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On the relationship between sound, acoustics, and San rock art: An archaeoacoustic study at twenty-seven sites in the Maloti-Drakensberg mountains (South Africa)

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ABSTRACT

Over the past two decades, scholars have proposed the existence of a strong relationship between sound, acoustics, and the production of San rock art in certain places. However, this intriguing hypothesis had never been tested through the systematic application of a rigorous method to a substantial sample of sites. In this paper, we present an unprecedented archaeoacoustic study conducted at 27 shelters with San paintings located in the Maloti-Drakensberg mountains (South Africa). The results obtained through the use of the impulse response (IR) method indicate that such a relationship should not be considered a pattern, but a circumstantial occurrence identified only in specific parts of the South African territory. Drawing on these data, we suggest that in our study area, the choice of sites to be painted may have been predominantly influenced by ontological beliefs concerning how the San perceived the shelters and the surrounding landscape.

1. Introduction

Sound is a substantial component of San people's cultural practices (e.g. Katz, 1982: 51; Barnard, 1992: 81). In his pioneer work *"The native races of South Africa"*, the ethnologist George W. Stow (1905: 102) claimed that San might have been the most musical people in the country, while the anthropologist Lorna Marshall –who conducted several expeditions to Southern Africa and lived among the!Kung (Ju|'hoan San) of the Kalahari Desert in Namibia and Botswana during several periods in the 1950 s, 60 s and 70 s– highlighted that most of the time there was someone making music at the camp (Marshall, 1999: 79-80). Also, the emblematic San healing dance, argued to be the 'central ritual' of San religion (Guenther, 1999: 181) was permeated by singing, clapping, and the continuous clatter of rattles and thudding feet (Marshall, 1969: 359; Katz, 1982: 39; Keeny and Keeny, 2013). During this ceremony, the dense atmosphere formed by the sound helped the shamans to enter altered states of consciousness –also known as trance– in which they embarked on journeys through the spiritual world (Lewis-Williams, 1994: 286). Ethnographic evidence reveals significant variation in the size of San healing dances, ranging from smaller gatherings with as few as 10 participants (Kay, 1833: 841-842; Marshall, 1999: 64) to larger rituals involving up to 90 dancers and singers, with some suggesting that at least 15–20 adults are necessary for the dance to be fully effective (Lee, 1979: 365; Marshall, 1999: 64). However, songs, clapping, and other forms of sound-making extended beyond the healing dance, also playing a central role in ludic dances (Guenther, 2020: 206), children's games and songs (Katz et al., 1997: 48-49), and storytelling (Bleek and Stow, 1930: XXIV; Biesele, 1993).

The images depicted in rock art also afford us an indirect insight into the extent to which sound permeated the daily and ritual life of San

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people and their relationship with the surrounding environment. In addition to numerous representations of the aforementioned healing dance (Lewis-Williams and Pearce, 2012), figures of musical instruments such as musical bows (Vogels and Lenssen-Erz, 2017; Rusch, 2017), bullroarers (Rusch and Wurz, 2020), drums (Kumbani, 2023) and aerophones (Rust et al., 2022; Kumbani et al., 2019; Kumbani and Díaz-Andreu, 2024) can be found in different sites located in Namibia and South Africa (including the Maloti-Drakensberg mountains). Also, wavy lines associated with images of elephants have been interpreted by some authors as the representation of the sounds produced by these animals to communicate with each other (Parkington and Paterson, 2017; Rusch, 2017).

Building on this background, and influenced by the idea that the visual primacy of rock art imagery can sometimes blind researchers to equally important non-visual aspects of these cultural manifestations (Ouzman, 2001: 237), some scholars sought to investigate in greater detail the potential relationship between sound, acoustics, and San rock art. Using a digital recorder to register sounds produced and reflected at Klipbak I –an open-air site with rock gongs and engravings located in northwest South Africa– Rifkin (2009) identified the occurrence of audible echoes in the area with the highest concentration of motifs. Based on this evidence, the author suggested that rock art sites with such acoustic features would have been perceived by the San hunter-gatherers as places filled with supernatural potency, where spirits would dwell (Rifkin, 2009: 594). In a similar vein, although employing a variant of the impulse response method, Rusch (2024) identified a connection between distinct echoes and concentrations of rock art engravings at the Kurukop site (Nama Karoo, South Africa). According to the author, this acoustic effect was likely perceived and integrated into the cultural practices of the San hunter-gatherers and Khoe herders who occupied the region.

The relationship between sound, acoustics and rock art at painted sites has received less attention. However, Mazel (2011, 2023), mainly based on bibliographic research, proposed that the richness of the rock art found in Didima Gorge (Maloti-Drakensberg mountains, South Africa) is associated with the acoustics of the landscape, which remarkably amplifies and echoes the crashes of lightning storms and thunder. For this scholar, the acoustic properties of the gorge –whose name in Zulu means "the reverberating one"– must have contributed to establishing it as an important spiritual place for the San people, who would have used the large and densely painted sites of the area to perform potent ritual dances (Mazel, 2011: 292-293). In this context, Mazel (2011) emphasized the need to undertake in-situ archaeoacoustic research in the Maloti-Drakensberg with the aim of characterizing the acoustics of the painted shelters and investigating the particularities of the relationship between sound and the practices associated with rock art production and use.

In light of this need, the ERC Artsoundscapes project –in collaboration with the KwaZulu-Natal Museum– carried out an unprecedented fieldwork to systematically characterize the acoustics of 27 San rock art sites located in the Maloti-Drakensberg mountains. Using a methodology grounded in advanced technology and principles in the field of room acoustics, the sites were assessed as potential performance spaces in order to address three specific research questions: Could the acoustic properties of the rock art shelters have contributed to enhancing the sensory impact of sonorous cultural practices –such as healing dances, singing, storytelling, and the playing of musical instruments– conducted in them? Is there a correlation between the number of images painted at the sites and their acoustic features? Can the supposed relationship between sound, acoustics, and San rock art be considered a pattern or just a circumstantial occurrence? Over the next pages, we answer these questions and discuss the relevance of this contribution to the studies on the sensory dimension of San rock art.

2. San rock art in the Maloti-Drakensberg mountains and the study sample

The Maloti-Drakensberg range extends from the northeastern regions of South Africa, stretching southward along the border between Lesotho and KwaZulu-Natal Province, before turning westward into Eastern Cape Province (Fig. 1). For thousands of years, these mountains were home to San hunter-gatherers and their ancestors. From the 1840 s onwards, European colonists moved into the foothills of the Maloti-Drakensberg, which had previously been occupied by herders and agropastoralists. This process played a decisive role in the disappearance of most of the San from the area by the end of the 19th century (Prins, 2009; Francis, 2010). However, they left their mark in the form of thousands of finely detailed and complexly painted images in hundreds of shelters. For this reason, this area has been called "the richest storehouse of prehistoric art in the world" (van Riet Lowe, 1952: 7).

The KwaZulu-Natal section of the Maloti-Drakensberg, where our study area is located, stretches from the source of the Tugela River in the north to the source of the Mzimkhulu River in the south, covering some 200 km along the border with Lesotho. According to the database of the KwaZulu-Natal Museum, about a thousand sites have been recorded in this area, in which figures of humans, animals, and therianthropes can be observed either in isolation or forming complex scenes (Fig. 2). The dating conducted on these paintings reveals that they were produced between approximately 3,000 and 400 years ago (Mazel and Watchman, 1997, 2003; Bonneau et al., 2011, 2017, 2022), and that such images are the result of a tradition transmitted across many generations.

Given the infeasibility of characterizing the acoustic properties of all painted sites in the Maloti-Drakensberg, our study focused on the analysis of 27 shelters spread across two of its main rock art areas: Kamberg (11 sites) and Giant's Castle (16 sites) (Fig. 1). The choice of these sites was based on three criteria: 1) the images painted in these shelters form a representative sample of San rock art, reflecting its technical, typological and thematic diversity; 2) the shelters have enough space for cultural practices involving at least one performer (sound maker) and a small group of listeners/participants; and 3) most sites preserve their original morphological features, which implies that the current acoustic behaviour of the shelter is equivalent to that encountered by the San people. In this regard, sites with excessively small dimensions –that did not allow for a minimum source-receiver distance of at least 2 m to avoid excessive influence of direct sound from the loudspeaker and microphone clipping, and a minimum distance between the equipment and the nearest reflecting surface of a quarter of a wavelength of the lowest frequency measured, e.g., 1 m to measure down to 100 Hz– were not included in the study sample as they do not allow acoustic measurements in accordance with the ISO 3382-1 (2009) standards. Likewise, sites located in hazardous areas (e.g., high places where there is a risk of falling) and those whose original morphology has been significantly altered by the construction of stone walls that affect sound propagation, were also discarded.

3. Methodological procedure used for the archaeoacoustic study

3.1. Capturing the acoustic response of the shelters

In our archaeoacoustic analysis, each rock art site was assessed with the assumption that it was a place where the San might have carried out a series of cultural practices that may have benefited from (or perhaps have been motivated by) particular acoustics. For this reason, our study was performed in accordance with room acoustics principles. In this field of study, the acoustic response of a performance space is captured by gathering a set of impulse responses (IRs) according to the internationally standardized procedures described in the ISO 3382-1 (2009). The methodological procedure defined to characterize the 27 San rock art sites followed the ISO guidelines, although it was necessary to make certain adaptations –both when capturing and analyzing the IRs– due to

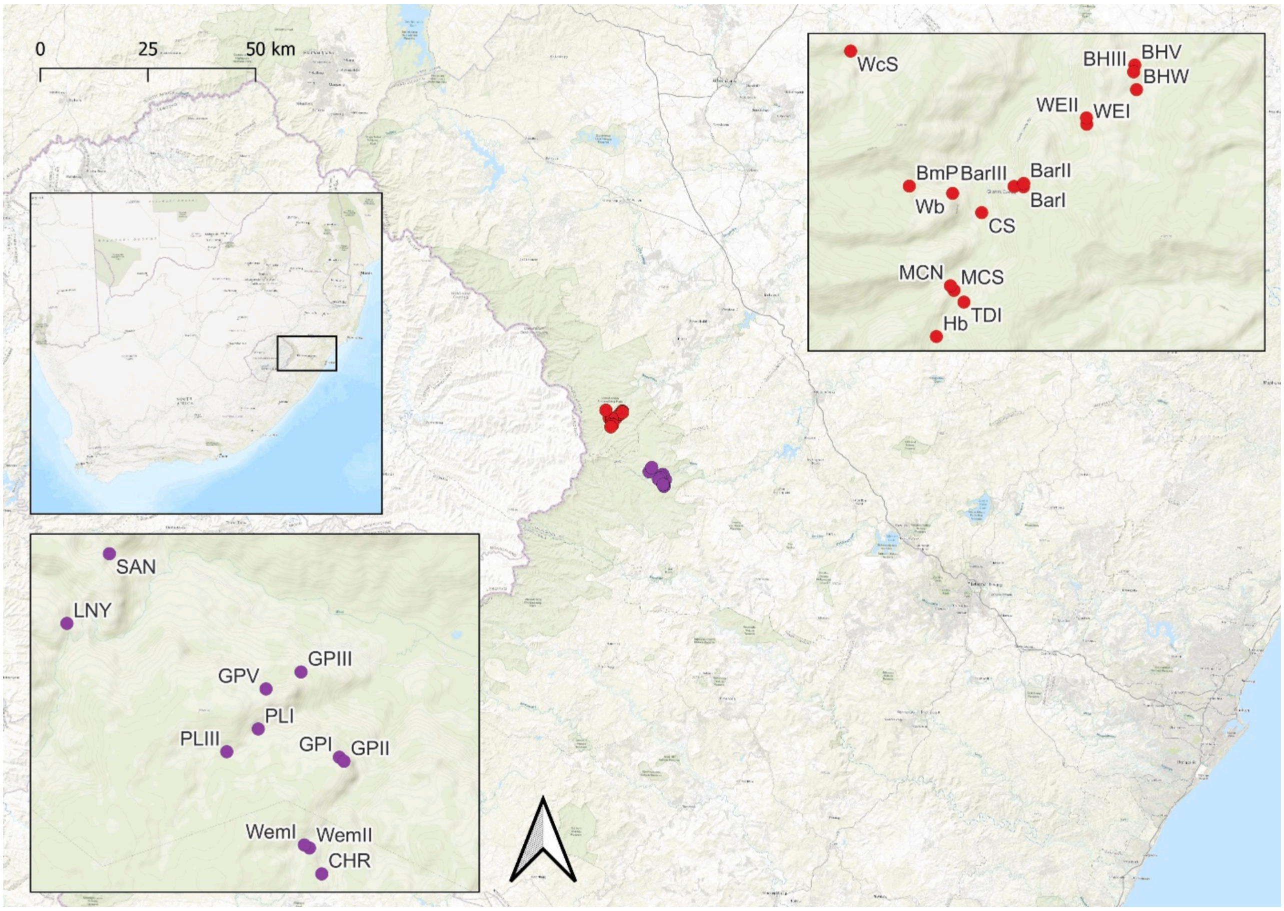

Fig. 1. Map with the location of the sites studied by the ERC Artsoundscapes project. Kamberg (lower left corner) and Giant's Castle (upper right corner) areas. GPI – Game Pass I; CHR – Christmas; GPII – Game Pass II; GPIII – Game Pass III; GPV – Game Pass V; PLI – Pluto I; PLIII – Pluto III; WemII – Willem II; WemI – Willem I; LNY – Lonyana; SAN – Sandra; CS – Camp Shelter; BarI – Barnes I; BarIII – Barnes III; BArII – Barnes II; WEI – White Elephant I; WEII – White Elephant II; BHV – Bamboo Hollow V; BHIII – Bamboo Hollow III; BHW – Bamboo Hollow Waterfall; BmP – Bannerman Path; Wb – Wildebeest; MCS – Main Caves South; MCN – Main Caves North; TDI – Two Dassie I; Hb – Hartebeest; WcS – Wilcox Shelter.

the fact that the shelters are semi-open spaces (for further discussion on this issue, see Alvarez-Morales et al. (2023a) and Rindel (2023)).

Given that an impulse response captures how a particular space modifies sound across different frequencies for a specific emitter and receiver position, gathering a representative set of IRs is key to accurately describing the acoustic response of the shelters itself and, given that these are semi-open spaces, the surrounding landscape. Furthermore, the selection of the emitting and receiving points must be meticulous, so that the different sound events that possibly occurred in the space are represented. Thus, up to four sound source locations (S) and two to twelve reception positions (R) were considered for each shelter (Table 1). The latter were distributed with some flexibility throughout the available area to capture the listeners'/participants' impressions, taking into account the site's size and geometry (Fig. 3). In contrast, the placement of the source position followed specific criteria: a) the first source position (S1) was placed either in front of the site's main rock art panel or in a central position in case paintings were scattered throughout the shelter; b) the second source position (S2) was set either in front of other relevant panels, or right in front of S1 in the smallest shelters; c) additional positions (S3, S4, and so on) were used, following the same principles adopted for S2 in shelters with large dimensions and more space for potential performances (Figs. 3 and 4). Also, the source and receiver height were set at approximately 1.45 m, as an approximation of the height of the mouth and ears height of a standing person. Considering the limited information available regarding the exact positions occupied by participants during the different San sonorous cultural practices, establishing a common and well-defined criterion for selecting source-receiver (S-R) positions across all spaces allows us to make meaningful comparisons between sites. Moreover, this approach minimizes deviations due to differences in point selection among shelters and enhances the repeatability of the study.

The equipment used to register the IRs includes an IAG DD4 mini dodecahedral loudspeaker connected to a pre-equalized IAG AP4GB amplifier, an omnidirectional microphone micW n201 connected to a Zoom F4 audio interface, and a 3rd order Ambisonics spherical array Zylia ZM-1 connected to a laptop via USB. To capture how each site reacts to different frequencies, the sound source emitted a test signal called an exponential sine sweep (ESS), which can be described as a tone that gradually increases to a high frequency over time in an exponential manner, covering all frequencies audible to humans in a single, continuous sound (Farina, 2000). The ESS were captured by the microphones to register monaural (omnidirectional) and spatial IRs in High Order Ambisonics (HOA). The monaural IRs were synchronously registered using the EASERA 1.2 software tool,[1] which allowed deriving standard acoustic parameters as established in ISO 3382-1 and real-time monitoring of the captured signals. The spatial IRs, in turn, were obtained through post-processing of the Zylia recordings. These recordings

[1] EASERA. Electronic and Acoustic System Evaluation and Response Analysis (EASERA) AFMG Technologies GmbH, Germany https://www.afmg.eu/en/afmg-easera (last accessed 06/03/2023).

Fig. 2. Example of San rock art found in the Maloti-Drakensberg mountains: a and b) Game Pass I; c) Lonyana; d) Barnes I; e) Sandra Shelter; f) Main Caves North.

not only serve to provide parameters related to spatial impression but also allow for the rendering of auralisations at multiple levels of spatial resolution

Moreover, an anemometer and the ARTA SPL Meter[2] software tool were employed to monitor environmental conditions during each measurement session. As seen in Table 1, in twelve of the 27 shelters, the proximity of streams and rivers, water drippings, or waterfalls made the overall environmental sound levels considerably high, with five sites presenting levels around 60 dBA. The wind was negligible in most shelters, although a light breeze of about 2.5 m/s was registered in some of them. These conditions were carefully considered to prevent them from affecting the data's usability, both during the data collection and during the analysis phase (Guski, 2015). More specifically, efforts were made to ensure the highest possible quality of IRs, with an optimal signal-to-noise ratio and smooth energy curves, allowing for the extraction of reliable acoustic data.

[2] Ivo Mateljan (2019) Arta software User manual. Program for Impulse Response Measurement and Real Time Analysis of Spectrum and Frequency Response. Version 1.9.3. Artlabs, Croatia. https://artalabs.hr/download/ARTA-user-manual.pdf (last accessed 06/03/2023).

Table 1
Details of environmental data and the IRs gathered at each site in Kamberg (K) and Gianťs Castle (GC) areas.

Site ID	Site Name	Site Area	N° of Figures	Environmental data			Number of S positions	Total S-R combination
				L_{Aeq} (dB)	T (°C)	Wind speed (m/s)		
GPI	Game Pass I	K	+300	43.0	20.65	1.35	2	5
CHR	Christmas	K	101–200	48.7	21.7	1.30	1	3
GPII	Game Pass II	K	11–50	42.8	17.3	0.10	2	5
GPIII	Game Pass III	K	1–10	28.1	19.1	1.85	2	6
GPV	Game Pass V	K	1–10	38.0	21.4	0.25	2	2
PLI	Pluto I*	K	11–50	62.6	16.8	0.00	1	2
PLIII	Pluto III*	K	1–10	66.7	13.5	0.55	2	4
WemII	Willem II	K	1–10	43.9	15.7	0.00	2	6
WemI	Willem I	K	101–200	46.7	16.7	0.00	2	6
LNY	Lonyana*	K	51–100	50.4	26.7	0.00	2	4
SAN	Sandra*	K	+300	51.4	22.0	0.00	3	4
CS	Camp Shelter	GC	101–200	49.6	14.1	0.00	2	4
BarI	Barnes I*	GC	+300	52.9	22.3	0.00	3	8
BarIII	Barnes III*	GC	101–200	60.7	20.7	0.00	2	4
BArII	Barnes II*	GC	11–50	54.7	21.1	0.20	2	4
WEI	White Elephant I	GC	11–50	36.2	15.6	0.00	2	8
WEII	White Elephant II	GC	1–10	42.9	16.6	0.80	2	4
BHV	Bamboo Hollow V	GC	11–50	38.6	25.0	0.00	2	4
BHIII	Bamboo Hollow III	GC	101–200	42.1	22.8	1.30	2	6
BHW	Bamboo Hollow Waterfall*	GC	1–10	52.7	26.4	0.55	2	5
BmP	Bannerman Path	GC	51–100	48.7	28.8	0.00	2	6
Wb	Wildebeest	GC	11–50	49.3	25.8	0.25	2	8
MCS	Main Caves South	GC	101–200	46.1	19.8	0.00	3	12
MCN	Main Caves North*	GC	201–300	51.9	14.8	0.00	4	8
TDI	Two Dassie I*	GC	11–50	52.3	14.1	0.00	2	4
Hb	Hartebeest*	GC	11–50	58.5	17.6	0.00	2	2
WcS	Wilcox Shelter*	GC	101–200	59.6	20.6	2.50	2	5

*Sites with high levels of environmental sound caused by the proximity of riverbeds.

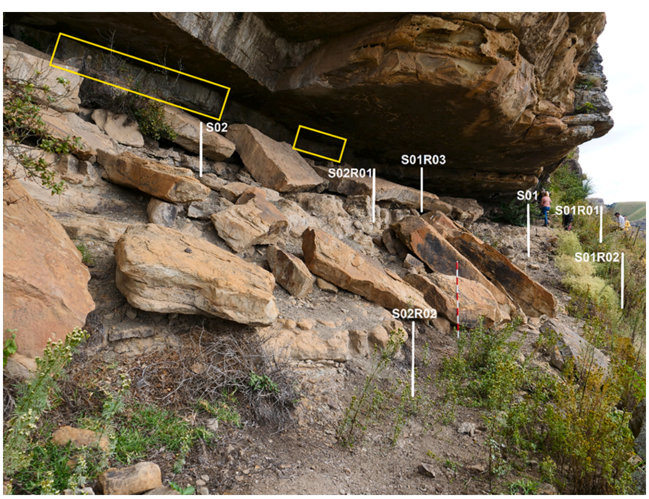

Fig. 3. Example of sound source and receiver positions set for the acoustic characterization of Game Pass II shelter (rock art panels framed in yellow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2. Assessment of the acoustic properties of the shelters

The acoustic properties of the selected shelters were evaluated based on several parameters listed in the ISO 3382-1, which were calculated from the omnidirectional responses recorded on-site. In this sense, T_{20} (s) was selected to assess the reverberation in the space. However, given that studied sites are semi-open spaces with non-diffuse conditions, the non-linearity parameter ξ (‰) defined on the ISO 3382-2 (2008) was also considered to evaluate the reliability of the T_{20} estimation. On the other hand, the capacity of each site for musical clarity and speech definition was assessed with the energy ratios C_{80} (dB) and D_{50} (−), respectively. The center time, T_S (ms), another indicator of sound clarity, was also used to detect strong delayed reflections or echoes, leveraging the fact that its formulation does not strictly differentiate between early and late reflections (Paini et al., 2011). In addition to T_S, the presence of audible echoes for speech and/or music reproduction was objectively evaluated with the Dietsch and Kraak echo parameter (Dietsch and Kraak, 1986). Finally, the capacity of each site to increase the loudness of sounds produced in them was assessed via the strength parameter G (dB), which is referenced to the level emitted by the sound source at a distance of 10 m in the free field. Such reference signal was measured in an anechoic chamber –a reflection-free room– before fieldwork, according to ISO 3382-1.

To characterize the sites as 'performance spaces,' the analysis of the IR structures and the discussion of the parameter values focused on the octave bands from 250 Hz to 4 kHz, since results at lower frequency bands were discarded due to technical limitations of the equipment. Moreover, given that no particular acoustic behaviour was observed within a specific frequency band, comparisons among specific recording positions and sites were established using the single values calculated according to ISO 3382-1, which for the aforementioned parameters involved the 500 Hz and 1 kHz frequency bands.

3.3. Comparison between sites: Details on the data selection process

The differences in size, morphology, and location in the landscape identified among the sites that comprise the study sample inevitably resulted in a substantial variation in both the number and location of the source-receiver combinations used in each shelter. Consequently, with the exception of the reverberation time, acoustical parameter values vary with source-receiver position, comparing the sites using spatially averaged values would lead to biased conclusions. In light of this issue, a comparison based on a representative single source-receiver position at each shelter was deemed appropriate after evaluating the relative consistency of the results obtained from the full set of source-receiver combinations in each case. To ensure a balanced comparison, it was necessary to select a source-receiver combination at each shelter that adhered to a consistent positioning criterion. Thus, the combination of

Fig. 4. Example of sound source positions used in Barnes I set according to the stablished criteria: (a) detail view of S1 in front of a dance scene; (b) General view of S1 and the receiver in R1; (c) General view of S2, placed in front of S1 at a central location, and the receiver in R1; and (d) S3 on the top of rocks to cover the right part of the shelter, with the receiver in R3.

the source placed in front of the main rock art panel (S1) and the receiver positioned centrally in the listeners'/participants' area, approximately 5 m from the source, was selected as the most representative, since it is common to all sites.

4. Results of the acoustic characterization

Following the methodology described above, the acoustic analysis of the sites focused on the monaural IRs measured synchronously with EASERA software, incorporating all S-R combinations used in the shelters. The analysis of these data confirmed the validity of using a single impulse response, selected according to a consistent positioning criterion across all sites. This strategy enabled controlled comparisons between the rock art sites, ensuring that the acoustic conditions were assessed in a standardized manner. Accordingly, this section presents the acoustic parameter results derived from the omnidirectional IRs captured at the S-R combinations considered most representative of the acoustic characteristics of each shelter. (Table 2; Fig. 5).

Given the semi-open nature of the sites, the IRs exhibit low reflection density and lack a relevant reverberation tail, as illustrated in the examples from Fig. 5. In this sense, the sites' conditions coupled with elevated levels of environmental sounds (see Table 1) resulted in short and non-linear decays in the EDCs curves –as in the case of Pluto III, where a valid decay of only 15 dB was obtained– which prevents a reliable estimation of the reverberation parameters. Also, it must be noted that the ξ values exceed the limit for a reliable calculation of the reverberation parameter ($\xi \leq 10$ ‰) in most of the sites, which means that the estimated values of T_{20m} are potentially inaccurate and should be interpreted with caution. For this reason, exact values of T_{20m} are not included in Table 2.

Nevertheless, general conclusions about the reverberation conditions can be drawn by conducting a wide-ranging analysis of the results. Such analysis is based on a detailed examination of the IR structures and their EDCs across different frequency bands (from 250 Hz to 4 kHz), considering not only the selected reference positions, but all the IRs collected at each site. In this regard, the spectral behaviour of the reverberation parameters suggests no substantial enhancement or detriment of any frequency, meaning that the acoustics of the shelters do not add any warmth or brightness to the sounds produced in them. Furthermore, the approximated values of T_{20m}, estimated from the EDCs with the least

Table 2
ISO averaged acoustical parameters values calculated for each site's reference position IR. The source-receiver distance is also included.

Site ID	S-R dist. m	D_m –	C_{80m} dB	T_{Sm} ms	G_m dB	ΔG_m dB
GPI	5.0	0.95	18.9	17.1	9.0	3.0
CHR	4.5	0.97	25.9	15.8	11.7	4.8
GPII	6.0	0.97	23.6	13.4	10.6	4.5
GPIII	5.0	0.99	28.7	8.9	10.5	4.5
GPV	4.7	0.98	25.1	10.4	10.8	4.2
PLI	3.4	0.96	17.7	18.9	13.1	3.7
PLIII	4.0	0.97	16.3	29.6	12.6	4.6
WemII	5.2	0.98	24.6	16.2	11.7	6.0
WemI	4.3	0.96	20.2	15.7	10.8	3.4
LNY	5.0	0.99	23.5	13.7	7.3	1.2
SAN	5.0	1.00	28.6	8.2	11.2	5.1
CS	5.0	0.99	27.3	8.1	13.9	7.8
BarI	5.1	0.97	20.3	15.5	11.5	5.7
BarIII	5.0	0.99	21.8	14.1	11.7	5.7
BArII	5.0	0.98	22.8	12.5	9.5	3.5
WEI	5.0	0.92	16.6	19.4	12.0	5.9
WEII	5.1	0.96	23.8	13.5	13.8	8.0
BHV	5.0	0.99	25.3	10.8	11.7	5.7
BHIII	4.6	0.97	22.7	10.7	8.6	1.8
BHW	3.8	1.00	30.4	8.9	13.3	4.9
BmP	4.9	0.96	21.5	18.2	9.9	3.7
Wb	4.3	0.99	28.1	11.8	12.1	4.7
MCS	5.8	0.89	14.0	24.9	10.5	5.8
MCN	4.9	0.91	15.2	21.4	11.2	5.0
TDI	3.5	0.95	19.6	16.3	13.1	3.9
Hb	3.5	0.99	22.7	12.9	13.1	3.9
WcS	3.5	0.98	20.9	17.6	12.2	3.0

irregularities in their decay profiles, fall in the 0.10–0.35 s range, with the only exception of Main Caves North (MCN) and Main Caves South (MCS) where a T_{20m} of about 0.40–0.45 s was found. However, these two sites are the most altered of the sample, since walkways have been built at their entrances and life-sized human models representing a San family were positioned in the centre of MCS, which may have slightly changed the reflection pattern of the recorded responses. Taking these particularities into account, the data indicates that the shelters that comprise the study sample exhibit minimal levels of reverberation, which allows a clear transmission of sound as long as it is not contaminated by an elevated ambience noise level (Ando et al., 1982).

Regarding sound clarity, an "excellent" definition of speech could be assumed in view of D_m values, which exceed 0.89 in all shelters (see Table 2) (Rindel, 2023). High values of musical clarity were also obtained, with C_{80} above 14 dB in all cases. Nevertheless, the interpretation of these data is not straightforward. A low concentration of late energy occurring after 80 ms following the arrival of the direct sound can explain the high values of these parameters. Although these results reinforce the idea that no disturbing reflections or reverberation tails negatively affect the clarity of music perceived in space, it cannot be said that they necessarily indicate a good scenario for music performances. Furthermore, the low T_{Sm} values obtained at all sites ($T_{Sm} < 30$ ms), which are not calculated using an established division between early and late reflections, expose not only a satisfactory degree of speech intelligibility (Fürjes and Nagy, 2020), but also the absence of any echoes or relevant delayed reflections. In addition to this initial cue on the lack of echoes, the Dietch & Kraak echo criterion for both speech and music (Dietsch and Kraak, 1986) was explored without obtaining any positive value.

Concerning the G_m values, it is at least 3 dB above the free field reference levels in most shelters (see ΔG_m in Table 2). The only exceptions are Lonyana (LNY) and Bamboo Hollow III (BHIII), which present lower values due to a lack of close reflective surfaces around the painted area (LYN is a shallow shelter, while BHIII is a straight wall). Given that the just noticeable difference (JND) set for the G_m parameter in enclosed spaces is 1 dB (ISO 3382-1, 2009; Kytö et al., 2012: 68), these results suggest that the acoustics of most shelters increase the perceived loudness of sounds produced in them. This is especially remarkable in White Elephant I and II (WEI, WEII), Willem II (WemII), Barnes I (BarI), Barnes III (BarIII), Camp Shelter (CS), Main Caves South (MCS) and Sandra Shelter (SAN), where such increment is in the range of 5.1 to 8 dB.

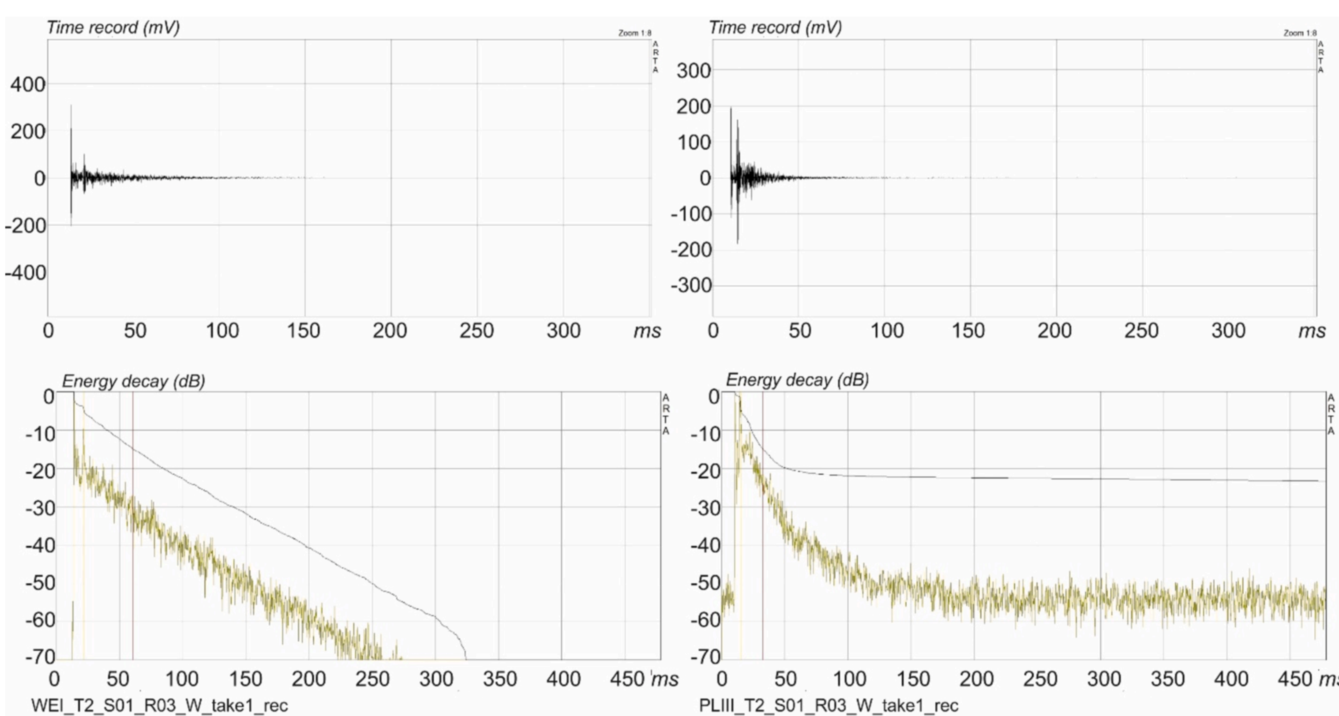

Fig. 5. Example of omnidirectional IRs and early decay curves (EDCs) analysed in this study. Data from White Elephant (left) and Pluto III (right). In the case of Pluto III, it can be seen that the background noise limits the available linear decay in the EDCs for the correct estimation of the reverberation parameters.

5. Discussion

The interest in the potential relationship between sound, acoustics, and rock art is not exclusive to scholars working on South African rock art, as many archaeoacoustic studies have been conducted at sites with paintings and engravings from various chronologies around the world. In this regard, it is worth noting the investigations carried out in French and Spanish Palaeolithic caves (Reznikoff, 1987; Waller, 1993; Dauvois, 1996; Till, 2014; Fazenda et al., 2017) and those developed in post-Paleolithic open-air sites and shelters located in the United States (Waller, 2005), Canada (Waller and Arsenault, 2008), Mexico (Díaz-Andreu et al., 2021), Russia (Díaz-Andreu et al., 2022a, 2022b, 2023), Finland (Reznikoff, 1995; Rainio et al., 2014, 2018), and Spain (Díaz-Andreu and García-Benito, 2012; García Atiénzar et al., 2022; Alvarez-Morales et al., 2023a, 2023b, 2023c; López-Mochales et al., 2023; Santos da Rosa et al., 2023), among others. Using different methodological approaches, the authors of these studies found that, in some cases, the acoustics of the sites and the surrounding landscapes could have been highly relevant to the cultural practices conducted in these places, enhancing their sensory impact (e.g., Díaz-Andreu et al., 2012), contributing to creating affective engagement through musical performances (e.g., Santos da Rosa et al., 2023), and even influencing the choice of places to be painted and the selection of images to be represented (e.g., Waller, 1993). On other occasions, acoustics seem to have played a less determinant and more complementary role, with only a subtle relationship being identified between it and the rock art (e.g., Fazenda et al., 2017).

With regard to the rock art sites located in the Maloti-Drakensberg mountains, the absence of echoes in the 27 shelters analyzed suggests that, contrary to what was proposed at two engraved sites in South Africa (Rifkin, 2009; Rusch, 2024), the production of San rock art in the Kamberg and Giant's Castle areas would not be influenced by the presence of these acoustic effects. Also, the lack of reverberation and sound envelopment –effects through which strong emotional responses can be generated during the appreciation of musical performances (Västfjäll et al., 2002; Pätynen and Lokki, 2016)– implies that if ritual dances, singing, storytelling, or the playing of musical instruments were performed in the shelters their impact on the participants' emotional state would not exceed that experienced in open-air areas. In this sense, we must emphasize that although the acoustics of most sites increase the perceived loudness of sounds produced within them, the amplification is not sufficient to alter the auditory perception of listeners/participants present in the shelters, nor does it allow the sounds produced in these places to be heard at great distances by individuals located outside them. Thus, addressing the first of the questions posed in the introduction of this article, we observed that the acoustic properties of the shelters do not seem to have contributed to significantly enhancing the sensory impact of sonorous cultural practices potentially conducted in these painted spaces.

Concerning our second research question, no correlation was identified between the number of figures painted in the shelters and the values of the acoustic parameters analysed. As can be observed in Tables 1 and 2, all sites exhibit similar acoustic features, with no relevant differences between densely painted shelters and those with only a few scattered images. Hence, while particular soundscape and acoustics may be considered a key factor in explaining the richness of rock art at Didima gorge (Mazel, 2011) and the concentrations of motifs at Klipbak I (Rifkin, 2009), in Kamberg and Giant's Castle the choice of locations for painting large quantities of images must have been guided by other principles that go beyond a connection between sound and rock art. In this regard, when seeking possible explanations for such choices, it is crucial to take into account that the San experienced far more in the landscape than we do, given that they considered the mountains and valleys as special places inhabited by beings and animals from another realm, where it was possible to interact with the spirit world (Lewis-Williams and Challis, 2011: 172). Furthermore, the way the San conceived the shelters was distinct from how we perceive these spaces based on our Western ontologies, given that, for them, the walls were not merely inanimate rock surfaces that served as supports for paintings, but rather a kind of membrane behind which supernatural entities dwelled (Lewis-Williams and Dowson, 1990). These beliefs might have influenced not only the choice of places to be painted in the landscape but also the selection of shelters that would eventually become densely painted, whether in a single episode or as a result of repeated visits to the site.

These data allow us to address our third and final question, and suggest that the relationship between sound, acoustics, and rock art in the Maloti-Drakensberg mountains cannot be considered a consistent pattern but rather a circumstantial occurrence.The San people and their ancestors are not a homogenous cultural entity that remained static over time and through space (Pargeter et al., 2016). Though their belief system is so widespread that it has been termed the 'pan-San cognitive system' (McCall, 1970: 18; Lewis-Williams, 1984: 227), studies on regional differences demonstrate that substantial variations in how the images were produced can be found in many areas of southern Africa (Laue, 2020, 2021a, b; Green, 2022). In this work, we suggest that such differences could also manifest in the way the San experienced a relationship between sound, acoustics, and their rock art paintings. Therefore, the conclusions reached through our study of the Kamberg and Giant's Castle sites do not invalidate or diminish the value of the proposals presented by Rifkin (2009), Mazel (2011) and Rusch (2024). On the contrary, by expanding the sample size and applying a rigorous procedure based on advanced methods in the field of room acoustics, our findings complement those of the aforementioned scholars and allow us to add another piece to the challenging puzzle that represents our understanding of San rock art.

6. Conclusion

Over the past two decades, the growing interest in the non-visual aspects of prehistoric images and the sensory dimension of practices related to their production and use has led scholars to explore the relationship between sound, acoustics, and San rock art from diverse perspectives, ranging from the study of representations of musical instruments and sound waves to the acoustic analysis of painted and engraved places. In this context, it was proposed that acoustic effects such as echoes and long reverberations would be directly related to the presence of large concentrations of rock art in certain parts of the Maloti-Drakensberg as well as other regions of South Africa, and that the acoustics of the shelters could have even influenced the performance of potent ritual dances at these places. Seeking to investigate this relationship between sound, acoustics and rock art in a systematic and rigorous way, we conducted archaeoacoustic analyses on sites located in two of the main areas with paintings in the Maloti-Drakensberg mountains. Our findings indicate that, in our study area, shelters with paintings do not possess acoustic properties capable of significantly increasing the sensory impact of sonorous cultural practices conducted in them, and that concentrations of images are not related to the presence of particular acoustic effects. Based on these data, we suggested that the relationship between sound, acoustics, and rock art should not be considered a pattern, but a circumstantial occurrence identified only in certain parts of the San territory.

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CRediT authorship contribution statement

Neemias Santos Da Rosa: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Lidia Alvarez-Morales:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Diego Moreno-Iglesias:** Methodology, Investigation, Formal analysis, Data curation. **Ghilraen Laue:** Writing – review & editing, Writing – original draft, Investigation. **Margarita Díaz-Andreu:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data is available on https://doi.org/10.34810/data1398

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