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Ortoleva, Jacqueline K.

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Sounds of the blue daemon: A new aural study of the Etruscan Tomba dei Demoni Azzurri, 450–420 BCE

Jacqueline K. Ortoleva

University of Birmingham, Department of Classics, Ancient History and Archaeology, United Kingdom

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ABSTRACT

The archaeological record of ancient Etruria suggests that different sounds were significant across sacred and secular settings. This is represented in everything from surviving musical instruments to vibrant images of musical performance and religious ritual involving natural phenomena. Nowhere is this more acute than the painted tomb where hundreds of images of musicians and dancers crowd tomb walls with their visually compelling yet silent sounds. Although multiple painted tombs survive intact, we know very little regarding their aural nature.

This article presents data from a recent acoustic study in Tarquinia, Italy. The study constitutes the first archaeoacoustic study developed to study the Etruscan archaeological record. Drawing from the resulting acoustic data, the Tomba dei Demoni Azzurri is shown to exhibit similar levels of reverberation documented inside St. Paul's Cathedral in London, particularly in areas of the tomb where funerary rituals were conducted. Aural perception inside the tomb space is of focus, particularly with respect to the transactional nature of sound and vision. The methodology, which was developed to investigate the painted tomb, emphasises the importance of investigating the Etruscan funerary record from an aural perspective, thereby forging a new path forward in assessing the funerary record in pre-Roman Italy and the broader ancient Mediterranean.

1. Introduction

Aural experiences were extremely significant across sacred and secular settings in pre-Roman ancient Etruria. This is represented in Etruscan painted tombs, where images of musicians and dancers crowd tomb walls with their visually compelling yet silent sounds. Emerging during the seventh century BCE in the Etruscan regions of Veii and Cerveteri, painted tombs later developed across other Etruscan regions of Central Italy, with the bulk culminating in Tarquinia (Naso 1996; Moretti Sgubini et al. 2001; Fig. 1). Although numerous painted tombs survive structurally intact, we know little regarding their aural nature.

As Etruscan archaeology stands today, new methods involving landscape settings, archaeobotanical evidence and phenomenological reviews have successfully clarified Etruscan society, particularly in terms of sanctuary and urban contexts (Bonghi Jovino & Chiaramonte Trerè 1997; Warden 2011; Bagnasco Gianni et al. 2018; Stoddart et al. 2020). However, Etruscan painted tombs are primarily approached from iconographic, epigraphic, and typological perspectives (Moretti 1966; Weber Lehman 1985; Bonfante 1981; Steingraber 1986; Steingraber, 2006; Naso 1996; Minetti 2006; Roth 2012; Marzullo 2018; O'Donoghue

2022; Brandt et al., 2015). The acoustic assessment of the Tomba dell'Orco in Tarquinia offers an alternative perspective that considers the behavior of sound inside the painted tomb (Ortoleva 2021). Another notable painted tomb, the fifth century BCE Tomba dei Demoni Azzurri, is also located in the Necropoli dei Monterozzi in Tarquinia. The tomb's tripartite structure is perhaps most infamous for its namesake, a large blue figure with fiery hair and red lips depicted inside the tomb's burial chamber (Fig. 2). New experimental fieldwork suggests the tomb's acoustics are similarly striking.

Although not immediately 'visible' to the naked eye, over a century of research in various fields of inquiry including neuroscience, cognitive science, and experimental psychology, tells us that sound propagation partially shaped the painted tomb experience during the funerary event (Guttman et al. 2005; Aglioti et al. 2010; Linos 2012). One simple way to consider the extent that sound can affect human experience involves a modern cinema. An integral part of the film industry involves the post production addition of sound effects to emotionally manipulate the viewer (Falkenberg 1967–8). Dialogue is dubbed to create the illusion of impactful conversation and artificially generated sounds are integrated into the final film to make a fight scene feel more 'poignant.' Clearly, a

E-mail address: Jxo644@alumni.bham.ac.uk.

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Fig. 1. Map of Etruscan regions with painted tombs. Tarquinia. Highlighted in green. Map: C.S. Ortoleva.



Fig. 2. Right-hand wall close up of the Tomba dei Demoni Azzurri's namesake, the blue 'demon.' Sketch courtesy of: Joseph Ortoleva.

tomb is not a cinema. However, visual content, whether presented in a film or another context, is influenced, often greatly so, by sound.

This article presents data obtained as part of an acoustic study in Tarquinia, Italy. The study represents the first archaeoacoustic study developed to study the Etruscan archaeological record. Drawing from

acoustic data obtained during fieldwork, the Tomba dei Demoni Azzurri exhibits similar levels of reverberation documented inside St Paul's Cathedral in London, notably in areas of the tomb where funerary ritual is structurally represented.

2. Significance of auditory experience in Etruria

Etruscan iconography and Greek, Roman, and Early Christian texts attest to the observation of different sounds throughout Etruscan regions (Cic. *De Div.* 2.38.80; Sen. *QNat.* 2.32.2). One notable part of the Etruscan religion relates to the observation of natural phenomena. Latin texts describe such rituals (Cic. *De Div.* 1.41.92; 2.38.80; Ov., *Fast.* 4.812–18; Livy 1.34.3–10) and Etruscan imagery illustrates it (Maras 2018). The practice of *auspiciu*m (divination from observing birds) is depicted in the Tomba degli Auguri, 530 BCE in Tarquinia. Another important sound in Etruria is detailed in the Brontoscopic Calendar, which is entirely known from a sixth century CE Greek translation by Johannes Lydus from a late Republican copy. In her review of the calendar, Turfa (2012) has suggested that the Etruscan observer may have equated thunder with a variety of other sounds. Such an observation is important when considering the low frequencies that thunder can generate between 63 and 250 Hz (Abegunawardana et al. 2016). Interestingly, thunder is also one of the loudest sounds in nature, extending across 60–120 Decibels (Ortoleva 2021, 1191). Music and dance are identified in Greek and Roman texts during various cultural activities from mundane activities in kitchen settings to sacred contexts (Liv. 7.2, 9.30; Ath. *Deip.* 5.39). Such testimony is supported by the archaeological record where different musical instruments have been uncovered in sacred, secular, as well as funerary settings in areas such as Tarquinia and Cerveteri (Carrese et al., 2009). However, instruments made from wood and other organic materials have never been found in burial contexts, likely because of the fragility of such materials.

The inferior nature of rudimentary 18th–19th century 'excavations' in Italy call into question whether musical instruments were, in fact, present, and simply discarded. Supporting such a conclusion, plectrums, which were often created from bone and used to play chordophone instruments such as the lyra have been found in subsequently excavated seventh century burial contexts in areas such as Cerveteri and Tarquinia (Cataldi Dini 1986; Rizzo 1987). Fragments of tortoise carapaces (often used to construct chelys lyres), were discovered inside the Tomba dei Demoni Azzurri (Adinolfi et al. 2005b). While the latter is often read as part of sacrifice, Maras has suggested the fragments could indicate that one or more lyres were used inside the painted tomb (2016). The fact that tortoise fragments have been discovered across multiple sanctuary settings in Etruria, including Tarquinia, Veii, and Pyrgi is also noteworthy, particularly when considering that such sites have been recently excavated, unlike most painted tombs in Etruria (Sorrentino 2013; Maras 2016). Although less commonly depicted in Etruscan iconography, bronze instruments, such as the lituus and cornu, have also been found *in situ* in funerary and votive deposits in Tarquinia, Tuscania, Cortona, and Populonia (Carrese et al. (eds.) 2010). When considering such evidence, it is extremely likely that musical instruments played a role in burial events performed inside and outside of Tarquinian painted tombs.

The depiction of musical instruments and/or musicians are the second and third most common motifs in Tarquinian tomb paintings (musicians: 56 tombs; dancers: 49 tombs; Moretti 1966; Steingraber 1986). The recognition of sound throughout Etruria, whether human-made or natural phenomena collectively illustrate a society that took the time to note the unique characteristics of different sounds. Exploring *how* this long tradition of sound recognition and music in Etruria may have been cognised is imperative if ever hoping to further understand funerary contexts. Aural experience has been explored as part of multiple sub-fields of archaeology.

3. Study's approach to aural experience

In Sensory Archaeology, it is often postulated that there is visual bias in traditional archaeological perspectives involving the material record of past cultures (Hamilakis 2013; Betts 2017; Skeates & Day 2019). However, as recognized in cognitive and neuroarchaeological perspectives, modern neuroscience postulates that approximately 2/3 of the brain performs either a primary or associative role in the processing of visual data (Hodgson 2003; Malafouris 2007). The dominance of visual interpretations in Etruscan Archaeology and Etruscology therefore seems logical. Yet, acknowledging this fact does not negate the importance of considering the material record from non-visual perspectives (Warden 2009; 2012). If a larger portion of the brain is allocated to vision, does this mean that visual stimuli consistently dictates audition or can audition affect visual perception as much as vision seems to guide audition? How do environmental deficits affect the perceptual interplay between sight and sound? Most of these questions fall outside the perimeters of the present article, yet deserve mention because they collectively demonstrate how little we know regarding Etruscan funerary activities. This is perhaps most easily understood when considering sound from the perspective of human cognition.

Sound waves, or, more accurately, pressure waves, constitute a highly sensitive form of bodily touch, as illustrated with the process of echolocation used by those who are sight impaired to move across space. However, those who are not sight impaired also use echolocation (Ortoleva 2021). As such, sound directs the body to physically move within and across space, often without any conscious awareness (Aglioti & Pazzaglia 2010). A good example of this involves music. Studies have shown that when classical music is streamed for a surgeon during surgery, the surgical process tends to be faster and also, more accurately completed. Interestingly, anaesthesiologists, who are not involved in similar motor activities as the surgeon, are often *negatively* affected by similar instrumentals and contexts (Linou 2012). Therefore, motor related tasks involved in surgery are improved with the auditory experience of music whereas the same music interferes with non-motor-related actions. Guttman et al. (2005) recently performed experiments involving vision and audition and found that 'cross-coding' seems to occur with visual and auditory sensory constructs. Not only was auditory data found to be influential in terms of temporal perception, but the visual system actually seemed to rely on auditory temporal data to 'see' temporal changes (*Ibid*). This phenomenon suggests that the allocation of brain structures to process visual data does not necessarily mean vision influences aural perception, but rather, that both senses provide primary information that ultimately results in a sensorily perceived reality. The present study required the development and implementation of a replicable acoustic protocol informed by the unique challenges of the Etruscan painted tomb. Although archaeoacoustic studies have only recently considered the Etruscan record (Ortoleva, 2022b; Ortoleva, 2021; Ortoleva & Barnard 2021), the general field of Archaeoacoustics offers a successful trajectory of studies informed by acoustic science (Fazenda et al. 2017; Diaz Andreu et al. 2017; Diaz-Andreu and Garcia, 2012; Yioutsos et al. 2018; Till 2019; Cox et al. 2020).

While still a relatively young subfield of archaeology, the study of acoustics in archaeology ('Archaeoacoustics') has largely centred on prehistoric sites with rock art (Reznikoff & Dauvois 1988; Reznikoff & Taratsi 1995; Devereux et al. 2008; Díaz-Andreu et al. 2017; Fazenda et al. 2017; Mattioli et al., 2018). While cave interiors have been considered in conjunction with rock art, others, such as Watson & Keating (1999) and Till (2019) have analysed acoustics in man-made structures. Such studies provide a foundation of methodologies utilising auditory data to further understand past cultures. The painted tomb record in Tarquinia is diverse in terms of size, spatial attributes, and construction materials. These variables are crucial when considering sound propagation.

4. Material and architectural attributes of the Tomba dei Demoni Azzurri

How does space shape sound perception? Conversely, how does sound shape space? The answers to such questions are dependent on cultural interpretations of different sounds, language, and the material realities of the space where sound is experienced (Arsenault et al., 2004). Tarquinia is surrounded by volcanic activity, and yet its bedrock is largely composed of biocalcarene limestone from the Upper Pliocene interbedded with a weaker fossiliferous biocalcarene (Caneva et al. 2020). In sum, Tarquinia's bedrock is less porous and therefore more resilient than tombs located in surrounding regions such as Cerveteri. Although likely a contributing factor in terms of the continuity of painted tombs in Tarquinia, the more resilient tomb composition did not prevent illegal looting. Similar to painted tombs throughout Etruria, all Tarquinian painted tombs were illegally mined. The Tomba dei Demoni Azzurri is however unique. During the second half of the 20th century, the Tomba dei Demoni Azzurri was catalogued via survey work without noting the extent of its tomb paintings (Lerici 1959). The tomb was looted sometime before 1832 when the main roadway flanking the Necropoli dei Monterozzi (Strada Provinciale dei Monterozzi) was restructured (Cataldi Dini 1987). Subsequent road work made the tomb less accessible to the tombaroli until construction began on the municipalities' aqueduct in 1985 and the tomb's dromos was accessed (Adinolfi et al. 2005a). The Tomb was ultimately excavated as part of a larger project in the southern sector of the Calvario region of the necropolis between 1985 and 1997 and amazingly seemed to indicate only one illegal entry (*Ibid*). Therefore, archaeologists were able to ascertain more information from the tomb's excavation than other painted tombs that were extensively looted, or the subject of inferior excavation (Leighton 2004). Similar to other painted and unpainted chambered tombs in Tarquinia, the burial chamber of the Tomba dei Demoni Azzurri was closed with two limestone slabs. The looters chiselled through the top slab causing a portion of the fill from the dromos to enter the front of the chamber (Cataldi Dini 1987).

The tomb's burial chamber is spacious, measuring 6.20 m. in length by 6.10 m. in width and 2.20 m. in height. Its steep entrance corridor, or dromos, is approximately 13 m. in length by 2.5 m. in width (Fig. 3). The dromos had three fills, one from the illegal entry and two others dated between 450 and 420 BCE (Aldofini et al. 2005; Marzullo 2017; 2018). Multiple animal remains were found in the first fill including dogs, pigs, goats, and two horses. Two thin layers of sandy matrix separated the first fill from the second fill, and included pig and horse remains believed to have been part of the first fill (De Grossi Mazzorin 2016; Fig. 3).

Similar to over 90% of painted tombs in Tarquinia, the tomb's burial chamber has a double sloping roof and consists of one open space (Steingraber 1986; 2006). Eight indentations or 'base marks' are carved into the chamber's floor (Fig. 4). Although base marks are common in fifth century BCE painted tombs, most include four indentations. The entrance corridor also includes a wall niche roughly two metres into the tomb. Also akin to many painted tombs, the Tomba dei Demoni Azzurri's paintings (including dancers, musicians, and daemons) are thematically distinct, with a procession on the left wall of the chamber, daemons covering the right wall with two human figures, possibly the deceased, and a banquet on the rear wall with mostly male figures and one male and female couple in the centre of the wall. Although the paintings on the entrance walls are not well preserved, a recent assessment confirmed the presence of a hunting scene (Adinolfi et al. 2019). The depiction of a female and male figure on two of the walls (rear and right) have led to suggestions that the tomb was commissioned for one married couple, rather than multiple burials (Roncalli 1997).

A large irregular trench (fossa) carved into the chamber's floor differs from those in other tombs. Measuring 2.3 m. in length by 1.30 m. in width it was constructed next to the procession scene on the left wall (Fig. 5). Although the entire floor of the chamber was plastered with a mixture of limestone dust and macco shards, the pit itself was not,

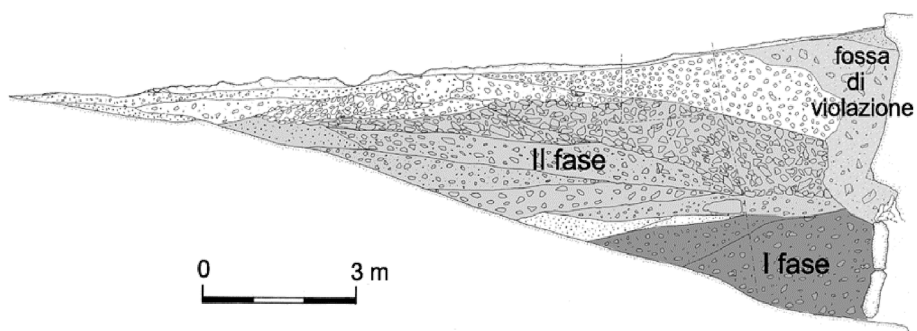


Fig. 3. Dromos of the Tomba dei Demoni Azzurri at the time of excavation. After: De Grossi Mazzorin, 2016, pg. 325, Fig. 1.



Fig. 4. Base marks inside the Tomba dei Demoni Azzurri. Photograph: C.S. Ortoleva. After: Ortoleva 2022a, pg. 195, Fig. 7.14.



Fig. 5. Model of the Tomba dei Demoni Azzurri's burial chamber with a large irregularly shaped trench carved into the floor (left-hand side of the chamber), Model created in Metashape by J.K. Ortoleva. After: Ortoleva 2022a, pg. 191, Fig. 7.11.

suggesting that it was constructed after the tomb was completed (Cataldi Dini 1987). Minimal evidence of burning is noticeable inside the pit and yet, three piles of burnt remains were placed outside of it (*Ibid*). One

large pile was placed to the right of the pit with two tortoise carapaces, and several other fragments of animal bones Attic pottery, fragments of a spear and chariot pieces, and small pieces of human bone (from a

mandible, skull, ribs, and ulna). Two additional piles were placed in front of the right wall, one containing pottery, wood, and bone, and another with fragments of an iron spear and chariot (Adinolfi et al. 2005b). Cataldi Dini has argued that the cremated remains of the original owner of the tomb may have been placed in the pit as a form of devotion by descendants along with other objects (1987). Other than the several fragments of bone discovered next to the pit, no other human remains were recovered from the chamber which supports Cataldi Dini's suggestion. It may be tempting for the Etruscan scholar to compare the human and animal remains to an Etruscan ritual detailed in several secondary textual sources whereupon specific animals supposedly provided immortality (Serv. *Ad Aen.* 3.168; Arnobius *Adv. nat.* 2.62, 3.40). However, barring more conclusive evidence it remains difficult to infer anything more regarding the trench.

When the tomb was excavated, as mentioned, very little fill from the dromos was found inside the chamber and what was present was contained near the chamber's entrance. The manner in which the tomb was entered indicates that more extensive fill would have been inside the chamber if large items had been removed. Whether the tomb was robbed one time as suggested by Adinolfi et al. (2005b) or several, it is clear that either an intact body was never deposited inside the chamber or, if an inhumation was conducted inside the burial chamber, the remains were moved elsewhere, as seen at other painted tombs in Tarquinia (Vincenti 2009). The unique acoustics documented inside the Tomba dei Demoni Azzurri provides further clues with respect to the underlying use of the tomb space.

5. Acoustic method: The examination of sound inside the Tomba dei Demoni Azzurri

The present study analyses the acoustics of space inside the painted tomb's burial chamber and dromos using digital and live reconstructions of sound. Acoustic fieldwork was conducted at the Tomba dei Demoni Azzurri in May and October of 2019. The acoustic analysis reviewed sound inside 14 painted tombs in Tarquinia using live music and digital recording. In terms of the digitalised protocol, as part of preparation for the fieldwork, a 'digital track' was created to be used in each tomb following consideration of the types of instruments (double pipe, lituus, concert kithara) depicted in Etruscan tomb paintings. A female acapella song was also included on the digitalised track. The need to include a human generated sharp sound to measure reverberation led to the use of five digitally recorded claps which provided consistent acoustic data across the assessed tombs. The inclusion of claps are further addressed later in this article. A musician was brought into five tombs, including the Tomba dei Demoni Azzurri to play a chelys lyra. Live female speech was also acoustically assessed.

The inclusion of female speech was debated because the Etruscan language is no longer spoken; making it impossible to gauge what vocal inflections were present with a vocal composition. Nevertheless, the fact that male and female vocals tend to have a consistent fundamental frequency range between 77 and 482 Hz for males and 137 to 634 Hz for females led to the additional assessment of female speech (Debertolis and Bisconti 2014). With respect to the digitalised acoustic protocol, the final digital track was created using the open-source platform, 'Wavepad Sound Editor' to splice each bite into a complete recording spanning one minute, 15 s, including a period of silence (two second increments) separating each clip to allow for the assessment of reverberations. The extremely delicate nature of Etruscan painted tombs necessitates that the paintings are maintained at a specific level of humidity. As such, there were time constraints inside the burial chambers lasting no > 15–20-minutes to scientifically document formal acoustical measurements and photograph each chamber required that the acoustic protocol was timed to the second. The final digital track was projected from two-six locations (Sound Sources identified as SS1, SS2 and so forth) inside each burial chamber and corresponding dromos. A BOSE loudspeaker (SoundLink) was chosen for its acoustic clarity, cost

effectiveness and portable nature. The speaker was placed on a tripod measuring 1.37.5 m in height. Analyses of osteological remains of Etruscan male and female elites in Tarquinia suggest that males measured 1.69–1.7 m with women measuring 1.55–1.6 m (Becker 1993). If considering the upper estimate of height for males and females, the mean is 1.65 m. The placement of an instrument at the level of the shoulder as seen in tomb paintings allowed for the deduction of 27.5 cm.

Two placements inside each dromos were identified as Sound Source One (SS1) and Sound Source Two (SS2). The second sound source (SS2) was placed inside each dromos in the small vestibule-like area separating each dromos from the burial chamber's entrance. Some dromoi survive intact or partially intact, which made the designation of each Sound Source quite simple. However, some dromoi have not survived and this affected the overall placement of both sound sources. When the original dromos could be identified upon examination of the tomb's walls and/or floor, the SS1 marker was placed at the beginning of its original construction. If this was not identifiable, each SS1 was placed at a location at the beginning of the modern corridor. When time permitted or when able to revisit some of the tombs, additional sound source locations were identified. With respect to the Tomba dei Demoni Azzurri, because the tomb was visited two times, this allowed two acoustic surveys to be administered. Inside the Tomba dei Demoni Azzurri three additional Sound Sources were therefore designated, two inside the burial chamber and one inside the dromos (Fig. 6). For each acoustic survey conducted inside the tomb, a recording apparatus, (digital recorder PCM-10 by Sony with a three-way microphone set at a 48 kHz sample rate and 16-bit depth) was placed in different areas of the space. The sound device (SR) was set atop a tripod set at a height of 1.54 m (computed from 1.65 m minus 11 cm which is estimated to be the size of the human head from the ear to the top of the head for an individual measuring at 1.65 m (Robinette and Whitestone 1992). Prior to the tomb visits, a recording filter (Sony noise cut filter) was applied for voice parameters to alleviate distortion (Mattioli and Diaz-Andreu 2017, 88). Most tombs allowed for three different areas of each burial chamber to be designated sound receiver sites (SR1, SR2 and SR3). The aforementioned second acoustic survey (digital and live acoustic protocol) reassessed the originally placed sound source and sound receiver placements as well as three additional sound source placements (two inside the burial chamber and another inside the tomb's dromos) and three additional sound receiver placements, one inside the dromos, and two final placements inside the burial chamber resulting in a total of five sound source placements and six sound receiver placements (Fig. 7). The acoustics inside the Tomba dei Demoni Azzurri were found to be quite extraordinary. For the purposes of this article, the most important acoustic metric often relied on to study interior spaces in acoustic science is presented, that of reverberation as well as another acoustic metric known as AlCons.

6. Acoustic data: Reverberation and AlCons

The resulting aural measurements of each structure provide information regarding the behaviour of sound inside each tomb space. Reverberation is commonly emphasised in Archaeoacoustic studies (Watson & Keating 1999; Fazenda et al. 2017; Till 2019; Santos da Rosa et al. 2023). Archaeoacoustic studies generally analyse acoustic criteria defined by the International Organization for Standardization (ISO 3382-1, 2). ISO defines reverberation per the duration required for the space-averaged sound energy density in an enclosure to decrease by 60 dB after the source emission has stopped' (ISO 3382-1, 2). In other words, reverberation is the accumulation of sound within a confined or semiconfined space as it reflects across all surfaces until eventually terminating (Ortoleva 2021). Reverberation therefore magnifies sound and the longer the reverberation time, the more startling the effect may seem. Lengthy reverberation can often preclude an individual's ability to locate where a sound is emerging from, creating the effect that the sound is coming from multiple areas of a space.

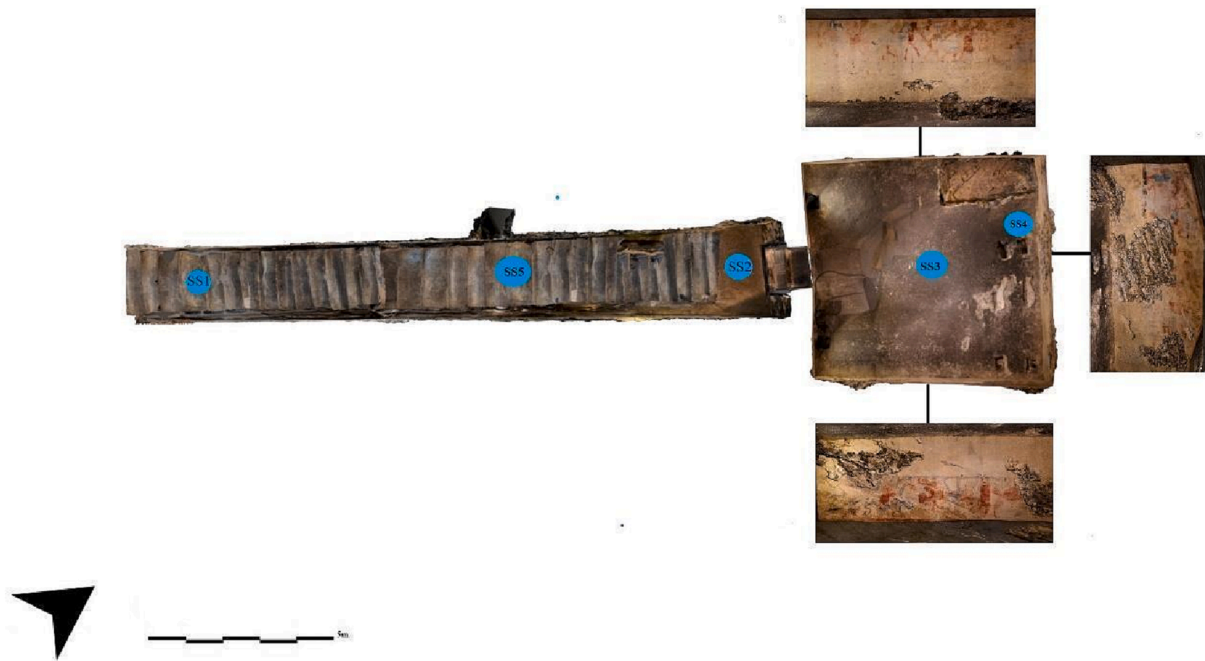


Fig. 6. Tomba dei Demoni Azzurri ground plan showing all Sound Source placements in blue. Ground plan: Created in Metashape and Meshmixer by J.K. Ortoleva. See supplementary material for details on the creation of photogrammetric models for the present study. After: J.K. Ortoleva 2022a, pg. 188, Fig. 7.8.8.



Fig. 7. Tomba dei Demoni Azzurri ground plan showing all Sound Receiver (SR) placements in green. Ground plan: Created in Metashape and Meshmixer by J. K. Ortoleva.

Low frequency reverberation is noteworthy because of its tendency to vibrate objects, space, and the body. For example, very long reverberation at 125 Hz can cause an interior space to literally shake in response to certain frequencies. As intimated, low frequencies can further affect the human body via bone conduction as well as the bodily organs such as the skin and heart (Johnson 2001). Other things that affect how reverberation is cognitively perceived are more nuanced. For example, anyone who learned a second language before the age of six likely perceives reverberation more strongly than monolinguals or those

who learned second languages after age 6 (Rogers et al. 2006). With respect to the Tomba dei Demoni Azzurri, the acoustic data that emerged during the present study demonstrates that the tomb's burial chamber is extremely reverberant across multiple frequency bands between 125 and 2000 Hz. This in itself is interesting because many of the studied tombs were more reverberant at specific frequencies, such as frequencies below 500 Hz (Ortoleva 2021).

Reverberation is studied by triggering an acoustic sound that quickly increases and then decreases across multiple frequency bands. Multiple

sounds can be used to assess reverberation, such as hand claps, gun shots, bursting balloons, or the propagation of an artificial sine sweep that spans 20–20,000 Hz. The choice to use recorded hand claps for this study was guided by the need to quickly (8–10-minute limit for the acoustic protocol) document sound and visual constructs inside each burial chamber. Although the use of live claps have proved problematic in previous acoustic studies, the recorded claps provided a way to quickly replicate the sound source across multiple tombs and were found to provide replicable acoustic measurements (Seetharaman & Tarzia 2012). Unlike gun shots or a bursting balloon, hands claps also provided a more ‘organic’ IR that may have potentially been present during the funerary event. Subsequent to the fieldwork, a randomized portion of the resulting data for the study was statistically assessed by an acoustics engineer (Andrew Barnard) at Michigan Technological University and now based at Pennsylvania State University using MATLAB thereby supporting the validity of the final data (Ortoleva & Barnard 2020). It must be noted however that the handclap did not consistently capture octave bands above 6300 Hz which are not of primary focus here.

The calculation of reverberation in a space is assessed via different times (EDT, RT20, RT30, RT60) which are measured according to how long it takes for a sound to decrease 60 dB. ‘EDT or early decay time, is evaluated from the slope (per a 60 dB decay) of the integrated impulse response (IR) curves which itself is determined from the slope of the best-fit linear regression line of the initial 10 dB (between 0 dB and –10 dB) of the decay (ISO 3382-1, 15).’ EDT was of primary focus for the present study because it can accurately assess how sound is perceived in specific positions in space whereas other measurements (RT20 etc.) assess a space in its entirety.

The acoustic measurement AlCons also provides a way to assess speech sounds. Although our inability to speak any regionalised form of the Etruscan language may limit our understanding of visual imagery as represented to the Tarquinian citizen, an acoustic assessment provides a workaround to this limitation. AlCons (articulation loss of consonants) measures the intelligibility of speech inside an enclosed space such as the chambered tomb by assessing consonant versus vowel sounds. Speech across cultures tends to be focused around 2000–4000 Hz (Rogers et al. 2006; Till 2019). Because architectural structures, such as niches in walls (for example, the niche inside the entrance corridor of the Tomba dei Demoni Azzurri) affect sound propagation, a niche with a

depth of 0.3048 m. magnifies frequencies of 1000 Hz and niches that are 0.1524 m. in depth magnifies frequencies of 2000 Hz. (Weber & Katz 2022; Andrew Barnard *pers. comm.*). Aural data from the Tomba dei Demoni Azzurri elucidates this interplay between structure and sound.

7. Study results: Sound propagation inside the Tomba dei Demoni Azzurri

Amongst the studied painted tombs, those with the longest reverberation times are the Tomba dei Demoni Azzurri and the Tomba dell’Orco I and dell’Orco II. The Tomba dei Demoni Azzurri is however unique in that strong reverberation times were documented across numerous octave bands whereas dell’Orco I and II were found to be more reverberant at lower frequencies (Ortoleva 2021). When considering the sonic ‘fingerprint’ of the Tomba dei Demoni Azzurri, EDT times (reverberation measured during the first ten seconds of acoustic decay) were significant, reaching a mean of six seconds at 125 Hz towards (Fig. 8; Table 1). Experiencing such a long reverberation time creates an inability to speak and be heard. It also prevents sound localisation with respect to being able to identify a sound’s origins. During the funerary event, lower frequency chants, prayer, and any other sounds would have seemed to emerge from all around the funerary observer. Another acoustic metric known as AlCons is further revealing. AlCons measures speech sounds, and more specifically, the loss of consonants in an enclosed space (Table 2). When assessing AlCons inside the Tomba dei

Table 1

Tomba dei Demoni Azzurri, 450–420 BCE table of EDT values across 125–6300 Hz. Created in EASERA by J.K. Ortoleva.

	N	Minimum	Maximum	Mean	Std. Deviation
EDT 125 Hz	7	4.67	7.52	5.9700	1.27763
EDT 250 Hz	7	2.34	5.62	3.2529	1.15697
EDT 500 Hz	7	2.35	5.03	3.0843	0.90647
EDT 1000 Hz	7	1.90	2.37	2.0814	0.15826
EDT 2000 Hz	7	1.35	1.88	1.6571	0.16760
EDT 4000 Hz	7	0.86	1.17	1.0329	0.11600
EDT 5000 Hz	7	0.79	1.12	0.9743	13,302
EDT 6300 Hz	7	0.52	1.39	0.9986	26,736
Valid N (listwise)	7				

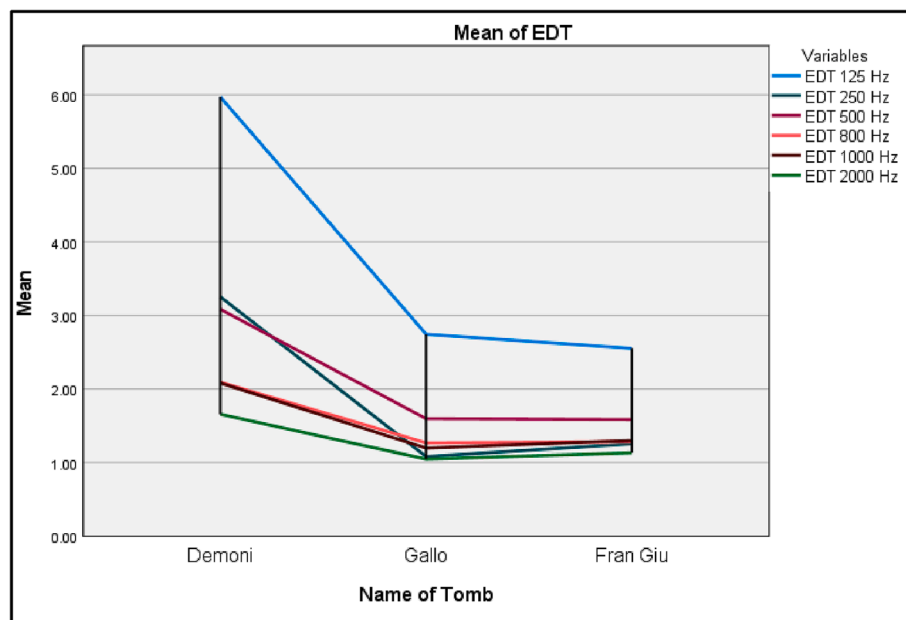


Fig. 8. Overall mean of EDT inside the Tomba dei Demoni Azzurri versus The Tomba del Gallo and the Tomba Francesca Giustiniani. Created in SPSS by J. K. Ortoleva.

Table 2

Articulation loss of consonants (ALcons) ranges for speech. Table after: R. Till, 2019, table 1.

Ideal intelligibility	<3%
Very good intelligibility	=3% to 8%
Good intelligibility	=8% to 11%
Poor intelligibility	>11% to 20%
Worthless intelligibility (limit value 15%)	>20%

Demoni Azzurri in response to female speech, the burial chamber was found to be completely intelligible (Fig. 9). In other words, As seen with the tomb's reverberation scores, in that it is highly unlikely that funerary participants were able to ascertain where sounds originated inside the burial chamber. Instead, once entering the chamber, words with consonants would have been difficult to understand. However, the present data suggests that the burial chamber was not acoustically consistent. This is best clarified when considering reverberation times at different locations inside the burial chamber.

Although the Tomba dei Demoni Azzurri is reverberant across multiple octave bands, reverberation times, particularly at lower octave bands, varied depending on where sound was assessed inside the burial chamber. The longest reverberation time inside the Tomba dei Demoni Azzurri was documented in the rear area of the chamber where a banquet is depicted with musicians and where eight base marks were carved into the chamber's floor. Here, at 125 Hz, reverberation times rose to a high of 7.52 s (Table 1; Fig. 10). Interestingly, such a reverberation time is consistent to those documented inside modern Catholic cathedrals, such as St. Paul's Cathedral in London, which has reverberation times ranging between seven and 11 s (Lewers & Anderson 1984, 288). Not only would sounds have been greatly magnified at this frequency, but such an effect would have been quite noticeable. The chamber's right wall, where multiple daemons are depicted exhibited the lowest EDT times inside the chamber. Whilst this latter fact is interesting, it differs from other studied tombs such as the Tomba dell'Orco where two of the tomb's burial chambers (Tomba dell'Orco I and dell'Orco II) were both more reverberant where daemons are illustrated at 250 Hz and below (Ortoleva 2021).

8. Discussion of study data: The Tomba dei Demoni Azzurri

The present acoustic assessment elucidates the behaviour of sound inside the Tomba dei Demoni Azzurri across multiple frames of reference. Clearly, the reverberation times inside the tomb's burial chamber

are long, particularly towards the rear wall. This is especially interesting because scholars such as Torelli (1983) and Roncalli (1997) have suggested that the rear portion of burial chamber was reserved for the dead. Both scholars have largely relied on iconography and architectural structures such as funerary trenches and benches. It is therefore striking that the present acoustic results support such an argument. Moreover, continued reverberation times were documented at 1.68 s at 2000 Hz throughout the chamber, which contributed to the chamber's poor AlCon scores. Sound is not linear, thus it tends to bounce off surrounding surfaces such as walls, ceilings, and floors of a structure (Ortoleva 2021; Weber & Katz 2022). One will recall that deep niches (carved into the wall or floor of a structure) enhance sound inside the tomb space. The trench located towards the rear wall probably contributed to longer reverberation times at 2000 Hz. The present AlCon data also informs regarding Etruscan speech and provides new options for future exploration of epigraphic sources.

The Etruscan language, a non-Indo-European agglutinating language, was clearly not phonemically connected to the languages of Etruria's contemporaries, such as the Gauls, Sabines, Ligurians, and Greeks (Wallace 2008). At present, it is minimally linked via textual correlations to two additional (extinct) languages, Lemnian (language of the pre-Greek populace on the island of Lemnos) and Raetic, (a language previously spoken in the sub-Alpine areas of Eastern Italy; Rix 1998). Even though we lack a clear understanding regarding Etruscan speech patterns and dialects, as demonstrated here, acoustic measurements, such as AlCon, can relay accurate information regarding speech audibility, sound localisation, and the audibility of specific speech sounds. An assessment of speech sounds as documented in surviving funerary inscriptions can assist in further understanding how space was aurally perceived, not simply from the vantagepoint of the modern observer, but in terms of the funerary participant.

In other words, the present AlCon scores tell us that consonants, and therefore higher frequency speech sounds, were either poorly understood inside the Tomba dei Demoni Azzurri, or completely unintelligible. As human beings age, sensitivity to consonants tends to decrease leading to the need for hearing apparatuses (Diehl et al., 2004). Such individuals can often hear vowels, but because consonants are not heard, words become unintelligible and this same tendency is indicated by the poor AlCon scores documented inside the Tomba dei Demoni Azzurri. However, slow chants without consonant sounds and initiated by male and/or female vocals would have magnified, particularly towards the rear wall. Upon entering the tomb space, the ability to perceive most speech was largely negated, and yet sounds remained, some blurring

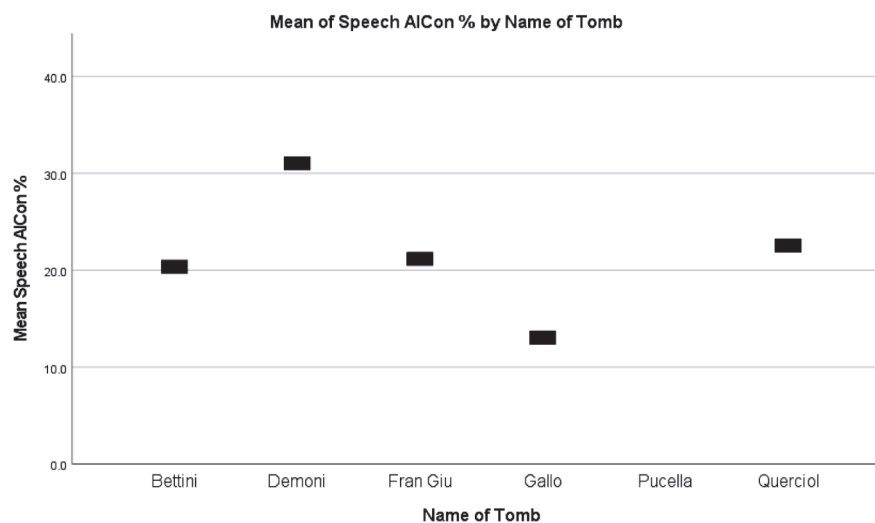


Fig. 9. AlCon percentage, Tomba dei Demoni Azzurri versus other 5th century BCE painted tombs in Tarquinia. Created using SPSS by J.K. Ortoleva.

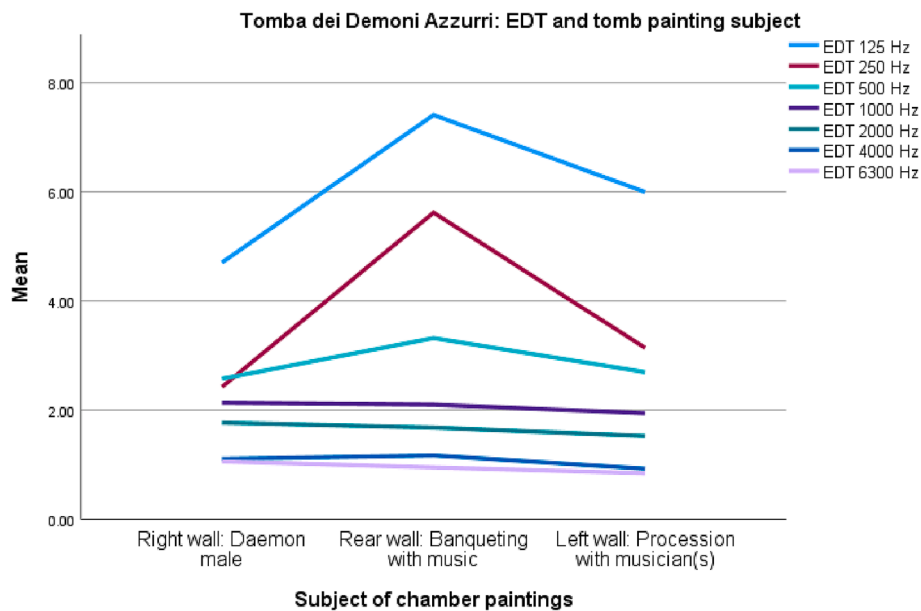


Fig. 10. Tomb painting subject and EDT between 125 and 6300 Hz in the Tomba dei Demoni Azzurri. Created in SPSS by J.K. Ortoleva.

together creating an aural experience that was not fully eased even when exiting the tomb space altogether as sound tends to travel through dromoi so quickly that some dromoi extend sounds emerging from the tomb across multiple metres (Ortoleva, 2022b). When acoustically documenting the Tomba dei Demoni Azzurri, an interesting result of the present aural data was noted inside the burial chamber.

When standing inside the chamber, conversation taking place outside the tomb, estimated by the researcher to be over 14 m from the burial chamber was clearly heard inside the chamber as though the conversation was occurring within not 14 m away. The modern dromos has a metal staircase that leads to the underground chamber. At first, it was assumed that the metal may have contributed to the sound effects. However, the metal staircase is not solid but instead interspersed with holes, thus, it is highly unlikely that the staircase alone caused the acoustic effect (Andrew Barnard, *pers. communication*). The experience of hearing sound travelling so far outside the tomb space speaks to the acoustic nature of Tarquinia's bedrock and the general construction of the tomb space. Perhaps more interesting, if generated inside the burial chamber, sound was greatly limited in terms of sound localisation. Conversely, if originating from outside the tomb itself, sound was experienced inside the tomb proper in a much clearer manner. Notably, this was not a phenomenon documented in all of the studied painted tombs. For example, conversation generated from outside of another studied tomb, the Tomba Francesca Guistiniani, c. 500–450 BCE was not similarly heard inside the burial chamber.

Current scholarship pertaining to different Etruscan musical instruments has thus far been unable to conclusively clarify which, if any, instruments were played inside the painted tomb space (Sarti 2010). While not able to firmly identify which instruments were played in specific tombs, the present study informs us regarding the acoustic nature of different instruments inside the tomb. One commonly depicted instrument in Tarquinian tombs is the *chelys lyra*. When considering the strong reverberation times documented inside the tomb. The strumming of a B3 note on a lyra creates sounds across 125–250 Hz. The lyra therefore seems to have the ability to trigger lengthy reverberation. If the funerary participant stood near the rear wall of the chamber, the strumming of a lyra would have triggered a strong rumbling sound that would have propagated throughout the chamber. The sound of the lyra would have not only been magnified, but would have also made it difficult to localise sound creating the sense that such effects were emerging from the tomb itself. This leads to a final suggestion that is

important to consider. The Tomba dei Demoni Azzurri, may have never used as a final depository for human remains but instead served a similar purpose to funerary structures in necropolises at Tuscania with painted scenes throughout to practice ancestral cult (Steingraber 2022, 177).

There is a great deal of unclarity regarding the inhumation process inside the Tomba dei Demoni Azzurri. The tomb seems to have been looted one time (Adinolfi et al. 2005b). This, along with the fact that the illegal entry was performed through a very small section of the chamber's entranceway suggests that inhumation was either not conducted inside the tomb or that any inhumed remains were relocated. This lack of clarity assumes further significance if revisiting what different sounds represented to Etruscan society. Higher frequency bird song and low frequency thunder were translated as sacred or divine messages from beyond (Cic. *De Div.* 1.41.92; 2.38.80; Ov. *Fast.* 4.812–18; Livy 1.34.3–10). Experiencing the magnification of low frequency thunder (63–250 Hz) that was already an extremely loud naturally generated sound inside the human-made burial chamber would have been physically felt by those who entered the tomb. In other words, lengthy reverberation across low frequencies causes a rumbling sensation, much like thunder. It is difficult to imagine such an experience going unnoticed or being ignored particularly if lasting well over six seconds. A space that amplified such sounds could have been experienced as 'otherworldly' thus, perhaps necessitating ritual performance and other activities intended to relay certain messages. To be clear, I am not suggesting that the Tomba dei Demoni Azzurri was intentionally constructed to perform such activities. Upon experiencing such clear aural phenomena inside the tomb, it seems logical to suggest that the tomb was perhaps 're-envisioned' as a sacred space where funerary ceremony was practiced with intact as well as cremated remains. Following such ceremony, the bodily remains were then removed to be interred elsewhere.

9. Conclusions

The Tomba dei Demoni Azzurri is filled with visual and aural contradictions. A trench and base marks were constructed inside the burial chamber, and yet, intact bodies were seemingly not deposited inside the tomb. Vibrant tomb paintings depicting multiple noisy events including a procession with dancers and musicians and a large mural-like display of a banqueting scene visually represent different sounds without any evidence of accompanying noises that tend to permeate such activities.

As demonstrated in this paper, the tomb is also a place where various musical and human generated sounds assume a sonic life of their own and magnify if certain sounds and/or instruments such as the lyra are sounded.

What we see or hear is never because of a singular sense, but rather the product of the brain synthesizing different sensory data to ultimately construct personal and collective experience (Seth 2018). Clarifying such processes outside the realm of visual experience strongly suggests that the modern scholar may envision the painted tomb differently than those who originally used painted tombs to bury their dead. As such, we cannot pretend to understand exactly how the sonic phenomena discussed in the present article emotionally affected the original funerary participants inside the Tomba dei Demoni Azzurri. Nevertheless, what is quite clear is that aural experiences inside the tomb space almost surely affected how the funerary event was cognitively experienced because the funerary participant was personally effected.

Whether experiencing an inability to sound localise or witnessing certain sounds that exponentially magnified whilst other sounds faded, the material nature of the Tomba dei Demoni Azzurri constructed the aural experiences of funerary participants just as much or more so than the tomb's paintings likely ever did. As such, sound itself served as a boundary, similar to any other architectural structure (for example each tomb's dromos). As demonstrated throughout this article, because of the extraordinary preservation status of so many painted (and unpainted) chambered tombs in Tarquinia (and elsewhere in Etruria), the sounds and resulting sonic effects once experienced during the funerary event remain uniquely accessible via a properly administered acoustic method and subsequent analysis. The present results therefore attest to the crucial importance of further aural investigations not only across additional Etruscan chambered tombs but other cultural contexts in the ancient Mediterranean and beyond.

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Declaration of Competing Interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2023.104000>.

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