu" (引込).

[44] The text here reads "agaruoto" (アガル音).

[45] The text here reads "ukeoto" (受ケ音).

[46] The text here reads "ori-kake" (折懸). This neume most resembles the Middle Byzantine *ison*, but whereas the latter notates a repeated pitch, 'ori-kake' seems to have more of an articulatory and, ultimately, durational function. In the Buzan sub-sect, 'ori-kake' has morphed into the graphically distinct 'nomu'(のむ). The latter is strictly applied to Chinese characters of which, in their Sino-Japanese readings, the final morpheme is represented by the kana 'tsu' (ツ). Such Chinese characters are, as a rule, in the entering tone (入声), a phonetic feature that is realized musically with an abrupt cutting-off of the sound towards the end of an intonation.

[47] The text here reads "tsuki-todome" (ツキトドメ). This is a compound neume comprised of elements from 'ikitsuzuki', 'tsuki-kasane', and 'ori-kake'.

[48] The text here reads "yuri-ori" (由下).

[49] The text here reads "yuri-kasane" (由重).

[50] The text here reads "yuri-sorasu" (ユリソラス).

[51] The text here reads "kaku ni soru to iu koto nashi" (角ニソルト云事無シ). This neume resembles the Middle Byzantine *oligon* with which it seems to share an overlapping function. In the Middle Byzantine system, *oligon* is used to notate an ascending second with no accentuation. In similar fashion, the neume from Kakui's treatise notates a movement to the pitch 'kaku' but without the use of the semitonal upward inflection known as 'sori'.

 This *hakase* graph is called ‘push and bend upward’.[52]

In practice, there are more *hakase* graphs than could possibly be enumerated. Not knowing this list of *hakase* graphs, and having not received oral transmission, one must not guess at their meanings thus giving disorder to their transmission. Also, with regards to the *hakase* graphs that are not listed here, each and every single one should be learned through oral transmission.

6.12 A list of techniques and concepts not indicated by the hakase graphs

‘Blowing voice’[53]
‘Self-descending’[54]
‘Flavouring’[55]

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[52] The text here reads “osu-soru” (推スソル). This neume resembles the Latin *virga* and Paleo-Byzantine *oxeia*. Once again, Kakui’s use of the term ‘soru’ in qualifying pitch movements on the basis of their ornamental rather than their structural scalar content seems to overlap with the Middle Byzantine system’s use of various neumes in specifying differing levels of accentuation amongst pitch movements that are otherwise of identical intervallic content. In this regard, we may note that the Middle-Byzantine version of *oxeia* notates an ascending second with moderate accentuation.

[53] Here, “blowing voice” translates the term “fuku-goe” (吹声). To this translator’s knowledge, no melodic type by this name is used in the extant traditions of Shingon Shōmyō, but its name, in both its ideographic representation as well as in the mental image that it evokes, is reminiscent of a melodic type used in the Tendai sect called “nodo-koe” (喉声), or “throat voice”. For example, in the Tendai Shōmyō piece *Kuyōmon* (供養文), this melodic type, which is really an articulatory technique, is used in the pronunciation of the compound, ‘issei’ (一切), more typically pronounced in *go-yomi* as ‘issai’ but here pronounced in *kan-yomi*. The compound translates to ‘all’. Here, on the last morpheme ‘I’, a quick and strong aspiration is given following the pronunciation of the vowel, precisely equivalent to how a visarga would be pronounced following a vowel in Sanskrit. It is the translator’s strong suspicion that the visarga sound was indeed mapped onto the phonology of Chinese Buddhist chant texts and included as an obligatory articulatory phonetic technique and feature of their recitation. We know, for example, from the writings of Siddham scholars (ancient and medieval Chinese and Japanese scholars of Sanskrit phonetics and orthography) that the compound ‘issei’ contains consonantal gemination which in Sino-Japanese is known as sokuon (促音). This phonetic event is determined by the rules of euphonic combination as applied to the junction of initial character finals and succeeding character initials, which themselves were in the writings of the Siddham scholars, classified into two groups of stops, one nasal and the other consonantal. These two groups of stops were known respectively as kūten (空点) and nehanten (涅槃点), both of which are translations of Sanskrit terms, ‘anusvara’ in the former case and ‘visarga’ in the latter. It is the nehanten that gives birth to the sokuon, and the term ‘issei’ is a classic example of this. The puff of air used in the pronunciation of a sokuon such as this is reminiscent of the Sanskrit visarga, and it is aptly described by both the terms ‘throat voice’ and ‘blowing voice’. For more on these and other phonetic adaptations of Sanskrit sounds to Chinese characters, see SChaudhuri 1998.

[54] The text here reads “jige” (自下). In the Buzan branch of Shingon Shōmyō, this is a highly melismatic melodic type that includes both a large ascent and descent. For an extensive look at the use of this melodic type in Shingon Shōmyō, see Gamo 1973: 117–43. The contour of this melodic type, as well as its name, meaning as it does “descent from oneself”, is strangely reminiscent of the ‘independent svarita’ in Sāmavedic chant, and the author wonders whether or not this melodic type is an example of the influence of Sāmavedic chanting practices on Buddhist chant.

[55] The text here reads “enbai” (塩梅), or literally, “salt and plum”. This refers to the upward semitonal ornamentation that is affected on the pitches ‘shō’ and ‘ū’ that expand the Shōmyō melodies outside of their anhemitonic pentatonic framework. The term ‘enbai’ in the context of Japanese Buddhist music occurs as early as the ninth century in the Tendai priest Annen (841–915)’s *Shittanzō*. Perhaps this term was originally a translation of the Sanskrit ‘rasa’, meaning ‘flavor’, but conceptually it is much closer to the concept of

'Looking-out-upon tune'[56]
'Dissenting view'[57]
'Prelude'[58]
In order to learn these, one must enter the house of Shōmyō and receive oral transmission.

6.13 *Regarding the thickness of* hakase *graphs*

Hakase graphs that are too small or too thin are especially undesirable. The indication of the *hakase* graphs should be large and vivid, and the affixing to them of the katakana script clear and in black ink.

6.14 *Regarding the method of affixing the katakana script*

For a practitioner of Shōmyō, properly affixing the katakana script to texts is of the utmost importance. Regrettably, there are many practitioners who do not understand this. The most frequently made mistake in this regard is affixing the kana 'u' to a Chinese character where in fact the kana 'fu' is required.[59] There are many examples of such characters of which the pronunciations are easily confused, but for the most part the matter can be summarized with the following examples:

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sādharaṇa. Indeed the metaphor of salt is used in the description of sādharaṇa, particularly that of the raised seventh scale degree, or *kākali-nī*, in the *Nāṭyaśāstra*, the foundational text of ancient Indian music and dramaturgy. See Bharata-Muni 1951: 13.

[56] Reizui's version of the text here reads "臨節", pronounced "rinzetsu", but the version of the text in the *Zoku-Shingon-shū-zen-sho*, one that was based on a coalescing of several different and later dated manuscripts, has the identically pronounced "輪舌". See Kakui 1986. Although the two renderings of the text are phonetically equivalent, only the latter can be construed as having any bearing on the practice of Buddhist chant, meaning as it does 'rolling tongue', and thereby apparently describing an articulatory technique used for enunciating chant texts. Hence, the *Zoku-Shingon-shū-zen-sho* version of the text is most likely correct. Reizui's rendering of the term in question, though possessing clear phonetic value, lacks apparently correct semantic value.

[57] The text here reads "isetsu" (異說). This is most likely not a technique but rather refers to the existence of differing views with regards to various topics within the oral tradition. In the twelfth century, the Shingon Shōmyō tradition was divided into four branches, namely, the Honsōōin (本相応院), Shinsōōin (新相応院), the Daigo (醍醐), and the Daishinshōnin (大進上人). It is very common in the *kudensho* literature for the authors to compare the teachings of their branch, in this case, the Daishinshōnin (later Nanzanshin) with those of others, for example, in this text, that of the Sōōin (presumably referring to both the Honsōōin and Shinsōōin).

[58] The word "prelude" here translates the Japanese term "Jo-kyoku" (序曲). In Tendai Shōmyō, this term refers to an unmetered shōmyō piece or section thereof. The "Jo" of "Jo-kyoku" also appears in the tripartite rhythmic and stylistic division of pieces utilized in the Nō theatre, known as Jo-ha-kyū (Jp. 序破急). There, "Jo" is an unmetered and slow introductory section, "Ha" a more briskly-tempoed intermediate section, and "Kyū" a fast-tempoed 'rush' to the end of the piece. The 'Jo-ha-kyū' concept has its theoretical origins in Japanese court music, or Gagaku, but in that tradition, there are few pieces that adhere to the tripartite 'Jo-ha-kyū' structure; more often, that structure is merely implied by gradual acceleration and deacceleration, and pieces tend to be categorized each by only one of the three types.

[59] In the modern realization of classical Japanese orthography, the kana 'fu' (フ) is pronounced as such only when it is in the word initial position. Otherwise, it follows pronunciation rules identical to those for the kana 'u' (ウ). Japanese Siddham scholars recognized both 'u' and 'fu' as consonantal stops, categorizing them

法 (ha-fu)
劫 (ko-fu)
業 (ke-fu)
搆 (se-fu)
答 (ta-fu)
合 (ka-fu)
入 (ni-fu)
立 (ri-fu)
納 (na-fu)
甲 (ka-fu)
及 (ki-fu)
十 (shi-fu)
習 (shi-fu)
拾 (shi-fu)

All of these characters are pronounced in the entering tone.[60] As such characters are innumerous, it is better to internalize the general principle rather than attempt to memorize them all.[61]

6.15 *Differentiating the nasal sounds 'n' and 'mu'*

Regarding the kana 'mu', though I have not myself received oral transmission from a teacher, I will give my own observations here. In such cases that the sound 'mu' is required in the middle of a *hakase* graph, it is written 'mu', but when the sound 'mu' comes at the end of a *hakase* graph, it should be written as 'n'.[62]

6.16 *Differentiating double and triple kana*

The differentiation of triple kana from double kana is of the utmost importance. Affixing triple kana where double kana are required, and conversely affixing double kana where triple kana are required, is indicative of a lack of study. Refer to the following examples:

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as *kūten* (空点) and *nehanten* (涅槃点), respectively. The sound 'u' was classified as a guttural (kōnai, 喉内) nasal stop and 'fu' as a labial (shinnai, 唇内) oral stop. See Chaudhuri 1998: 86.

[60] Here, for the first time in this short treatise, the tones of the Chinese characters (Ch. *sìshēng*, Jp. *shisei*) employed in *Shōmyō* texts take center stage. In general, there were four such tones, and in many early *shōmyō* texts these were indicated by way of circular dots at any of the four corners of a character in question. The dots themselves were and are known as *shiseiten*, and their functions can be specified as follows; a *shiseiten* at the lower left-hand corner of a character indicates that that character is in the level tone. In like fashion and proceeding clockwise, a *shiseiten* in the upper left-hand corner corresponds to the rising tone, in the upper right-hand corner to the departing tone, and in the lower right-hand corner to the entering tone. Kakui's main concern at this point in the treatise is with pronunciation, but as we will see, the *shisei* were also one of the determinates of melodic movement and direction in Shōmyō pieces. Also of interest here, is the fact that the neumatic notations known as *fushihakase* that preceded the advent of the *go-in bakase* system were drawn in such a way that they emanated from the *shiseiten*. By the time of the invention of the *go-in bakase* system, these marks were still used in some contexts but had also given birth to a separate but parallel set of dots that functioned exclusively as indicators of the points from which *go-in bakase* graphs emanate. These can be seen in all of the *hakase* graphs that appear in Reizui's treatise, and by extension in the images provided in this translation.

[61] Literally, "it is better to know the ten-thousand by the one".

[62] In the modern pronunciation of classical Japanese orthography, a word final 'mu' (ム) is read as a nasal 'n' (ン). The latter sound in modern Japanese is represented with the kana 'n' (ン) , of which the origins are slighlty obscure, but not completely so. By all estimations this special kana evolved from the graphically similar *candrabindu* used in the Siddham script to represent a final nasal in Sanskrit. Japanese Siddham scholars categorized 'mu' as a labial nasal stop, or kūten (空点). It is not entirely clear when the kana 'n' (ン) first came into use. See Chaudhuri 1998: 100.

Triple Kana[63]	Double Kana
乗 [shi-yo-u][64]	朝 [te-u]
勝 [shi-yo-u]	消 [se-u]
承 [shi-yo-u]	照 [se-u]
	繞 [ne-u]

6.17 Mouth-meeting Kana

There is the matter of the ‘mouth-meeting kana’. For example, when intoning a Chinese character for a long time, sometimes the pronunciation-indicating kana that would normally appear at the end of a Chinese character does not so appear, and it is instead exchanged for a kana such as ‘u’.

6.18 Un-notated sounds

There are musical matters that, though not being indicated by the *hakase* graphs, should in-fact be present in the voice. In order to learn these, one must receive oral transmission. If the sound one makes is exactly that which is indicated by the *hakase* graphs, this is evidence that one has not received oral transmission. In contrast, if one has received oral transmission, one will intone those sounds that, though correct, are not indicated by the *hakase* graphs.

6.19 The method of composing a hyōbyaku[65]

Depending upon one’s station and the time at hand, one may unexpectedly be required to compose a hyōbyaku. Knowing how to indicate the *hakase* graphs in such times is of the utmost importance.

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[63] In these examples, the matter at hand is the differentiation between two sets of characters that, though agreeing (in Kakui’s time) with regards to their vocalic sounds, were in fact descended from two different pronunciation groups, a fact made most evident by their accompanying orthography as well as in the pronunciation preserved in the current traditions of Shingon shōmyō. Therefore, I have opted to diverge from the modified Hepburn romanization system employed heretofore, opting instead for the use of hyphens to separate the roman text into sections representative of what are, in the Japanese text, individual kana.

[64] Voicing is often not indicated in Reizui’s version of Kakui’s text, and the romanization here reflects this. Hence, the character “乗”, which in modern Japanese pronunciation would be ‘jō’ (ジヨウ), is given in Reizui’s manuscript as “shō” (シヨウ).

[65] A *hyōbyaku*, alternatively pronounced *hyōhyaku*, is a piece in a mostly recitative style, and it is one that explains the purpose of a rite to the central deity/bodhisattva/buddha to whom that particular rite is addressed. *Hyōbyaku* is a sub-genre of pieces that is ultimately descended from the narrative-style of Buddhist chant known as *shōdō* in Sino-Japanese and *chàngdǎo* in modern Chinese pronunciation. This pedigree is shared with the sub-genre *kyōke* which Kakui discusses later in his treatise. The origins of *chàngdǎo* and the legends associated with its earliest master performers in China is discussed at length in the thirteenth volume of the *Memoirs of Eminent Monks* (Ch. *Gāosēng Zhuàn*, Jp. *Kōsōden*) compiled by the Chinese Buddhist monk Huìjiǎo (497–554) in the sixth century. Here, we can see that the *chàngdǎo* originated as stylized sutra lectures performed at large-scale maigre feasts. Given their didactic function, they were, naturally, performed in the vernacular, a linguistic feature that persists in the Sino-Japanese offshoots of *chàngdǎo* to this day. For a modern Japanese translation of the relevant section, see Ekō 2010.

The Shin and Sōō-in branches differ in their methods of creating a hyōbyaku.[66] The indication of *hakase* graphs is mostly standardized in both branches, but the basic pattern is deviated from on the basis of sandhi that occurs between adjacent characters upon euphonic combination. One must take this matter to heart.

One must not arbitrarily indicate the *hakase* graphs without knowing the tones of the kana in question.[67] For example, there are regulations regarding the kana that function in the capacity of grammatical particles, namely, 'te', 'ni,' 'wo', and 'ha'. The tone of the kana 'no' is indeterminate. If the Chinese character from which a particular kana is derived is in the level tone, then accordingly, the diacritical marking of the tone of that kana is low. If the Chinese character from which a kana is derived is in any of the other tones, then accordingly, the diacritical marking of the tone of that kana will be high.[68] When composing a hyōbyaku, one must distinguish between the provincial sounds and the correct sounds.[69] It is a terrible thing for one to indicate the *hakase* graphs without knowledge of the difference between the *go-on* and *kan-on*. [70]

It is an enormous error, for example, to compose a piece based on the provincial sounds just because one prefers them. If one confuses the distinction between *go-on* and *kan-on*, then the melody will be low when it should be high, or conversely, it will be high when it should be low. In short, failing to distinguish between the provincial and correct sounds, and rather, arbitrarily indicating *hakase* graphs according to one's will, is not proper.

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[66] Here, as elsewhere, "Shin" refers to the Nanzanshinryū branch of Shingon Shōmyō. This was Kakui's branch, and it is the only branch of Shingon shōmyō to have been transmitted to the present time.

[67] Here, "the tones" refers to the *shisei*, which according to a note by Reizui not included in the present translation, were applied to the kana on the basis of the tones of their progenitive Chinese characters. For example, the kana 'ア' (representing the syllable 'a') was derived from the Chinese character "阿", a character presumably pronounced in the level tone. As such, the kana 'ア' received a shiseiten in its lower left-hand corner, just as would a Chinese character in the level tone. A kana originating from any of the other three tones was given a *shiseiten* in the upper left corner. That is, the tones of the kana were classified into only two categories, not four. This two-part classification of tones is apparently based on the bifurcation of Chinese character tones into level (平, Ch. píng, Jp. hyō) and oblique (仄, Ch. zè, Jp. soku) categories, with the oblique category encompassing all of the tones other than the level one, be they rising (上, Ch. shǎng, Jp. jō), departing (去, Ch. qù Jp. kyo), or entering (入, Ch. rù, Jp. nyū).

[68] In Mair and Mei (1991: 382–83), it is argued quite convincingly that the bifurcation of the Chinese tones was based on the concept of syllable weight transferred from Sanskrit prosody to Chinese Buddhist hymnody. For a look at how this manifests in *Shōmyō* pieces with Chinese-character-transliterated Sanskrit texts, a class of pieces known in Japan as *Bonsan*, please refer to the translator's Japanese-language PhD dissertation: Duran 2020. Here, it is demonstrated that a stress accent based on syllable weight, perhaps that of the Classical Sanskrit register, is a key determinate of melodic generation in a large number of those pieces.

[69] Here, "provincial sounds" most assuredly refers to the so-called *go-on*, one of the two systems of Chinese character pronunciation prevalent in Japan from Heian times and the one originating in the area south of the Cháng Jiāng (Yangtze) river. This layer of readings was in all likelihood imported to Japan via the Korean peninsula between the fifth and sixth centuries. On the other hand, "correct sounds" here refers to the second of the two systems, namely, the *kan-on*, which corresponds roughly to the pronunciation of Chinese characters in the Chinese capital Cháng'ān during the Tang Dynasty (618–907).

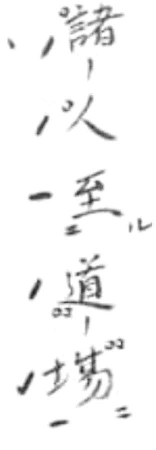
[70] Here, Kakui refers to the two sets of Chinese character pronunciation directly.

6.20 The 'Kō-Otsu-Hei-Tei' portion of a hyōbyaku

Hyōbyaku contain sections that are divided into four clauses indicated by the terms Kō, Otsu, Hei, and Tei, of which the melodic patterns are somewhat regulated; in such sections, there are times when one's indication of the *hakase* graphs is not entirely dependent upon one's knowledge of the 'correct sounds' of the characters. Depending upon the situation, one may indicate the *hakase* graphs in such a manner not in accordance with the sounds of the Chinese characters. Be this as it may, not knowing the distinction between the *kan-on* and *go-on* creates irregularities in the melodies that are not in accordance with the dharma; it is an embarrassment and renders one the object of ridicule.[71]

6.21 The method of positioning hakase graphs when moving from the level tone to the departing tone

There are times at which, when moving from the level tone to the departing tone, though it is indicated that the level-toned character be intoned at a high pitch and the departing-toned character at a low pitch, with regards to the actual sound there is no rise in the level-toned character's pitch. An example from the 'tei' clause is as follows: [72]



6.22 Differences between the shin and sōōin branches with respect to notating the kō clause

At the end of the line in the kō clause from the previously mentioned four-clause section of a hyōbyaku, the Shin branch indicates the *hakase* as 'chi' followed by 'kaku', as such:

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[71] Given the explicitly Buddhist context of this treatise, I have translated the character "法" with the Sanskrit term *dharma*, its most common correlate in Buddhist contexts, but it may as well have been translated here as 'rules'.

[72] In Kakui's example, the text reads "諸人至道場" (everyone proceeds to the *dōjō*). Note here that in the image, both characters "道" and "場" contain a doubling of the *shiseiten*. This indicates voicing of the initial consonant, much like (and progenitive of) the diacritical marks known as *dakuten* in modern Japanese, which likewise serve the function of indicating voicing. Once again, by way of comparison with the Nestorian neumes mentioned earlier, one notes that a doubling of the dots in that system affects an intensification of the melodic movement dictated by the positions of those dots.

Conversely, the Sōō-in branch, in this same section, exclusively uses the *hakase* ‘chi’. Nevertheless, in both branches, when a character in the level tone succeeds one in an oblique tone the level-toned character receives the *hakase* ‘chi’, as follows:[73]

No matter how many successive level-toned characters occur, there is no mistake in indicating them all with the *hakase* ‘chi’. All of the oblique-toned characters will receive either the *hakase* ‘strike and suspend’, as follows:

or the *hakase* ‘overlap’, as follows:

Which of these two *hakase* graphs is used is determined by the sandhi of the characters in question.[74]

6.23 Differences between the shin and sōō-in branches with respect to the notation of the otsu clause

In the Shin branch, the otsu clause *hakase* are indicated at the pitch levels ‘chi’, ‘kaku’, ‘shō’, and ‘kaku’. In the Sōō-in branch, the beginning of the clause is notated ‘chi’. This is followed in the next character by the *hakase* ‘chi’ and ‘kaku’. Finally, the *hakase* of the last character of the clause are indicated at the pitch levels ‘chi’, ‘kaku’, and ‘shō’.

6.24 Differences between the shin and sōō-in branches with respect to the notation of the hei clause

In the Shin branch, the hei clause is notated with the *hakase* ‘chi’, ‘kaku’, and ‘shō’, after which there is a pause. With regards to this clause, the Sōō-in branch’s melodic treatment matches that of the Shin branch’s kō clause.

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[73] Here, “oblique tones” (仄声) refers to any of the three tones other than the level one, whether they be rising, departing, or entering.

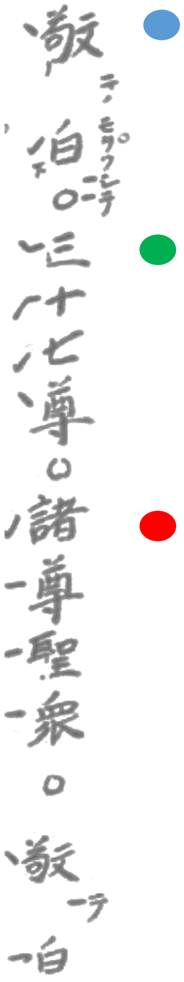
[74] The priority placed upon distinguishing between level and oblique tones for the purposes of determining melodic movements in this explicitly Buddhist chant context would seem to be yet more proof of the theory originally put forward by Victor H. Mair and Tsu-Lin Mei, that the concept of syllable weight was transferred from Sanskrit prosody to Chinese Buddhist hymnody before exerting influence on the genre of poetry known as ‘Recent Style Poetry’. Once again, for a look at how this manifests in *Shōmyō* pieces with Chinese-character-transliterated Sanskrit texts, a class of pieces known in Japan as *Bonsan*, please refer to the translator’s Japanese-language PhD dissertation (cited in footnote 38), where it is demonstrated that a stress accent based on syllable weight, perhaps that of the Classical Sanskrit register, is a key determinate of melodic generation in a large number of those pieces.

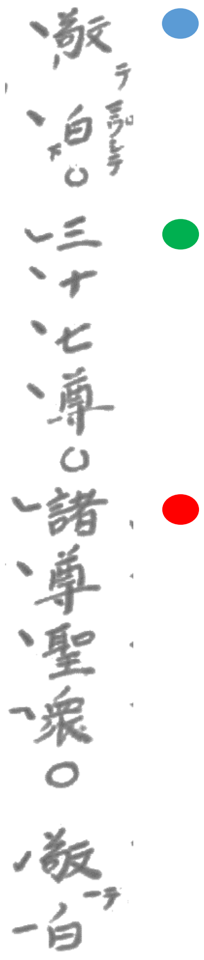
6.25 *Differences between the shin and sōō-in branches with respect to the notation of the tei clause*

In the Shin branch, the tei clause is notated as 'shō', 'kaku', 'shō', 'kaku', followed by a pause. In the Sōō-in branch, this is notated as 'shō', 'shō', 'shō', 'kaku', followed by a pause.

6.26 *Differences between the shin and sōō-in branches with respect to the notation of the kami-oroshi clause*

In the notation of the Kami-oroshi clause, there is a difference between the Shin and Sōō-in branches. Even though the texts of the two examples that follow are the same, there are differences in the *hakase* graphs:





Kami-oroshi Clause, Shin-Branch Kami-oroshi Clause, Sōō-in Branch

One must learn to distinguish between these two versions of the same text by studying the *hakase* graphs.[75]

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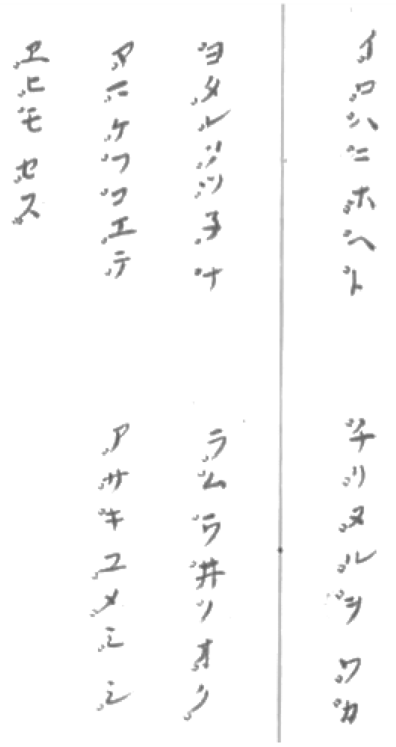
[75] Kakui here gives not two versions of a single line from the kamioroshi-clause, but rather, multiple segments of that clause. In Kakui's examples, the individual segments of text are separated from each other by circles. See Appendix V for a transcription of the current Buzan tradition's realization of several of these segments, as they appear dictated in Kuriyama and Koizumi 1998. The blue, green, and red dots accompanying the images here are intended to be used in matching the relevant text sections to the transcription in Appendix

Also, with regards to the five-layered melody of the piece Kyōke, there are notational differences between the Shin and Sōō-in branches.

Everything written heretofore is that which was imparted by the master. Memorize this treatise as quickly as possible, and upon doing so, throw it into the fire. What has been written here has so been written that it will not be forgotten, and it represents only the most basic of principles.



イロハニホヘト　チリヌルヲワカ
ヨタレソツネナ　ラムウ井ノオク
ヤマケフコエテ　アサキユメミシ
ヱヒモセス

The tones of the katakana script[76]

END OF KAKUI'S TEXT

V. Note that in the current Shingon traditions this piece is composed in *ōshikichō*, a mode that is classified as neither *ritsu*, nor *ryo*, but rather, as *chūkyoku*. Chūkyoku is considered to be an amalgamation of the *ritsu* and *ryo* modal types, but in its anhemitonic pentatonic form, its interval structure is equivalent to that of a *ritsu* mode. The anhemitonic pentatonic version of *ōshikichō* is A-B-D-E-F#.

[76] This final image, containing no explanation, is an arrangement of the pangrammatic song known as the *Iroha-uta*, and it is apparently included here to teach the various tones of the katakana characters, which as stated before, were based on the tones of their progenitive Chinese characters. One presumes that this song was at some point chanted in a melody, the contours of which were determined by the tones of the constituent kana characters. One further surmises that this acted as a device for ingraining the sounds of the different kana tones in the minds of the officiant priests hence facilitating their powers of rapid recall, powers to be called upon in such events requiring the construction of a *hyōbyaku* or any other such *shōmyō* piece in the kanbun-kundoku style that would necessarily involve the use of kana, as opposed to only Chinese characters.

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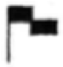
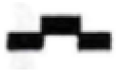
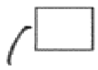
Appendix I: A comparison of the Carolingian gestural neumes (circa 800), the Dunhuang neumes from the *Avalokiteśvara Sutra* (948) and the Japanese *fushihakase* (1034–1202)[77]

Carolingian Neumes	Name	punctum	virga	podatus	clivis	torculus
	Square-note shape					
	Gestural Neume					
Dunhuang Neumes		NA				
Japanese *Fushihakase* (including *shiseiten*)		● or ••				

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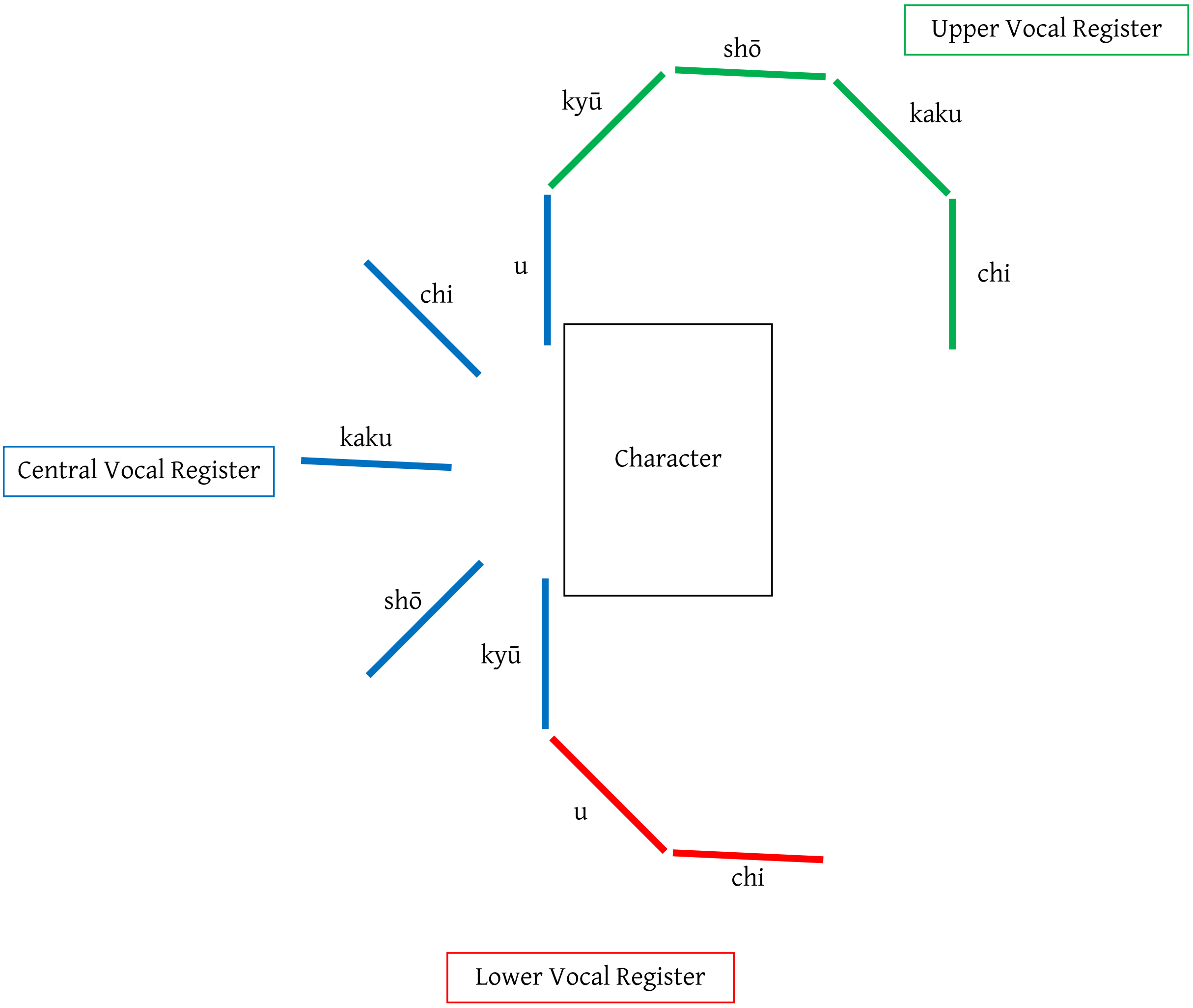
[77] The Carolingian neumes presented here are of the archetypical 'Type-2 Gestural' variety as deduced in Levy 1987: 75. The images of the Dunhuang neumes provided here are taken from Kobayashi 2014: 176, and that of the *fushihakase* are as they appear in Numoto 1991: 72.

Appendix II: How to read the *Go-in Bakase* graphs[78]



Ryo Pentatonic Scale:	kyū [2] shō [2] kaku [3] chi [2] u
Ritsu Pentatonic Scale:	kyū [2] shō [3] kaku [2] chi [2] u

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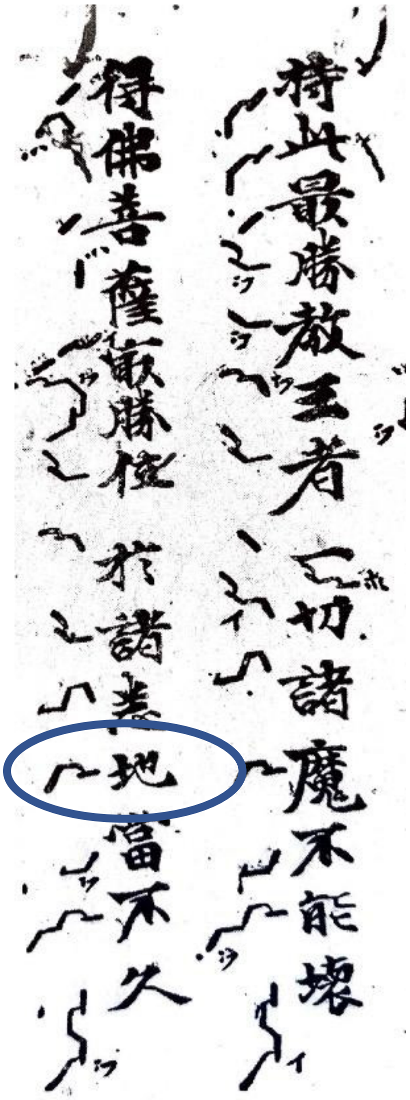
[78] The intervallic sequences of the *ryo* and *ritsu* pentatonic scales are here expressed by way of pitch names followed by bracketed Arabic numerals indicating the number of intervening half-steps between any pair of successive scale degrees. Note that the distance from a lower ‘u’ to an upper ‘kyū’ in both the *ritsu* and *ryo* pentatonic scales is three half-steps.

Appendix III: The notational treatment of the character 'ground' ("地") from the *Rishukyō* (理趣経)[79]



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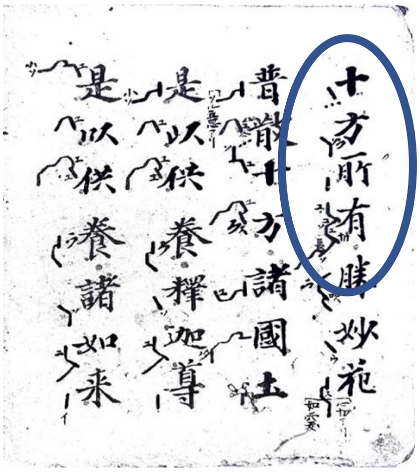
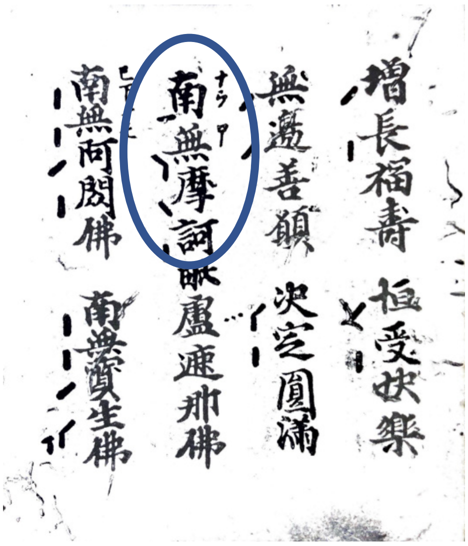
[79] This example is taken from the 1472 Shōmyō-shū, printed at Kōyasan and published in facsimile format by Nelson and Fukushima. See Fukushima 2018: 35. The relevant section of text, as referred to by Kakui, is indicated with a blue oval. It is the only such instance of the character in the texts of the *Rishukyō* that this translator could identify. Here, as described previously, the second *hakase* graph affixed to the character "地" though indicating the pitch 'u' does not appear at a 90-degree angle as it theoretically should, but rather, it is tilted slightly to the left. Note that the image has been slightly modified such that succeeding text sections separated from each other in the publication of the anthology appear together without a break. In the current traditions, this piece is in the *chūkyoku* mode *ōshikichō*.

Appendix IV: Examples of re-positioned *hakase*[80]

Excerpt from Unga-bai (長寿)[81]



Excerpt from Bonnon (十方所有)[82]



Excerpt from Monju-no-san (土法王家)[83]

Excerpt from Kongōkai-Raibutsu (南無摩訶)[84]

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[80] All of these examples are taken from the 1472 Shōmyō-shū, printed at Kōyasan and published in facsimile format by Nelson and Fukushima. See Fukushima 2018. In Appendix IV, the relevant text sections, as referred to by Kakui, are indicated with blue ovals.

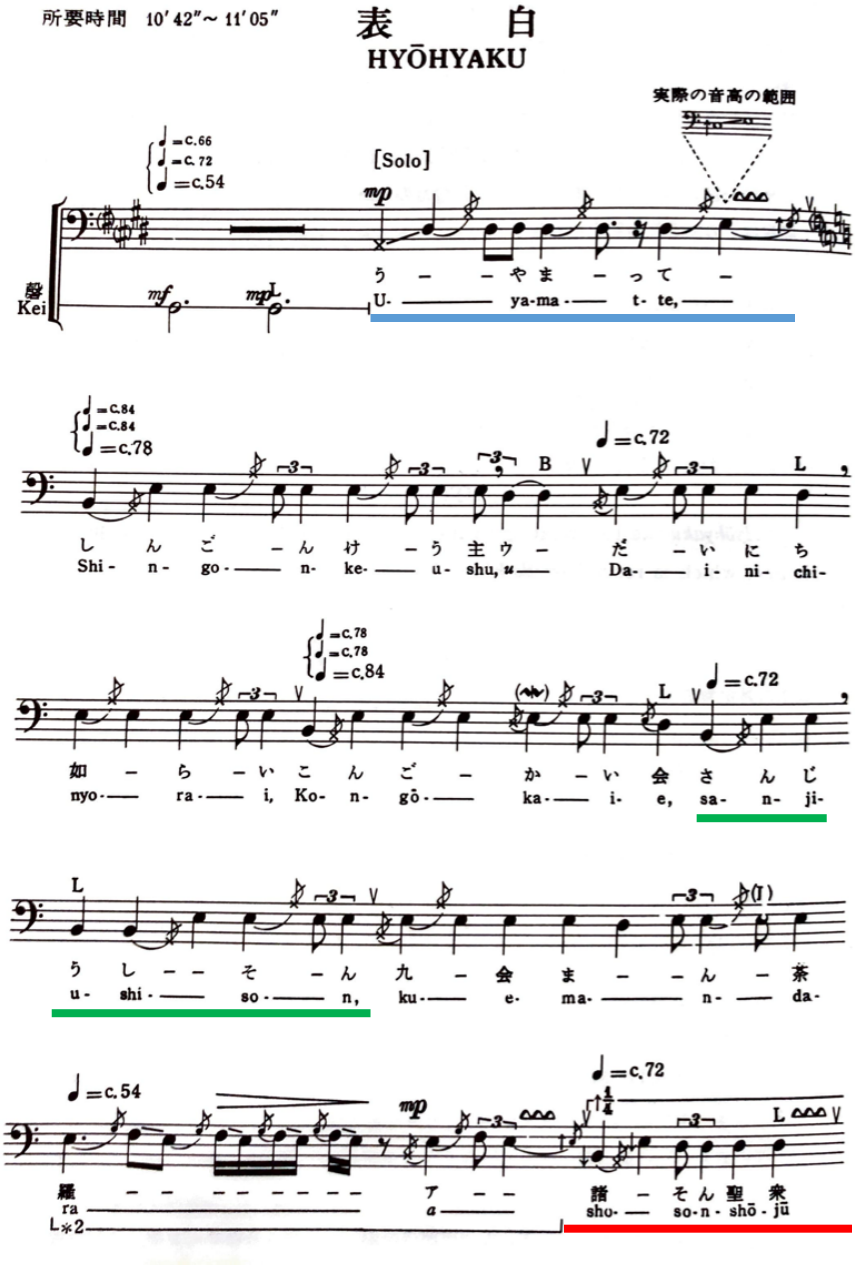
[81] Fukushima 2018: 9. In the current Shingon traditions, this piece is in the *ryo* mode *sōjō*.

[82] Fukushima 2018: 11–12. In the current Shingon traditions, this piece is in the *ritsu* mode *banshikichō* .

[83] Fukushima 2018: 40. This piece is in the *ritsu* mode *hyōjō*.

[84] Fukushima 2018: 26. This piece is in the *chūkyoku* mode *ōshikichō*.

Appendix V: Transcription of a segment from the Hyōbyaku Kami-oroshi Clause[85]



🔵 “敬テ”; 🟢 “三十七尊”; 🔴 “諸尊聖衆”.

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[85] This transcription can be found in Kuriyama and Koizumi 1998: 140.

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Pre-Columbian Maya Valveless Tube Trumpets

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Abstract

There are some 77 representations of non-conch shell pre-Columbian Maya tube trumpets known, but only one extant ceramic version survives. The others are known from paintings, engravings, and sculptures. Of these there appear to be two primary types: trumpets of one or more materials (gourd being one of those) and wrapped trumpets. For this chapter I discuss the evidence for these instruments, their materials and means of manufacture, and their uses. I will also examine the sonic signatures on replications of the ceramic trumpet and a dipper-gourd trumpet.

Keywords

Maya – Trumpet – Gourd – Iconography – Pre-Columbian music – Experimental archaeology

In this paper I discuss the evidence for pre-Columbian Maya non-conch shell, end-blown, valveless trumpets (referred to here as valveless tube trumpets) including their materials and means of manufacture, their sonic signatures, and their uses. The data set contains one ceramic trumpet, two ceramic trumpeters, and seventy-seven artistic depictions on thirty-three different objects and in various media, all attributable to the pre-Columbian Maya.[1] I will concentrate on the valveless tube trumpets on the three ceramic objects, the three wall paintings at Bonampak, and eight painted pottery pieces, as representative examples of the set. All extant trumpets are ceramic and small. They will receive some attention shortly, but I will focus on the larger ones shown in Maya

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[1] The seventy-seven trumpets are found among depictions on architecture at Tikal, three Jaina Island figurines, a Campeche column, Rooms 1, 2, and 3 at Bonampak, as decoration around respective doorways at Hormiguero and Chicanná, as graffiti on architecture at Nakum, Dzibanche, Rio Bec, Tikal, La Blanca, and Yaxha (Źrałka 2014), and on the following pieces of pottery: Grolier nos. 31, 33, 36; Kerr nos. 1210, 1453, 3092, 3814, 4120, 4412, 4625, K5534, K5795, K5937, K6294, K6317, a Kerr vase in Schele and Freidel 1990: 268, the Xamac Vase, *Vaso de Ratinlinxul*, Dumbarton Oaks no. 16, and the plate 1989.110 (Metropolitan Museum of Art). In addition, I have seen photographs showing large Maya ceramic collections (public and private) – with depictions painted or carved on the objects in them – which suggests to me that there are probably more representations of the instrument than those listed here.

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Figure 1: Kerr Vase K1210. Reprinted by permission of the Maya Vase Database.

art works, as they are much more prevalent, and offer the best evidence of non-ceramic construction material, morphology, and uses.

Formerly, I have referred to the latter as gradually widening tube trumpets, but further review of the evidence leads me to believe that Maya trumpets of perishable materials – presumably all but the ceramic type – were made of various organics and in various shapes. To redefine my description, all were relatively long, all were narrow at their proximal or mouthpiece ends, and all were wide at their distal or bell ends. But not all were gradually widening. Wood is an obvious choice for the material used in their construction, producing long, sturdy and malleable planks that could be hollowed out. A tree native to southern Mesoamerica and South America, nicknamed "the trumpet tree" (*Cecropia peltata*) is locally prized for its light-weight wood (Standley 1927), and could have been used in the manufacture of the instrument eponymously named. I believe that it or another wood type may have provided the majority of tubes for a particular Maya trumpet that the Franciscan friar Diego de Landa described as "tienen trompetas largas y delgadas, de palos huecos, y al cabo unas largas y tuertas calabazas" (Landa 2021: 31). The Mayanist William Gates translates tuertas as "twisted," and therefore the rest of the sentence should read in English as a long thin trumpet made of a long piece of hollow wood with a long twisted gourd at the end (Landa 1978: 36). In fact, a review of the pictorial data shows trumpets literally in the shape and design that de Landa described (Figure 1).

These two trumpets are no doubt stylized, but the general shape is of a long thin tube attached to a twisted gourd decorated with tassels or flowers. Another vase painting shows trumpets that are analogous in design, but with bells that are only slightly twisted or not twisted at all (Figure 2).

Figure 2: Kerr Vase K6317. Reprinted by permission of the Maya Vase Database.

Figure 3: Kerr Vase K1453. Reprinted by permission of the Maya Vase Database.

Combining de Landa's historic account with pre-Columbian pictorial evidence mutually enforces the identification of a type of Maya trumpet, and so combining the historical with the pictorial seems a good method for continuing this approach. A second sixteenth century quote, by Domingo de Vico (n.d.), found in the *Vocabulario de la lengua cakchiquel con advertencia de los vocablos de las lenguas quiché y tzutuhil se traslado de la obra compuesta por el limo* addressing a language of highland Guatemala, describes the "tun" as a "calabaza como trompetas que tañen", "gourds like trumpets that they play"[2]. There are not only several Maya depictions of trumpets that seem to be made entirely of gourds, in fact the vast majority seem to be so, and as shown here my reasoning

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[2] Author translation.

Figure 4: Kerr Vase K5937. Reprinted by permission of the Maya Vase Database.

for believing this is based on the assumption that much art of the Classic era Maya (250–900 CE) favored naturalism: an attempt at an objective rendering of the natural world (Miller 1999: 20).

This means that those things that appear as known objects in art works are likely to be those objects. With that explanation in mind, I propose that what are largely being depicted in the artworks are trumpets made from two distinct species of gourd: the long neck dipper or handle gourd (*Lagenaria siceraria*), and the snake gourd (*Trichosanthes cucumerina*).[3] Both are long tubular gourds that can be manipulated through growing or *post-growing* techniques, and when hollowed out their thinner ends can function as the mouthpiece ends of a valveless trumpet.

K1453 (Figure 3) is a vase painting showing two long neck dipper gourd trumpets. It is of more than cursory interest that the indentation or cupped shape of the bells may have been an attempt to depict a hollowed object by an artist unaware of 3D painting techniques (see Figure 5). On the right, the bowl holding liquid being drunk by one of the attendants and the larger pink bowl in the front both have the same cup shape at their tops, perhaps indicating that they too are hollow.

Another vase painting (Figure 4) of a long neck dipper gourd trumpet, does not include additional hollowed objects which we could use for comparison, but its faithfulness in its depictions of other objects characterizing the featured ball game – the ball, the yokes, the stance of the player – may mean that in this scene the trumpet bell happens to be the only hollowed object present.

Figure 5 shows a model of a long neck dipper gourd trumpet, which the author made from a single dried gourd in this general shape, purchased at Pumpkin Hollow, in Pigott, Arkansas. In this

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[3] Erickson et al. (2015) propose the bottle gourd, of the *cucurbitaceae* family, or its seeds, traveled from Asia to the New World with early hunter gatherers who migrated there over ten-thousand years ago. The snake gourd is of the same family and may have been dispersed similarly. That said, I have not located confirmation of the early dates of the snake gourd's emergence in the Americas, but to turn the question around, the fact that they appear in pre-Columbian artwork as trumpet bodies suggests that the plant made its way to Mesoamerica at or before the time of Maya civilization.

Figure 5: Author playing a long-neck dipper gourd trumpet. Photo by Stephanie Artz.

exercise in experimental music archaeology, the player's lips are pursed and caused to vibrate at the cut proximal end, without use of a mouthpiece. The trumpet's fundamental sounds the pitch 566 Hz, or approximately C#5 in Western notation. A sampling of its sonic potential proves its propensity to sound partials of the overtone series, with the root and its fifth being the two easiest pitches to produce. An octave and higher pitched glissandos are also relatively easy to sound.

Despite my initial focus on long neck dipper gourd trumpets – with their thin bodies and bulbous ends – the majority of Maya trumpets depicted could correctly be labeled gradually widening tube trumpets; and all or the majority, of these I believe were made from snake gourds, or a hybridized combination of snake and dipper gourds (Figure 6).

This long widening tube trumpet is most famously shown in the murals of the Late-Classic lowland site Bonampak, painted in 791 CE, where eight are depicted in three rooms: The scene in Room 1 concerns the naming and tribute ceremony of a future heir to the throne and shows two gradually widening tube trumpets, with the players blowing into the smaller ends of the conical tubes held aloft at 45%. They are both orange except for black or green ruffle or flower-shaped protuberances around the ends of their bells (Figure 7, bottom right panel).

Two similarly shaped trumpets intrude into the battle scene in Room 2 (second panel from the left), with the

Figure 6: Three light-colored snake gourds. Photo courtesy of Savvy Gardening.

Figure 7: Room 1, Bonampak, Mexico, Maya, AD 791. Reconstruction, Yale University Art Gallery, Gift of Bonampak Documentation Project, illustrated by Heather Hurst and Leonard Ashby.

Figure 8: Room 2, Bonampak, Mexico, Maya, AD 791. Reconstruction, Yale University Art Gallery, Gift of Bonampak Documentation Project, illustrated by Heather Hurst and Leonard Ashby.

Figure 9: Room 3, Bonampak, Mexico, Maya, AD 791. Reconstruction, Yale University Art Gallery, Gift of Bonampak Documentation Project, illustrated by Heather Hurst and Leonard Ashby.

one held aloft differing slightly by having crossed bones painted along its upper length. The other trumpet faces down and is without designs (Figure 8).

Room 3 featuring a court dance, includes four trumpets (bottom right panel), with two of those being blown while the other two are held in the right hands of their players (Figure 9). Additional representations of almost identically shaped trumpets include figurines from the Mexican gulf coast necropolis on Jaina Island, which in the example below is a duct-activated whistle, making a small sculpture of one instrument sound like another (Figure 10).

In Kerr Vase K3814 three gradually widening tube trumpets play for a ball game, with the ball and players wearing yokes, as was noted in the earlier vase with a ball game and dipper gourd

Figure 10: Jaina Island ceramic whistle depicting a trumpeter. Photo courtesy of Sainsbury Centre for the Visual Arts.

trumpets (Figure 11). It is worth pointing out that this vase includes glyphs of the Primary Standard Sequence (PSS), a formulaic glyphic sequence that indicates specific details about the vessel, which can include the individuals or scene depicted, the type of material it contains, or a dedicatory ownership. Ownership information is indicated by a possessive glyph known as the God N Head variant and/or the *ik* (T-shaped) sign for wind – which coincidentally is tied to music in origin and metaphysics.

The scene on Kerr Vase K4120 (Figure 12) features a dancer performing before a ruler, and includes rattles accompanying the gradually widening tube trumpets. In addition, an apparent God N Head variant and the *ik* symbol in its literal form as breath emanating out of the mouth of the god can be seen at the top. The fact that two vase paintings of the ball game feature trumpets that are of different designs – one in the shape of a dipper gourd and the other in the shape of a snake gourd – suggests that perhaps the activities musicians played for were not conditional on the use of specific shaped trumpets. It is also possible that for Maya music the quality of sound, the timbre, was of equal or greater importance, and a change in

Figure 11: Kerr Vase K3814. Reprinted by permission of the Maya Vase Database.

Figure 12: Kerr Vase K4120. Reprinted by permission of the Maya Vase Database.

tone quality might signify a different type of ritual, or a portion of a ritual. We also cannot assign different trumpet types to different time periods, as the majority of known depictions are from the Late-Classic period (600–900 CE). However, there may be some reason to believe that trumpet shape is conditional on geographical areas of use, as gourd trumpets are so far only known from the Maya lowlands and wrapped trumpets, discussed next, are most often depicted on pottery found in the highlands.

The distinctive weave pattern encasing the body of a type of Maya trumpet that I call the wrapped trumpet may have been used for decorative purposes, or to provide a solution to the restriction on length that might have been imposed by local materials. If, for example, the desired non-conch trumpet was narrower at its mouthpiece end and wider at its bell the possible lack of local material of a suitable length might have necessitated that shorter sections of available substances be attached together to achieve the desired length and shape. In art works wrapped trumpets are represented as gradually widening tubes with some type of thin-stripped material probably of cane or cloth wrapped around their proximal ends.[4]

The ethnomusicologist O'Brien-Rothe (O'Brien 1983) has proposed trumpet wrapping as constituting the instrument itself or being utilized to cover the joints connecting separate pieces of wood tubing, held together by pins or dowels. She mentions an indigenous precedent for this design in South America, where there are native trumpets with bells of material woven in the manner of baskets (*ibid.*: 22; Izikowitz 1934: 233; 235 Figure 113).

This type of trumpet is sometimes painted on a highland vase type, known as Chamá, which was manufactured during the Late-Classic period (600–900) in the Chixoy River valley in the northern mountains of Guatemala. Figure 13 shows a famous Chamá vase known as the *Vaso de Ratinlinxul*.

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[4] The wrapped trumpet types covered here use one of two techniques for instrument wrapping: plait weave, which is an interlacing of two or more strands of flexible material in a pattern like a braid (see Figure 13); and layering, which is the placing of a flexible material around an object in a spiraling motion, from top to bottom or bottom to top (see Figure 15).

Figure 13: *Vaso de Ratinlinxul* (Kerr Vase K594). Reprinted by permission of the Maya Vase Database.

Figure 14: Xamac Vase rollout. Photo courtesy of Linda O'Brien-Rothe.

This one, like other Chama vases with music scenes doesn not have PSS glyphs, so interpretation is dependent on an analysis of the scenes depicted. The scene on the *Vaso de Ratinlinxul* features a wealthy man being carried in a litter, a small black and white-spotted dog growling underneath his sedan, and an entourage that includes two porters and three figures holding gradually widening tube trumpets, encased in plaited wrappings on their lower portions. The three yellow and white trumpets appear to have separate mouthpieces, which resemble modern Western ones.

Another Maya vase with wrapped-tube trumpets is attributed to Xamac, a site located in the Ixil highlands near the modern town of Chajul, Guatemala. O'Brien-Rothe (O'Brien 1983) included this vase painting in an essay on Maya bone instruments, where her reproduction is barely clear enough to show three elaborately dressed individuals performing on trumpets, each differing slightly in design. At least one of the horns, the one in the rear, has a wrapping on the lower part of its body. Glyphs (likely dates) are included above the trumpeters and under one is a dog (an animal sometimes depicted in association with wrapped-tube trumpets) (Figure 14).

Figure 15: Kerr Vase K5534. Reprinted by permission of the Maya Vase Database.

O’Brien-Rothe (O’Brien 1983) has researched numerous small clay and bone tubes found at Maya archaeological sites and has determined that some of these may constitute pre-Columbian trumpet mouthpieces. A few bone tubes are even inscribed with plait-patterns, suggesting an association with other objects sharing that design. One such weave simulates a mat, and a class of high-ranking official went by the title of “keeper of the mat” or “he of the mat” (Miller and Taube 1997: 110–11; Tedlock 1996: 345). In addition, archaeologists Mary Miller and Karl Taube (1997: 110–11) define the Yukatek phrase *popol nu* as “mat house”, and propose it as a community house for young people where, among other activities, dance performances were held.

The archaeologist Michael Coe (1973) claims that Chamá vases were funerary offerings and that the scenes painted on them were probably of a mythological nature (Miller 1989: 137). The dog may be included because of the animal’s mythological connection to the underworld, where it often served as a guide. On the *Vaso de Ratinlinxul*, two figures carry articles that strongly suggest the man on the litter is a merchant, and the vase itself may have been a funerary object meant to celebrate, or at least describe, his life. It is known that among the Aztec deceased merchants were often placed on sedans and carried to a mountaintop to be cremated (*ibid.*: 112).

Vase Kerr file number K5534 (as well as K6317, Figure 2 above), includes the same four elements as are in the merchant scene: a wealthy man in a litter, a dog underneath it, and an entourage that includes porters and trumpeters with wrapped trumpets (Figure 15).

Apart from paintings on pottery, the wrapped trumpet is also found on at least one Maya sculpture, a limestone column discovered in the modern State of Campeche, Mexico, and on display in the capital of the state at the Maya Sculpture Museum. Carved on its surface are two performers playing plait-wrapped trumpets in accompaniment to a ceremonial gift exchange. A distance of 600 km separates its place of origin from that of the *Vaso de Ratinlinxul* but both are


Figure 16: Model of Villahermosa trumpet, constructed by Valerie Hanks-Goetz. Photo by author.

attributed to the Late-Classic period, indicating the extent of distribution for that instrument type during that era. Unlike gourd trumpets which so far are restricted to the lowlands, wrapped trumpets do occur in both the lowlands and highlands, even if more are known for the latter.

Maya tube trumpets of perishable materials such as gourd and wood, like those described by de Landa and de Vico have not survived. But there is at least one Prehispanic Maya trumpet, of fired clay, that has. It is on display in the Museo Regional at Villahermosa, and was made using the coil technique. [5] It is approximately 3 cm wide at the mouthpiece, 5 cm at the bell, and in keeping with known extant Mesoamerican clay trumpets, is short – only 17 cm long (Figure 16). This clay trumpet could be a toy, a model or a functioning instrument and if the latter, based on its length, it yields a slightly sharp E5 (676 Hz) as a fundamental tone (at −13 dB).

The Villahermosa trumpet is of one piece, but molded to resemble an object in two sections, the mouthpiece end and the flaring bell (Figure 16), its mouthpiece being a in a cup shape with its outer edges widened sharply like the instrument's bell. In addition to the functional sound-making components, the bell end is decorated with three slightly raised ovals in clay molded to form a broken line of ovals proceeding up the widening tube. Some light on the significance of this design may be shed by a small clay sculpture deposited as a funeral offering at Jaina Island. That object represents a musician who stands proudly holding the middle of a long trumpet in the crook of his left elbow (Guzmán Bravo et al. 1984: 124). The flaring bell of the instrument extends above the figure's head, and based on its shape would seem to represent the single-material long-tube type. An embossed design on the body of the trumpet vaguely recalls the oval elements on the short Villahermosa trumpet. The Mayanist Linda Schele (1997: 146) proposed that that embossed design

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[5] The Maya used coil and slab techniques. The coil method most likely involved the formation of clay into long coiled pieces that were wound into a vessel. The coils were then smoothed together to create walls. The slab method used square slabs of clay to create boxes or types of additions like feet or lids for vessels. Once the pot was formed into the shape, then it would have been set to dry until it was leather hard. The pot was next painted, inscribed, or slipped. The last step was the firing of the vessel. Kilns were used to fire the vessels, and they were normally found outside in the open air. Unlike many modern kilns, they were fired by wood, charcoal, or even grass.

Figure 17: Jaina Island ceramic whistle depicting a trumpeter playing a trumpet with a slide or brace. 38.B Whistle 1.2.75.204. Museo VICAL. Photo courtesy Jared Katz.

represented a functional though stylized device, a brace perhaps, used to help fasten the bell section to the body of the instrument, which the clay model copies.

Another ceramic trumpeter from Jaina Island clearly shows a brace, which the archaeologist Karl Taube has proposed to be a slide, a device that could move the bell along the body and thus change the length and pitch of the instrument (Figure 17: Katz 2018: 135 and 147). If true, this instrument is the first known representation of a pre-Columbian trombone. Coincidentally, one of the long neck dipper gourd trumpets, shown in Figure 3, had a similar brace or slide device.

Sixteenth-century accounts by Westerners do not make mention of Maya trumpet playing as sounding significantly different than trumpet playing in the West, nor do they make mention of any strange or unusual technique(s) used by these trumpeters. Therefore, one may conclude, that like modern Western trumpeters, pre-Columbian Maya musicians must have produced sounds on their trumpets by forcing air through pursed lips vibrating against the receiver end of a tube made from one or more resonating materials. This technique is distinct from the open-lipped blowing technique used to produce a sound on the gradually widening *dijeridoo*. Using varying degrees of lip tension and air pressure, a specific pitch is produced, derived from partials of the overtone series relative to the fundamental pitch of the horn.[6]

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[6] Specifically, the bell (distal end) of the trumpet utilizes the wave produced by lip buzzing, and serves as the end point of the wave. The total length of the vibrating air column causes a drop in resistance, forming the wave, which then travels back to the lips, changing their shape so that they match the pitch of the trumpet.

Figure 18: Two of the three Rab'inal Achi musicians, Rabinal, Guatemala: Photo by author.

The fundamental pitch of the particular instrument depends predominantly on the length of its tube (Tarr 1980: 211; 213). If the instrument functioned acoustically in a way similar to a metal one, an eight-foot-long (244 cm) valveless gourd trumpet should sound the following pitches: C1, C2, G2, C3, E3, G3, Bb3, C4, D4, E4, F#4, G4, A4, A#4, B4, C5 (Piston 1955: 209). That said, the overall size and register of the instruments can be estimated, but not the precise length and fundamental tone. The width of the bore primarily determines the instrument's timbre.

According to the archaeologist Norman Hammond (1972:225), the lengths of the trumpets painted on the three walls at Bonampak, estimated in proportion to the presumed height of their performers are: Room One, 108 cm; Room Two, 106–50 cm; and Room Three, 160 cm. It is possible, using ratios, to establish a relationship of trumpet length and interval for comparative purposes. Accordingly, Room 1 and Room 2 exhibit trumpets of similar length, so their relationship is one of unison; Room 3 to Room 1 and Room 2 are approximately 3:2, giving a difference of about a fifth. This means that the trumpets from Room 1 and Room 2 are a fifth higher than the trumpet from Room 3, which is ⅓ longer than they are. All of this is speculative and does not answer any questions conclusively about Maya concepts of keys or scales, but it constitutes data that might inform future researchers with better evidence of pre-Columbian Maya music practice.

The best indication for a continuation of pre-Columbian Maya music practice and the resulting sounds are a handful of dance-plays, called *bailes*, some of which continue to be performed in highland Guatemala. The most famous of these is the Rab'inal Achí, a drama about love, betrayal, and atonement in the centuries before Spanish conquest. It is accompanied by a band of two valveless trumpet players, playing brass trumpets, and a slit drummer (Figure 18).

The two trumpeters have two specific music roles. The one called alto plays high glissando lines and the one called bajo supports the slit drum rhythm by playing short and long notes on the root and fifth. In this way, the two trumpeters play sounds that are the most easily produced on a long-necked-dipper-gourd trumpet. This, however, is not meant to suggest proof of the continuation of a past Maya music practice.

To make a trumpet from a long neck dipper gourd is relatively easy. According to personnel at Pumpkin Hollow, where I purchased my gourds (personal communication 2021), the hardest part is growing and shaping the gourds. This entails hanging the plant after harvest so that the bulbous end straightens out from the stem due to gravity. Then the gourd is cut and boiled for further manipulation, and is turned into its final shape after curing (some are fabricated into shapes with circular or bent stems). After purchasing several straight stemmed gourds I chose three to fabricate into trumpets by making two cuts with a knife, one near the proximal end of the stem to form a mouthpiece, and one at the other, the bulbous part, to make a bell. A dowel was then inserted in the stem to clean out the interior membrane (alternately, a strong piece of stripped cane could be used).

In conclusion, an important point not discussed is the possibility that some, but probably not all, of what the Maya have painted and sculpted that resemble trumpets were not those instruments (or any kind of instrument). I mention this, not to cast doubt on the evidence presented, but to remind us of the nature of that evidence. Pictorial and sculptural images are subject to artistic license and subjective interpretation. Archaeological bias engendered by the particular artworks excavated may also confound the record. That said, a combination of the accumulated visual and historical evidence suggests that large gourds of one or more species were the core materials used to make pre-Columbian Maya trumpets, and as such, that they could have functioned similarly to the brass ones used in Mexico and Central America today.

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The ‘*talempong batu*’ Lithophone of Talang Anau (West Sumatra) and its Astonishing Tuning System

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Abstract

In 1995 I was asked to acoustically analyse recordings of a nearly unknown lithophone from a small village in West-Sumatra. The *talempong batu* consists of six large stones of unknown grey to beige material, which look quite rough and natural and are approximately 100 to 150 cm long, 30 to 40 cm wide and 15 to 25 cm thick. All six stones show a complex spectrum with inharmonic overtones that is typical of vibrating 3D objects. The interval matrix between the lowest partials of all six stones was determined. The analysis of the tuning system showed quite unexpected results: the four lowest stones establish a complex system of intervals, which perfectly matches some intervals that are known as perfect major third (5/4, 386.31 cent), ‘Pythagorean’ ditone (81/64, 407.82 cent), and syntonic comma (81/80, 21.51 cent). The deviation between these theoretical intervals and the measured intervals from the instrument is less than the just-noticeable pitch difference (JND) that the human ear can detect. If it is assumed that this system did not simply evolve by chance, its existence allows us to draw some important conclusions on the cultural background and capabilities of its creators.

Keywords

Lithophone – Tuning – Indonesia – Sumatra – Pythagorean intonation – Just intonation – Syntonic comma

1 Background

Back in 1995, when I started my career as research assistant at the Department of Musical Acoustics at Cologne University, my ethnomusical colleague Uwe Pätzold returned from field studies that he had conducted in Indonesia in 1994/95. He told me that he had been made aware by some local acquaintances of an interesting stone instrument called *talempong batu* in a small town in the mountains, which had so far received little attention from the scientific community. Although this subject had little to do with his main research interests, he decided to visit the instrument and to make some systematic recordings of the instrument and its local environment.

Back in Cologne some months later, he asked me to conduct some acoustical analyses of these recordings, mainly related to the sound characteristics and the tuning system of the instrument. At first glance, this didn't seem like a big deal – until the analyses revealed some quite astonishing results.

We presented our findings in two separate German conference talks, one from the ethnomusicological and one from the acoustical perspective. Unfortunately, for several reasons the proceedings of this conference were not published until 2003 (Louven 2003; Pätzold 2003) and didn't gain much attention in the scientific community. In retrospect, it would probably have been wiser to publish the results in an English-language international journal as early as 1995.

Even today, the *talempong batu* remains nearly completely unrecognized by the international scientific community. Besides the 2003 publications of Pätzold and myself, Google scholar lists only 12 other papers that mention the *talempong batu* in a musical context (and not as tourist attraction in the region). Nine of them are written in the Indonesian language and therefore not easily accessible to the international community. Nearly all of them mention the instrument only briefly, while mainly discussing the *talempong* instrument family of the Minangkabau culture (Adoma 2018; Ardipal 2013; Ardipal 2015; Barendregt 2002; Darlensis 2006; Fraser 2015; Hidayat et al. 2019; Rustayanti 2014; Sari, Desriyeni 2019; Takari 2008; Wahyudi et al. 2019; Wardizal 2022). Ultimately, these publications seem to assume that the *talempong batu* belongs to the Minangkabau culture, mainly *because* it shares the name talempong with other instruments of the Minangkabau tradition: "Minangkabau society have several types of talempong music ensembles, such as Talempong Pacik, Talempong Unggan, Talempong Batu, Talempong Jao, Talempong Batuang, Talempong Sambilu, and Talempong Kayu, and other talempong types" (Adoma 2018: 110).

However, there is no discussion of whether this name might have been chosen simply because people were used to naming such percussion instruments *talempong* – without claiming or even knowing anything about the actual origin of the instrument.

None of these papers gives any further description, explanation, or analysis of the *talempong batu* itself. Therefore, since our findings themselves remain valid and have been confirmed several times by other colleagues, it seems appropriate to revisit the state of musicological research on this astonishing instrument.

2 Description of the instrument

The *talempong batu* lithophone is located in a cabin in the small village Talang Anau in the mountain region of West Sumatra (see Figure 1). The location of the instrument, the village and the surrounding area are described in detail by Pätzold (2003: 277–8).

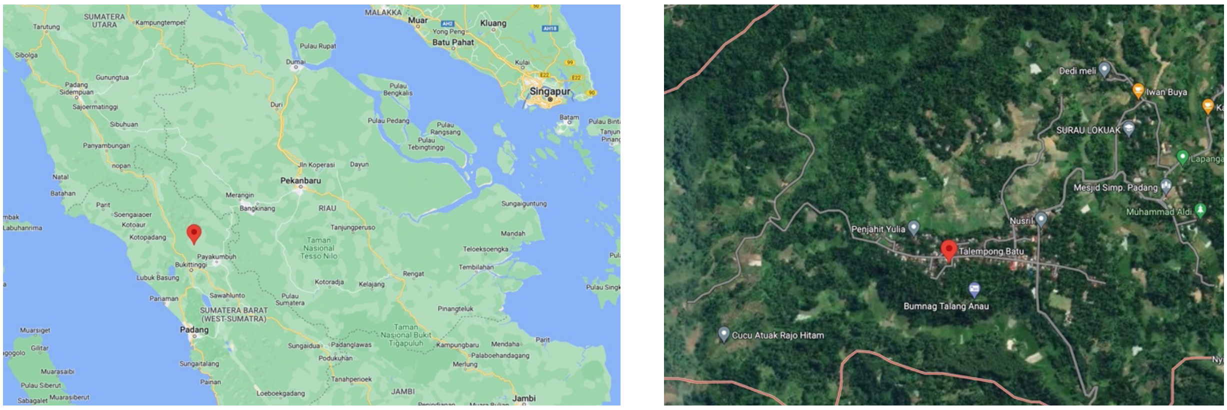

Figure 1: Location of the *talempong batu* in Talang Anau, West Sumatra.

The *talempong batu* consists of six large stones of a grey to beige mineral material. Since Pätzold neither had expertise in mineralogy nor could he take some samples for later analyses, at present one can only speculate on the exact nature of the mineral. The stones are approximately 100 to 150 cm long, 30 to 40 cm wide and 15 to 25 cm thick and rest on two bamboo poles above a resonance pit. As one can see from some recent videos on YouTube, the surrounding cabin and the bamboo poles have been renovated since Pätzold’s visit in 1995 (see the video stills in Figure 2).

The six stones are arranged in a seemingly irregular order that neither follows their sizes nor brings their pitches in a straightforward sequence. However, the analysis will show that this order is to some extent consistent with aspects of the tuning system (see below).

Figure 3 shows a schematic diagram of the instrument. The Roman numbers indicate the order of the stones and are used below to identify the stones.

The stones give a relatively natural or only very roughly worked overall impression. It does not seem as if the creator of the instrument paid special attention to the smoothing of the surface or the shaping of the overall form, for example in the sense of a cuboid or a symmetrically rounded form.

In addition to the actual material of the stones, the age of the instrument is still completely unclear, i.e. when the stones were collected, crafted, and arranged in exactly this order over the

Figure 2: The *talempong batu* lithophone in 1995 (left) and 2015 (right). Video stills.

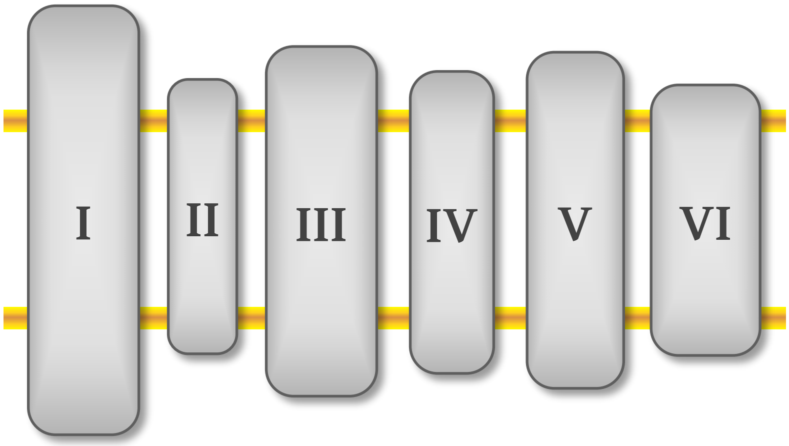

Figure 3: Schematic diagram of the *talempong batu*.

resonating pit. The available information on the instrument is not sufficient to make even an approximate dating. Pätzold (2003: 288) deduces from the statements of his informants on site and his research on oral tradition and local history at least that the instrument must have remained practically unchanged at this location since the beginning of the 19th century: "A relatively recent creation of the lithophone (cannot) be assumed." According to Pätzold's information and considerations, a much older origin of the instrument, possibly going back thousands of years, seems possible. However, there are still no reliable findings on this, so that any attempt at a historical classification must remain speculative and can only be made with caution.

3 Sound material and analysis methods

In 1994, Pätzold's recordings were made using an analogue Hi8-Video equipment with external microphones, using both the digital PCM (32 kHz/12 bit) and the analogue HIFI stereo audio tracks. The PCM digital track of the Hi8 system proved to be frequently overmodulated and therefore distorted. Therefore, to get the best material for the analysis, the analogue audio tracks, which were far less distorted, were digitalized with 48 kHz/16 bit in order to be digitally analysed.

During his recording session, Pätzold systematically recorded numerous single strokes with different levels and at different positions of the stones. From each of the three different stroke positions (left end, middle, right end) of each stone, we selected three suitable, not overmodulated strokes. Therefore, all in all, 6 stones × 3 positions × 3 strokes = 54 sounds were used as source material for the acoustic analysis.

4 Sound impression, transient response and spectrum

The stones sound quite homogeneous within the whole instrument and at the different stroke positions. The sound is clear with a distinct pitch perception and appears more reminiscent of a metal instrument like a gong or a bell than of stone.

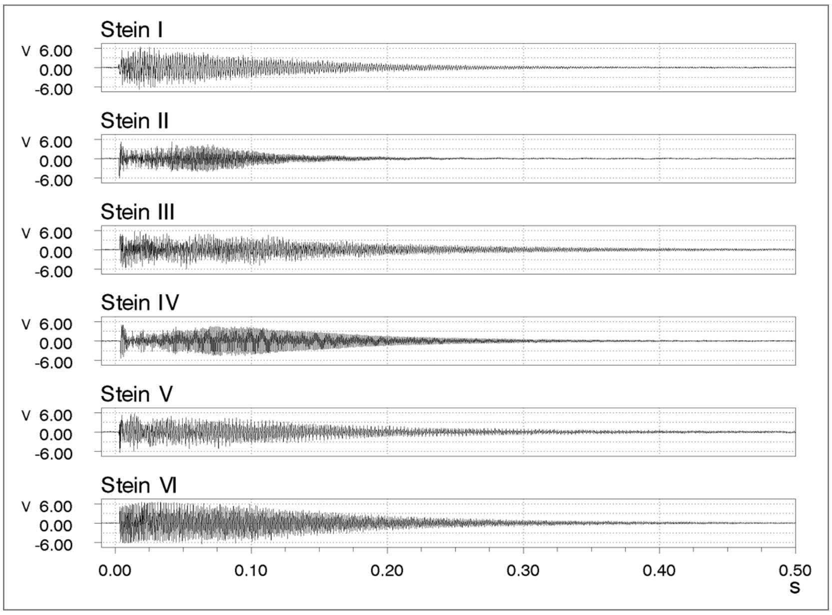

Figure 4: Transient response of all six stones.

Figure 4 shows a typical transient response for each of the six stones. All sounds are quite short (approx. 200 to 400 ms). It is noticeable that there is a slight delay in the transient response of stones II and IV, which reach their maximum only after approx. 60 - 80 ms. The shortness of the sounds would impact the possibilities of tuning such stones to a desired pitch (see below).

To analyse the spectrum and the partials of the stones, high resolution FFTs of all 54 selected sounds were calculated. Signal windows of approx. 1.5 s duration with the stroke in the middle were selected with Hanning signal windowing. Due to the high sampling rate, approx. 70000–80000 sampling values could be considered and thus a high-resolution FFT with 32767 interpolation points and a resolution of Df = 0.7324 Hz could be calculated.

All six stones show a complex spectrum with inharmonic partials, which is typical for any kind of irregularly shaped, vibrating 3D object. Figure 5 shows typical spectra from all three different stroke positions for stone I as an example. The spectra of the other stones overall look quite similar.

Not surprisingly, the details of the spectra slightly differ with the stroke position. However, the frequencies of the partial peaks seem to be quite stable and largely independent of position.

For each of the calculated spectra per stone, the frequency and level of the individual partial peaks were determined. With nine measurements per stone, this made it possible to minimise the error of the resulting arithmetic mean, since a Gaussian distribution of the measurement error of the individual measurements can already be assumed here. Calculated from the spectra of all nine strokes per stone, Table 1 shows the mean frequency and the standard error of the mean frequency for all partial peaks above approximately −20 dB for all six stones.

The partials marked + for Stones III and V in Table 1 resonate with a clearly perceptible delay compared to the fundamental, which results in the impression of a slightly lingering seventh in Stone III and a slightly lingering fifth in Stone V. Stone III shows a slight change in the fundamental

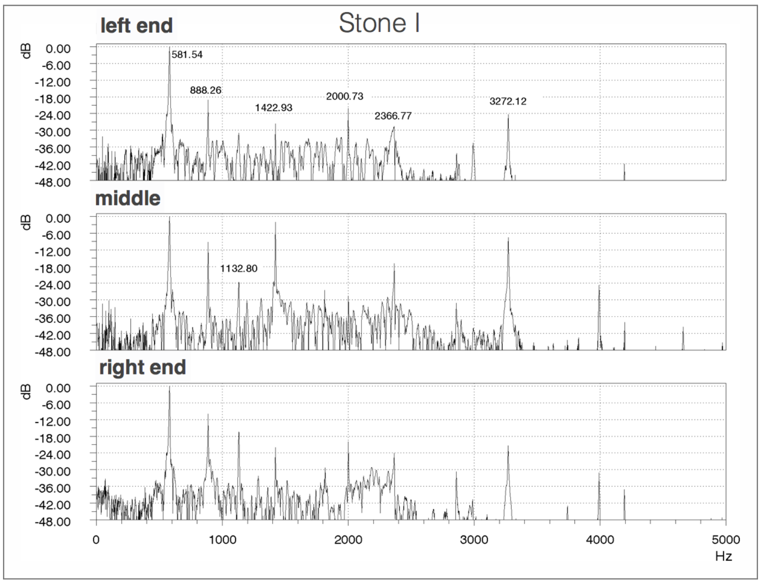

Figure 5: Spectrum of stone I at different stroke positions.

frequency with a change in the point of impact, which does not occur with the other stones, and which leads to a large standard error of the mean value. If the stroke positions of Stone III are considered individually, the fundamental frequency is absolutely stable within each position.

Stone	# (f_0)	f[Hz]	SE(f)
I	1	581.54	0.00
		888.26	0.11
		1132.80	0.12
		1422.93	0.11
		2000.73	0.12
		2366.77	0.18
		3272.12	0.13
II	6	1256.10	0.00
		1524.65	0.17
		2105.05	0.31
III	2	726.80	0.32
		1179.19	0.00
		+1333.24	0.12
		1475.09	0.00
		1943.84	0.00
		2409.74	0.08
		2693.84	0.00

Stone	# (f_0)	f[Hz]	SE(f)
IV	5	1111.65	0.11
		1658.99	0.47
		1814.20	0.17
V	3	736.08	0.17
		+1109.77	0.11
		1826.24	0.13
		2582.02	0.12
		3057.36	0.12
VI	4	918.53	0.08
		1422.60	0.25
		1602.77	0.12
		2841.05	0.00

Table 1: Number of the stone, ordinal number of the fundamental frequency, and mean frequencies with standard errors for each partial above –20 dB.

stone	cent	**I** 581.54 ±0.00	**III** 726.80 ±0.32	**V** 736.08 ±0.17	**VI** 918.53 ±0.08	**IV** 1111.65 ±0.11	**II** 1256.10 ±0.00
II	1256.10 ±0.00	1333.20 ±0.00	947.19 ±0.76	925.22 ±0.40	541.86 ±0.15	211.50 ±0.17	0
IV	1111.65 ±0.11	1121.70 ±0.17	735.69 ±0.78	713.72 ±0.43	330.36 ±0.23	0	
VI	918.53 ±0.08	791.34 ±0.15	405.32 ±0.78	383.36 ±0.43	0		
V	736.08 ±0.17	407.98 ±0.40	21.96 ±0.86	0			
III	726.80 ±0.32	386.02 ±0.78	0				
I	581.54 ±0.00	0					

Table 2: Intervals between the fundamental frequencies of the six stones (cent ±MSE).

5 Intervals and tuning system

Since the perception of the fundamental pitch and the partials may be crucially dependent on subjective phenomena such as residuals or combination tones, which would remain undetected in the applied acoustic analysis method, an auditory analysis of the individual sounds was carried out for comparison. In no case could a residual or a combination tone be detected that differed from the lowest partial, so that the frequency of the lowest partial can be assumed to be the fundamental frequency and primary perceived pitch. Therefore, the analysis of the tuning system was based on the intervals between the lowest partials (fundamentals) of the stones. Table 2 shows the complete cent-matrix of intervals (with Mean Squared Error of the cent value).

The analysis of the tuning system shows some very surprising results. When we take a closer look at the intervals between the four stones with the lowest pitches (framed in Table 2) we find some intervals that are nearly identical to some specific intervals that are of great relevance in documented tuning traditions, not least the Western: the ‘Pythagorean’ ditone, the perfect major third, and consequently also their difference, the so-called syntonic comma (see Table 3). Matching intervals in Tables 2 and 3 are marked with the same colours.

In the European tradition, the ‘Pythagorean’ ditone and the perfect major third mark the main difference between two historically important tuning concepts (Barbour 1951):

○ The so-called ‘Pythagorean’ Intonation derives *all* intervals solely from pure fifths (frequency ratio 3/2) and octaves (2/1). In this system, which dominated Chinese music theory and was also of eminent importance in Ancient Greek and subsequently Arabic and European music thinking, all the notes of the scale are created by staggering pure fifths and balancing octave crossings with pure

‘Pythagorean’ ditone (81/64)	407.82
Perfect major third (5/4)	386.31
Syntonic comma (s, 81/80)	21.51

Table 3: Theoretical intervals (cent).

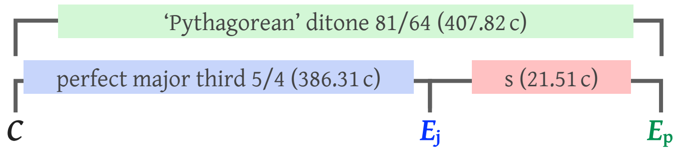

Figure 6: Theoretical relations between intervals.
E_j: *E* in just intonation; E_p: *E* in ‘Pythagorean’ intonation; s: syntonic comma.

octaves. For example, the frequency ratio of the third above the tonic (scale step 3, ‘*E*’ in a C-major scale) is effectively calculated by staggering four pure 3/2-fifths (C^1–G^1–D^2–A^2–E^3) and subtracting two 2/1-octaves (E^3–E^2–E^1). The resulting ‘Pythagorean’ major third then has a frequency ratio of $(3/2)^4 / (2/1)^2 = 81/64$ and is called the ‘Pythagorean ditone’ in European tuning tradition. Measured in cent, 81/64 equals an interval size of 407.82 cent.

- The idea of *Just Intonation* introduces ‘pure’ or ‘perfect’ major thirds (frequency ratio 5/4) into the calculation of the scale intervals. This 5/4-third is the same interval that is found in the overtone scale between the fourth and the fifth partial. In Just Intonation, scale step 3 does not have to be calculated in a complicated manner, but is simply tuned as the 5/4 perfect major third ratio, which equals an interval size of 386.31 cent.
- The syntonic comma marks the small difference between these two kinds of thirds. Its frequency ratio is calculated by dividing the ratio of the ‘Pythagorean’ ditone by that of the perfect major third: $(81/84) / (5/4) = 81/80$, corresponding to 21.51 cent.

Figure 6 shows the relation between the larger ‘Pythagorean’ ditone, the narrower perfect major third and syntonic comma in between.

In early European music history, ‘Pythagorean’ Intonation was the predominant system for hundreds of years. It works perfectly for all kinds of music with the (open) fifth as characteristic harmonic element, since, due to the construction principle of the scale, all fifths that occur in the music will be perfectly tuned. However, if the notes bounding a ‘Pythagorean’ ditone are sounded simultaneously, the resulting third is generally perceived as lacking in resonance. Therefore, when multi-part music began to focus more on thirds as a characteristic harmonic element in about the 15th century, ‘Pythagorean’ Intonation was predominantly replaced by the idea of Just Intonation. However, the syntonic comma was never used as a melodic or harmonic interval as such, but rather as an aid to conceiving different types of tuning for certain kinds of music and instruments.

As one can see from Tables 2 and 3, the intervals in the *talempong batu* nearly perfectly match the values of the theoretical intervals: the mean deviation of the *talempong batu* from the theoretical values is just 1.27 cent, the maximum deviation not more than 2.95 cent (between the 5/4-third and the interval V/VI). As we know from experimental psychoacoustics, this small deviation is far less than the pitch differentiation ability of the human ear: in this frequency range, the pitch differences between two tones must exceed about 5 cents for the ear to perceive the tones as different in a direct comparison (just notable difference JND, cf. Fastl, Weinberger 1981).

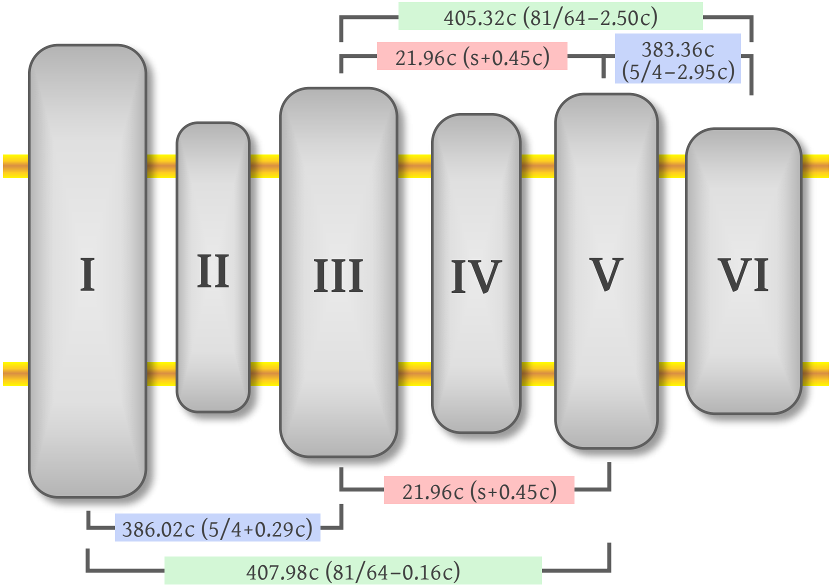

Figure 7: Order of intervals within the *talempong batu* (deviation from theoretical intervals in parentheses).

Figure 7 shows the arrangement of the matching intervals within the actual order of the stones of the *talempong batu*. If we compare this to the theoretical relations of the intervals in Figure 6, it becomes obvious that the intervals between the four lowest stones not only match the size of the theoretical intervals, but that the whole arrangement of the stones, which at first glance seems to be somehow irregular, reflects the theoretical meaning of the intervals *twice* in a perfectly symmetrical way, upwards and downwards with the syntonic comma in the middle.

6 Conclusions and open questions

When we first realized the surprising results of our analysis, we certainly were quite sceptical and wondered whether the results could be caused by some systematic errors, e.g. from the digitalisation of the audio material or the calculation of the FFTs. Therefore, we repeated the coding and analysis several times with slightly different approaches. Moreover, the original material was given to some colleagues with broad experience in sound analysis, musical acoustics and tuning systems, namely Wolfgang Auhagen of Martin-Luther-University Halle/Germany and Christoph Reuter of Vienna University/Austria. However, all these re-analyses confirmed that the frequencies of the stones and the intervals between them had been accurately measured as described above. In addition, I have recently conducted some new analysis based on the sounds of new videos of the instrument that can be easily found on YouTube now. Again, the results on the frequencies and spectra of the stones were almost identical to the results that I first found 27 years ago. There can be no reasonable doubt about the astounding fact that the tuning of this stone-made instrument in the Sumatra mountains indeed accurately matches some intervals that are well known in other tuning traditions and that the overall arrangement of the stones perfectly reflects the theoretical meaning of these intervals as well.

This of course does *not* imply that we suggest that the tuning of the instrument in any kind was directly influenced by any of these traditions. Quite possibly the underlying principles may have been realized independently in the Sumatra region.

Although very little is known about the age of the instrument (see above), our findings may help to learn something about the culture that created it. This assumes, of course, that the tuning system was actually intended by its creators to be exactly this way. However, it seems hard to believe that a complex system with this level of theoretical matching and perfect conceptual symmetry might simply arise by chance. If the *talempong batu*'s tuning system was indeed intentional, its existence may say a lot about the theoretical and practical resources and skills of the maker(s) and their cultural context.

- As explained above, the perfect major third can be found in the overtone scale. As such, it is not too complicated to discover and reproduce with quite simple means like an overblown pipe or a vibrating string. However, this is neither the case for the 'Pythagorean' ditone, not for the Syntonic Comma. 81/64 and 81/80 are relatively complicated ratios that cannot simply be found in nature. To find these ratios, the creators of the *talempong batu* had to have some competency to think in proportions and to calculate with fractions, may it be practically or theoretically.
- The conceptualization *and* realization of the 'Pythagorean' thirds in particular, would have depended on a tool to reliably reproduce reference intervals and pitches during the actual tuning process. The most reliable and easy to use tool to achieve this is a reference instrument based on vibrating strings (as has been the monochord in European tradition). An alternative might be a blown pipe, such as a flute with distinct finger holes. However, this seems less likely because, in contrast to vibrating strings, the frequency of wind instruments depends also on parameters that are difficult to control (e.g. air pressure and humidity) and hence makes it difficult to reliably produce defined reference pitches for tuning. Therefore, it seems more plausible that the culture of the creators of the *talempong batu* did know stringed instruments.

These considerations are of course somewhat speculative, but they nevertheless seem at least plausible. However, some essential aspects of the cultural background and the making process of the *talempong batu* remain totally unclear so far:

- Even with a fixed reference frequency from a stringed instrument, the actual process of tuning the stones remains mysterious. On the one hand, the accuracy exceeds the just-noticeable difference (JND) for pitch of the human ear. Therefore, the simple comparison of the desired reference pitch (whether it is produced by a pipe or a string) with the pitch of the stone that is to be tuned would never have achieved such accuracy. Of course, there indeed exists a tuning technique that could lead to such level of accuracy and that piano tuners still use every day: the technique of counting interference beats between the reference and target pitches. If the interference beats disappear while tuning the target pitch, both frequencies are perfectly equal. But this can only work if both sounds last long enough, so that the tuner has enough time to listen to the slow interference beats in the combined sound. But as shown above, the sounds from the *talempong batu* will last for only about 200 to 400 ms. This appears to be much too short to apply the interference technique for the tuning of these stones. So far, it remains unclear how the surprising precision of the tuning could be practically achieved.

- The actual tuning of a 3-dimensional body of hard, brittle, mineral material to a desired pitch naturally requires a very accurate and precise craftsmanship. But moreover, it requires precise knowledge and experience of where to work on the stone to obtain the desired result without taking the risk of ruining the work or even completely destroying it. As Pätzold (2003) stated, the *talampong batu* is a *unique* instrument. Even if the maker did not produce any further instruments, it remains unclear what might have happened to the preliminary works that went into acquiring this special expertise. So, one may wonder why no other similar lithophones have been discovered.
- The consistent tuning system that was described above includes only the four lowest stones of the instrument. So, what about the two highest stones (II and IV) that do not seem to fit the consistency of the system? Is there any plausible, consistent explanation for their pitches? This question will be hard to answer without further investigation of the instrument itself. It would be essential for example to look for some evidence that the pitches of the stones somehow might have changed due to damage or erosion.
- Last but not least, there is no plausible explanation so far as to how this complex tuning that was realized at least hundreds, maybe thousands of years ago, could remain unchanged with the described level of precision until today.

Considering all these open questions, the *talempong batu* is a quite fascinating, but also mysterious, object. To answer these questions, further interdisciplinary research with experts from the fields of musicology, archaeology, cultural history, and mineralogy seems absolutely necessary. Indeed, the answers to these questions could be an important testimony to the cultural history of the region.

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