Archaeoacoustic Investigations of Megalithic Monuments in Great Britain

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Contents

1 Introduction

Archaeoacoustics introduces a unique perspective on the past by focusing on sound and its role in shaping human experiences (Kolar, 2018). This interdisciplinary field explores the relationship between sound and archaeological sites and artifacts by combining acoustic science with archaeological data. Archaeoacoustic research involves the documentation and analysis of sound phenomena, examining what can be heard, from where, and under what conditions. Beyond the technical analyses, it considers how sound shaped human experience, emphasizing perception, sensory engagement, and social context.

The archaeoacoustic properties of many megalithic sites in Great Britain from the Neolithic and Early Bronze Age were extensively studied between 1995 and 2006 in research projects led by Aaron Watson at the University of Durham (Watson & Keating, 1999, 2000; Watson, 2006). These sites share a common historical context and were analyzed using similar archaeoacoustic methodologies, creating a large dataset for exploring sound in prehistoric Great Britain. This paper presents the findings from these studies, including the observed acoustic phenomena and their potential interpretations.

This paper begins with an introduction to the physics of sound, relevant acoustic effects and human sound perception, followed by an overview of the experimental methods used. Three case studies of megalithic sites in Great Britain with detailed archaeoacoustic investigations are presented. These sites are chosen for their variety in architecture and acoustic phenomena, as well as for the availability of published experimental data. The paper concludes with a discussion of some considerations for the interpretation of archaeoacoustic research.

2 Basics of Sound and Sound Perception

An acoustic wave is a longitudinal wave, meaning the direction of wave propagation aligns with the direction of vibration (Ginsberg, 2018). Energy is propagated through the compression and expansion of a medium, facilitated by the movement of atoms or molecules. Acoustic waves can therefore only exist in a medium, such as air, water, or solid materials. They can be characterized by their amplitude and frequency (Ginsberg, 2018). The amplitude of an acoustic wave describes the maximum displacement of particles from their equilibrium position. Frequency refers to the number of waves per unit of time. It is typically measured in Hertz (Hz), representing the number of waves per second.

Acoustic waves exhibit typical wave phenomena, such as reflection on surfaces and diffraction around obstacles in their path (Ginsberg, 2018). They are absorbed by materials, including the medium through which they travel, and therefore lose amplitude as they propagate. Under specific conditions, which include that the waves share the same frequency, acoustic waves can interfere (Ginsberg, 2018). Determined by the phase difference, which describes the relative shift between the waves, this interference can create new wave patterns. In the extreme case, two waves with the same amplitude are perfectly aligned and their crests overlap, which doubles the amplitude. Conversely, if a wave crest overlaps with the trough of another wave, they can cancel each other out. Standing waves are another important phenomenon of acoustic waves (Ginsberg, 2018). They form when acoustic waves in a confined space reflect off the volume's boundaries and the incoming and reflected waves interfere. This repeated interference creates a wave that continues to oscillate in time, but with a stationary peak amplitude. This means that certain locations within the space experience no wave activity, while others alternate between zero amplitude and the double maximum amplitude of the original wave. Another effect that can occur inside a confined space is Helmholtz resonance (Ginsberg, 2018). It arises when air is forced in and out of a cavity, causing the air inside to vibrate and generate an acoustic wave at a frequency determined by the volume's shape and size. A common example of this phenomenon is the sound produced by blowing across the top of a bottle.

Humans can hear acoustic waves with frequencies ranging from approximately 20 Hz to 20 kHz, which are referred to as sound waves (Ginsberg, 2018). Acoustic waves below 20 Hz are referred to as infrasound, while those above 20 kHz are called ultrasound. The pitch of a sound describes how "low" or "high" it is perceived (Ginsberg, 2018). It is linked to the frequency of an acoustic wave, with higher frequencies corresponding to higher pitches. However, unlike frequency, which is an objective quantity, pitch is a subjective perception that varies significantly between individuals and cannot be measured directly. Similarly, the volume of a sound is related to its amplitude or, more specifically, to the sound pressure, which refers to the pressure deviation caused by a sound wave (Ginsberg, 2018). Larger amplitudes result in greater sound pressure, corresponding to louder sounds. The sound pressure level, or perceived loudness, is defined using the formula $L = 20\log_{10}(\frac{p}{p_0})$, where p is the sound pressure of the sound, and p_0 is a reference value, typically the threshold of human hearing. Sound pressure is measured in decibels (dB). The logarithmic relationship means that sound perception is not linear; for instance, reducing the sound pressure by 10 dB makes the sound appear half as loud, while a 20 dB reduction results in the sound being perceived as one-quarter as loud. Additionally, the perceived loudness of a sound depends on its duration (Ginsberg, 2018). A short sound may seem quieter than a longer one, even though they have the same intensity level. Furthermore, the perception of loudness varies with frequency in complex, non-linear ways (Ginsberg, 2018).

3 Experimental Methods in Archaeoacoustics

For the archaeoacoustic investigations of megalithic monuments in Great Britain detailed in the following chapter the experimental setup is primarily designed to investigate archaeological acoustical features rather than to reconstruct specific sounds (Kolar, 2018). It consists of a frequency generator connected to an omnidirectional loudspeaker which is placed either at the center of the monument or at another significant location (Watson & Keating, 1999). This sound source can emit distinct frequencies to study the site's response to specific tones (Watson, 2006). Alternatively, for a broader and more general analysis, it can generate pink noise (Watson & Keating, 1999). Pink noise contains frequencies spanning the entire human audible range, distributed in a way that resembles the sounds found in biological systems (Szendro et al., 2001). It is therefore likely to capture the range of sounds produced in prehistory (Watson & Keating, 1999). The emitted sounds are recorded at various points throughout the site using microphones. The recordings are digitized, stored, and can later be analyzed by converting them into spectra using a spectrum analyzer (Watson & Keating, 1999). Control experiments are performed in open environments using the same equipment to ensure the validity of the setup and provide a baseline for comparison (Watson & Keating, 1999).

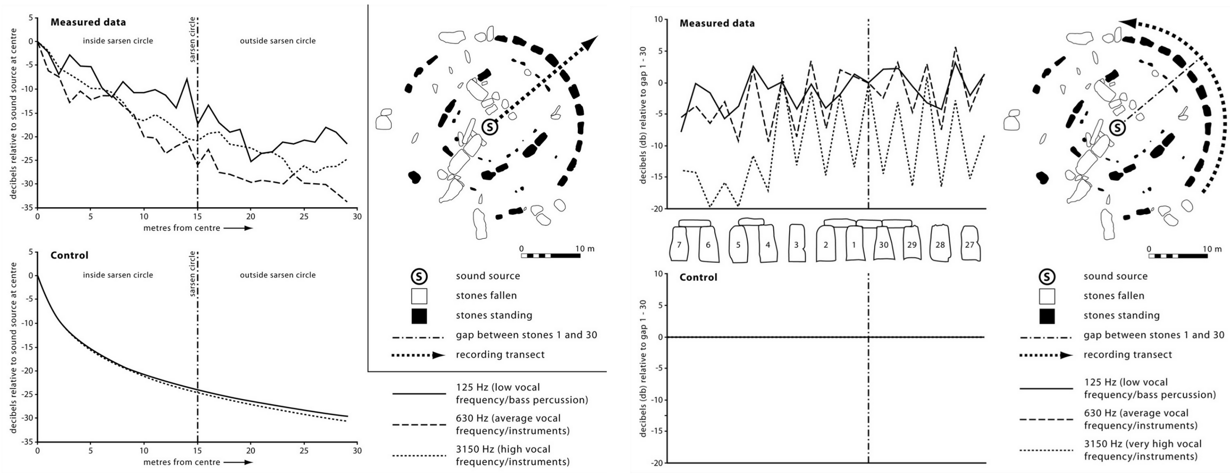
It is important to acknowledge that this setup involves interpretations of the archaeological site, including the selection of sound source and receiver locations corresponding to where sound production and listening may have occurred (Kolar, 2018). While these decisions are based on archaeological evidence, they should be considered plausible reconstructions rather than definitive conclusions.

Archaeoacoustics is an evolving field, with techniques continually improving as technology advances. However, the archaeoacoustic investigations presented in the following chapter date from 1995 to 2006, meaning they rely on methods that are not the most up-to-date. For example, contemporary archaeoacoustic research commonly uses sine sweep techniques to analyze site responses, rather than the method described above (Farina, 2007). Additionally, environmental factors such as temperature and humidity can influence sound behavior (Kolar, 2018), but these variables are not addressed in the case studies presented here.

4 Archaeoacoustic Case Studies of Megalithic Monuments in Great Britain

4.1 Stonehenge

Stonehenge is a megalithic structure in the south of England composed of an outer sarsen ring of vertical standing stones topped with horizontal lintel stones. Inside this outer circle is a smaller ring of standing stones as well as a set of freestanding trilithons, each composed of two vertical stones connected by a single lintel (Pearson et al., 2007). The construction of Stonehenge occurred over several complex phases, but the archaeoacoustical investigation in Watson, 2006 focuses on Phase 3, around 2500–1600 BCE, during which the monument took its current form (Pearson et al., 2007). In the study, a loudspeaker is placed at the center of the monument and set to emit frequencies at 125 Hz, 630 Hz and 3150 Hz, which corresponds to the frequency range of the human voice or typical musical instruments (Watson, 2006). The amplitude of the frequencies is measured and mapped along a transect extending from the center of the monu-



(a) Transect from the center to the outside.

(b) Transect around the outside.

Figure 1: Archaeoacoustic investigation of Stonehenge showing the amplitudes measured along a transect from the centre of Stonehenge to the outside (a) and along a transect around the outside (b) for three different frequencies compared to a control site. From Watson, 2006.

ment through the circles of standing stone to the outside. The specific transect and its results are shown in Figure 1a compared to a control site. The diagrams show that sound behaves very differently inside Stonehenge than at a control site and that the monument significantly alters sound dynamics (Watson, 2006). The peaks and troughs which are present on all three frequency graphs indicate the presence of standing waves (Watson, 2006). Through interference these standing waves cause the volume and characteristics of sounds to change unpredictably as listeners move around. The results also reveal differences in how sound waves of different frequencies behave within Stonehenge (Watson, 2006): Higher frequencies experience greater attenuation than lower frequencies throughout the monument and will be less audible. Higher frequencies are also largely confined to the interior of the monument and are significantly attenuated outside the sarsen circle, where their perceived loudness strongly decreases. In contrast, lower frequencies remain audible outside the monument as the their longer wavelengths are able to bend around the stones more easily. This effect is illustrated in Figure 1b which shows amplitude measurements taken along the outside of the monument. While high-frequency sounds are only audible directly through the gaps between the standing stones, low-frequency sounds can be heard all around the structure (Watson, 2006).

These acoustic properties create two contrasting experiences (Watson, 2006): On the exterior of Stonehenge sounds are significantly attenuated and distorted, as mainly low-frequency sounds are audible. The transition from the outside, with its ambient low-frequency sounds, through the opening between the standing stones where high-frequency components are introduced, to the interior where all frequencies can be heard, shaped by effects such as standing waves, is striking. One interpretation of these findings is that in the Neolithic and Early Bronze Age, the monument may have created a division between those inside and outside, potentially

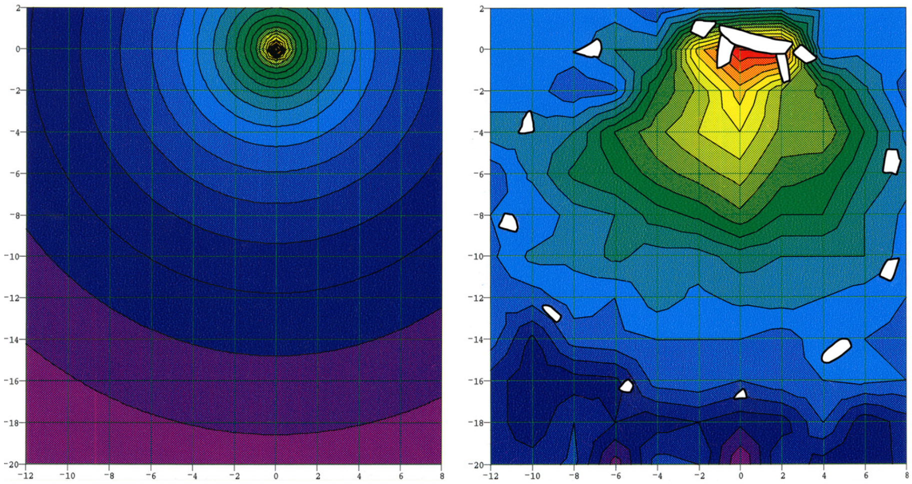


Figure 2: Acoustic survey of the East Aquhorthies Stone Circle (right) compared to a control site (left). Contours represent the perceived loudness in increments of 2 dB. From Watson, 2024b.

related to exclusion or differential access to knowledge and experiences (Watson, 2006).

The effect that the architecture of stone circles creates a barrier between the outside and inside with two very distinct acoustic experiences can also be also be observed in other stone circles in Great Britain. For example, the Standing Stones of Stenness and the Ring of Brodgar, both located on Orkney, Scotland, exhibit similar acoustic characteristics (Watson & Keating, 2000).

4.2 East Aquhorthies Stone Circle

The East Aquhorthies Stone Circle is an example of a recumbent stone circle, a distinctive form of Early Bronze Age megalithism found in eastern Scotland (Ruggles, 2014). These monuments are characterized by a large recumbent block, often flanked by tall standing stones forming an alcove (Ruggles, 2014). The acoustic properties of this feature are surveyed in Watson and Keating, 1999 by placing a loudspeaker emitting pink noise in the recess and recording sound throughout the monument. Figure 2 presents the results as well as sound behavior at a control site. While at the control site a regular decay in amplitude with increasing distance from the sound source can be seen, sound behavior within the East Aquhorthies Stone Circle is markedly different (Watson & Keating, 1999). A high sound amplitude is observed between the recumbent stone and the center of the circle due to sound being reflected, echoed and amplified within the alcove. The sound amplitude drops significantly outside the monument, similar to the effect observed at Stonehenge. In addition to the unique acoustic effects the recumbent stone and its flanking stones also provide a visually striking backdrop (Watson & Keating, 1999). This combination of sound modulation and visual emphasis can be likened to a stage in a theater, a feature which can also be found in other stone circles, such as Avebury in southwest England

(Watson, 2006, 2024a).

There is potential for expanding the study of the East Aquhorthies Stone Circle by Watson and Keating, 1999. Unlike the Stonehenge measurements in Watson, 2006, the experiments do not differentiate between frequencies. Analyzing how different frequencies behave, including if the echo and amplification effects support both music and human speech, could provide additional insights into the potential uses of the site. Furthermore, Watson and Keating, 1999 describe complex reverberations perceived by listeners, which may result from sound reflecting between individual standing stones in the circle. These effects, however, are too subtle to be captured with the applied methodology, and more advanced techniques could reveal additional acoustic nuances of the site.

4.3 Camster Round

The Grey Cairns of Camster are two enclosed megalithic tombs in northern Scotland dating to the Neolithic period (Masters et al., 1998). One of these tombs, Camster Round, is circular in shape with a central chamber that is accessed through a narrow passageway, which opens into an antechamber before leading to the main chamber via a narrow portal (Watson & Keating, 1999). The central chamber and passageway are enclosed by a cairn of boulders. The monument has been restored, but the minor differences between its original form and the current version are assumed to have a negligible impact on the behavior of sound (Masters et al., 1998; Watson & Keating, 1999).

Watson and Keating, 1999 conduct an acoustic survey experiment at Camster Round. A loudspeaker emitting pink noise is placed in the central chamber, and systematic recordings are made throughout the monument. The main observations are (Watson & Keating, 1999):

- The stone walls reflect sound waves, which amplifies sounds and creates echoes inside the central chamber.
- While sound travels along the passageway, it gradually softens with increasing distance from the loudspeaker.
- Outside the tomb, sound can be heard only emerging from the passage entrance. This is because sound moves more effectively through air than through the cairn material. However, the sound outside has a significantly reduced amplitude and altered frequencies.

The monument therefore has a filtering effect, where sounds originating in the central chamber are transformed before reaching the outside (Watson & Keating, 1999). To investigate this effect in more detail, recordings of different frequencies emitted by the loudspeaker in the central chamber are made at various locations outside the monument (Watson & Keating, 1999). The results show that the full range of audible frequencies is present in the chamber, along the passage, and immediately outside the entrance. However, as distance from the entrance increases around the circular monument, higher frequencies are progressively lost. At the opposite side of the entrance, only low frequencies remain. These results can be interpreted similarly to the stone circle monuments discussed above, where the monument creates a significant contrast in the acoustic experience for people within Camster Round and those outside (Watson & Keating, 1999; Watson, 2006).

Standing Waves

Another phenomenon observed at Camster Round is the presence of standing waves (Watson & Keating, 1999). After mathematical modeling which suggests that standing waves can be produced using frequencies within the range of the human voice, a frequency generator is used to emit continuous notes with varying pitches until an audible change in sound is detected inside the monument. Watson and Keating, 1999 also demonstrate that the same effect can be achieved through vocalization. A number of frequencies, whether produced by a loudspeaker or human voice, create standing waves within Camster Round, resulting in different acoustic effects:

- The source of the sound becomes difficult to locate.
- The standing waves create an environment where the amplitude, and therefore the perceived loudness, varies significantly between locations in the chamber. Even small head movements can result in noticeable changes in the volume and pitch of the sound.
- People inside the chamber can detect movement in the monument through changes in sound, as any movement changes the resonance space and therefore the standing waves.

Standing waves therefore create a unique acoustic environment that is particularly sensitive to movement. As standing waves can form in any enclosed space, the phenomenon can be observed in other megalithic chambered structures, for example Newgrange in Ireland (Watson, 2024c) or Maeshowe, the largest chambered mound in Orkney, Scotland (Watson & Keating, 2000).

Percussion Effects

An additional acoustic phenomenon investigated by Watson and Keating, 1999 at Camster Round is the effect of percussion: Similar to other sounds, drumming from the central chamber is most effectively transmitted along the passageway and can be clearly heard inside the monument. Outside the monument, the sound of drumming is unable to travel far due to the dampening effect of the cairn material and interference from natural background noise. However, a striking observation by Watson and Keating, 1999 is that the drumming can be perceived inside the neighboring monument, Camster Long, an elongated cairn tomb approximately 190 meters away from Camster Round (Masters et al., 1998; Watson & Keating, 1999). The exact cause of this effect remains uncertain, but one hypothesis by Watson and Keating, 1999 is that the calm air within Camster Long may enhance the perception of distant sounds. Additionally, low-frequency sounds, which are relatively rare in nature, may be more noticeable to humans.

This phenomenon is a remarkable acoustic feature of the site and suggests that drumming may have been used as a form of communication between the two tombs (Watson &

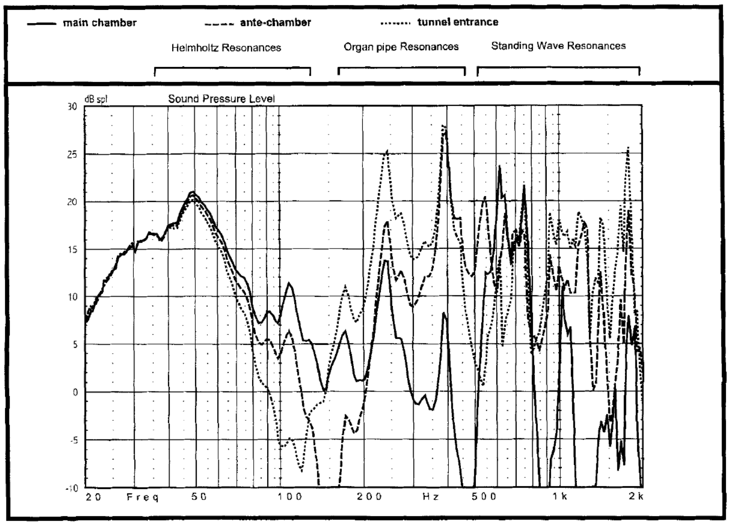


Figure 3: Resonances at a 1:10 scale model of Camster Round. The three different graphs correspond to microphone positions within the central chamber, antechamber and passageway. Acoustic resonances occur at frequencies where the graphs peak. They are classified into Helmholtz resonances, organ-pipe resonances, where standing waves are established along the length of the passageway, and transverse standing waves (Watson & Keating, 1999). Due to the selected scale, the acoustic frequencies in the model are ten times larger than in Camster Round. From Watson and Keating, 1999.

Keating, 1999).

Helmholtz Resonances

Inside passage graves, Helmholtz resonances can occur when a specific frequency determined by the volume of the central chamber and the passage is played (Watson & Keating, 1999). Mathematical models by Watson and Keating, 1999 indicate that Helmholtz resonance inside Camster Round is expected occur at approximately 4 Hz. This frequency falls within the infrasonic range, beneath the threshold of human hearing. A 4 Hz frequency cannot be produced with modern musical instruments, and it is therefore unlikely that prehistoric instruments would have been able to generate this frequency directly. Watson and Keating, 1999 suggest two alternative methods of stimulating Helmholtz resonance: It is possible that strong winds blowing across the passage entrance might induce Helmholtz resonance. However, requires very specific natural circumstances. Alternatively, rhythmic drumming at a speed of 4 beats per second can induce the effect. Watson and Keating, 1999 experimentally prove first on a small-scale model of the passageway and chamber (Figure 3) and then at an in-situ experiment at Camster Round that a single drum is capable of producing frequencies with enough energy to possibly induce infrasonic Helmholtz resonances. While infrasonic frequencies are inaudible, research suggests that they may be perceptible to humans through subjective physical sensations, such as vibrations or a sense of unease (Møller & Pedersen, 2004). These responses are reported by listeners in Camster Round during the Helmholtz resonance experiments, with significant variation between individuals (Watson & Keating, 1999).

These investigations should be approached with some caution due to the subjective nature of infrasonic perception and the inconclusive research on the subject (Møller & Pedersen, 2004). Watson and Keating, 1999 conclude that the production of infrasonic resonance through drumming in Camster Round could not be definitively proven. Helmholtz resonances are theorized to also occur in all passage graves. Watson and Keating, 1999 mathematically model the Helmholtz resonances of several other passage graves in Great Britain. In general, larger tombs exhibit lower resonant frequencies, which would require a slower drumbeat to evoke Helmholtz resonance. However, apart from Camster Round, no empirical tests have been conducted to test the effects in real-life scenarios. Conducting these experiments at other monuments could help clarify whether infrasonic resonances can exist within megalithic tombs.

5 Discussion and Conclusion

Archaeoacoustics introduces sound as an additional dimension into archaeological research, complementing the traditional focus on the visual aspects of material culture (Kolar, 2018). Investigating the relationship between architecture and sound provides an opportunity to explore how prehistoric communities may have experienced their environments in multisensory ways. An especially well-studied area of archaeoacoustic research are megalithic monuments in Great Britain from the Neolithic and Early Bronze Age (Watson & Keating, 1999, 2000; Watson, 2006). This paper discusses the how three of these monuments, a stone circle, a recumbent stone circle and a cairn, shape their acoustic environments. The investigations find that all three monuments create distinct acoustic effects, which result in strong auditory differences between the interior and exterior of the monuments (Watson & Keating, 1999; Watson, 2006). In the two case studies where frequency-specific analyses were conducted, the monuments exhibit filtering effects by attenuating different frequencies in varying ways (Watson & Keating, 1999; Watson, 2006). The cairn tomb Camster Round displays particularly complex acoustic phenomena, including standing waves, sound traveling between monuments, and possible Helmholtz resonances (Watson & Keating, 1999). These findings underscore the potential importance of sound in the use and perception of these monuments, and where possible, careful interpretations of the acoustical phenomena are included.

Considerations for Interpretation

Interpreting acoustic phenomena in an archaeological context is a complex task. Prehistoric sensory perceptions, including the experience of sound, may differ significantly from modern understandings. Some additional considerations for interpreting archaeoacoustic data include:

- People in the Neolithic and Early Bronze Age may not share our differentiation between nature and culture (Watson, 2006). Sounds from nature and their interaction with human-made monuments may have been perceived as part of a unified experience. Watson, 2006 gives the examples of Midhowe, a chambered cairn on the coast of Orkney, Scotland where the sounds from the nearby sea as well as any effects created by these sounds, like echos inside the monument, would have constantly been present and could be seen as an integral part of the monument, just like the building materials it is made of.

- The sensory perception of sound in prehistory may have differed significantly from our use of the sense. For example, sound might have been interconnected with other senses through synesthetic relationships (Watson, 2006). If sound is merely one sensory dimension among many attributed to a rock or a building, archaeoacoustic investigations become considerably more complex.
- It is also possible that people in the Neolithic did not establish a cause and effect relationship between actions that produce sounds, such as speaking or playing musical instruments, and the resulting sound effects, like echoes (Watson, 2006). This lack of a causal framework complicates the interpretation of archaeoacoustic results, which often rely on the assumption of cause-and-effect relationships.

Intentionality of Acoustic Design

Another key question in interpreting archaeoacoustic results is whether the acoustic properties of a monuments were intentionally designed and if material evidence supports that sound played a significant role at the site, thereby justifying the investigation of this dimension (Watson, 2006). For some monuments, evidence suggests possible acoustic intention. For instance, Watson, 2006 interprets the worked surfaces of standing stones at Stonehenge, where the inner faces are often flat or concave, so ideal for reflecting sound, while the outer surfaces are irregular, as indications for acoustic considerations.

Proving the intentionality of acoustic design is inherently challenging. To complicate this, acoustics may have been only one of many factors influencing a building's construction (Watson, 2006). Monuments often served diverse and overlapping functions, which makes it difficult to distinguish acoustic intent from other purposes. Furthermore, if sensory perceptions of sound or the rationalization of cause and effect regarding acoustic effects was different in prehistory, the concept of intentionality becomes even more complex (Watson, 2006).

Nonetheless, even if acoustics was not a primary consideration during a monument's construction or no material evidence for intentional acoustic design can be found, sound can still play a significant role in how the structure was used and understood. As prehistoric sites and artifacts were often used over many generations, their roles and meanings could evolve over time (Watson, 2006). Acoustic phenomena that occur within a site might have gained significance as time passed. This suggests that archaeoacoustic research remains important, even when intentionality cannot be conclusively established.

Bibliography

Farina, A. (2007). Advancements in impulse response measurements by sine sweeps. *122nd AES Convention*. http://www.aes.org/e-lib/browse.cfm?elib=14106

Ginsberg, J. H. (2018). *Acoustics - a textbook for engineers and physicists: Volume I - Fundamentals*. Springer.

Kolar, M. (2018). Archaeoacoustics: Re-sounding material culture. *Acoustics Today*, *14*(4), 28–37. https://doi.org/https://doi.org/10.1121/AT.2018.14.4.30

Masters, L., Henshall, A., Wickham-Jones, C., & Unwin, C. (1998). The excavation and restoration of the Camster Long chambered cairn, Caithness, Highland, 1967-80. *Proceedings of the Society of Antiquaries of Scotland*, *127*, 123–183. https://doi.org/https://doi.org/10.9750/psas.127.123.183

Møller, H., & Pedersen, C. S. (2004). Hearing at low and infrasonic frequencies. *Noise Health*, *6*(23), 37–57. https://pubmed.ncbi.nlm.nih.gov/15273023/

Pearson, M. P., Cleal, R., Marshall, P., Needham, S., Pollard, J., Richards, C., Ruggles, C., Sheridan, A., Thomas, J., Tilley, C., Welham, K., Chamberlain, A., Chenery, C., Evans, J., Knüsel, C., Linford, N., Martin, L., Montgomery, J., Payne, A., & Richards, M. (2007). The age of Stonehenge. *Antiquity*, *81*(313), 617–639. https://doi.org/https://doi.org/10.1017/s0003598x00095624

Ruggles, C. L. (2014). Recumbent stone circles. In C. L. Ruggles (Ed.), *Handbook of archaeoastronomy and ethnoastronomy* (pp. 1277–1285). Springer New York. https://doi.org/https://doi.org/10.1007/978-1-4614-6141-8_122

Szendro, P., Vincze, G., & Szasz, A. (2001). Pink-noise behaviour of biosystems. *European Biophysics Journal*, *30*(3), 227–231. https://doi.org/https://doi.org/10.1007/s002490100143

Watson, A., & Keating, D. (1999). Architecture and sound: An acoustic analysis of megalithic monuments in prehistoric Britain. *Antiquity*, *73*(280), 325–336. https://doi.org/https://doi.org/10.1017/s0003598x00088281

Watson, A., & Keating, D. (2000). The architecture of sound in Neolithic Orkney. In A. Ritchie (Ed.), *Neolithic Orkney in its European context* (pp. 259–263). McDonald Institute for Archaeological Research.

Watson, A. (2006). (Un)intentional sound? Acoustics and neolithic monuments. In C. Scarre & G. Lawson (Eds.), *Archaeoacoustics* (pp. 11–22). McDonald Institute for Archaeological Research.

Watson, A. (2024a). *Acoustics at Avebury*. https://www.aaronwatson.co.uk/acoustics-1

Watson, A. (2024b). *Acoustics at Easter Aquhorthies*. https://www.aaronwatson.co.uk/easter-aquorthies

Watson, A. (2024c). *Acoustics at Newgrange*. https://www.aaronwatson.co.uk/newgrange