KEYWORD: *Acoustics – Rock art – Levantine rock art – Reverberation – Echo*

ACOUSTIC ROCK ART LANDSCAPES: A COMPARISON BETWEEN THE ACOUSTICS OF THREE LEVANTINE ROCK ART AREAS IN MEDITERRANEAN SPAIN

Margarita Díaz-Andreu and Carlos García Benito

Abstract. This article focuses on the relationship between acoustics and rock art in Levantine art in Mediterranean Spain. It takes as a case study three rock art areas where Levantine-style rock art was produced: the Valltorta Gorge, the Mortero Gorge and the Godall mountains. The study centres on the analysis of reverberation and echoes. In each area a comparison was made between the acoustic properties of sections of the area with rock art and of others with none. Different sounds were also tested in order to identify which possible instruments had the best chance of producing a sensory reaction. Although we cannot hypothesise on the specific practices that may have taken place in these areas, we conclude with the proposition that the acoustic properties of a site indicate a sacred use of the landscape, in which sound was a key element of ritual performance.

Introduction: acoustics and rock art

Rock art research has traditionally focused on the material and visual world, disregarding other aspects that may have been equally or more important for its production and location. This article is framed within the context of a recent trend in the field that seeks to uncover the more intangible aspects of pre-Historic rock art. It focuses on acoustics as a way of hypothesising pre-Historic communities' reasons for making and using rock art.

Despite the relative novelty of research into acoustics in the field of rock art studies, we should acknowledge that the sonority of rock art landscapes was mentioned by a handful of early researchers, although the emphasis on typology and chronology powerfully skewed their attention towards iconography and stylistic dating. Because of this, their comments on the auditory properties of the sites were always made in passing and they never considered this singularity as crucial for the production of the art (Arco 1917; Pager 1971). At that time archaeologists dealing with pre-Historic 'art' remained unaware of the information coming from anthropological literature, which connected rock art and acoustics among contemporary societies such as the Hopi (Talayesva 1942). Unfortunately no authors have attempted to link research into the musical instruments found at pre-Historic sites and the production of parietal art at them (Piette 1874; Passemard 1922; Seewald 1934). This situation only began to change in the 1950s and 60s after the discovery of rock gongs in Africa (Fagg 1957; Lanning 1958). This immediately preceded the studies of lithophones in Upper Palaeolithic caves with rock art undertaken by André Glory (Glory 1964, 1965; Glory et al. 1965). Although the literature makes no mention of it, we suspect that Fagg and Glory's studies may be connected, as they had met at the first two Pan-African Congresses of Archaeology[1]. Sadly, Glory's work was cut short by his untimely death in 1966 and a temporary revival of interest in the mid-1980s (Dams 1984, 1985) was short-lived.

Current research into acoustics and rock art has its roots in the work of a music specialist, Iégor Reznikoff, and a Palaeolithic specialist, Michel Dauvois (Reznikoff and Dauvois 1988; Dauvois 1989). As with Glory and Dams, their initial interest was in Palaeolithic 'art',

1 In the second Pan-African Congress of Archaeology held in Algiers in 1952, Glory had been responsible for an excursion to visit rock art. In the third they talked about rock gongs (Fagg 1957). Another scholar present at the second Pan-African Congress (Balout 1955) was the Swiss art historian, Sigfried Giedion, who years later also commented on the acoustics of caves and ambiguously linked this to cave art (Giedion 1962). Neither Glory nor Giedion attended the third Pan-African congress in Livingstone in 1957. However, given their common interests, it is possible that they remained in contact and that Fagg sent an off-print of one of his many articles on rock gongs to Glory and perhaps also to Giedion. Epistolary and offprint exchanges were extremely common at the time, and were fostered by encounters at international archaeological congresses (Díaz-Andreu and García Benito 2012).

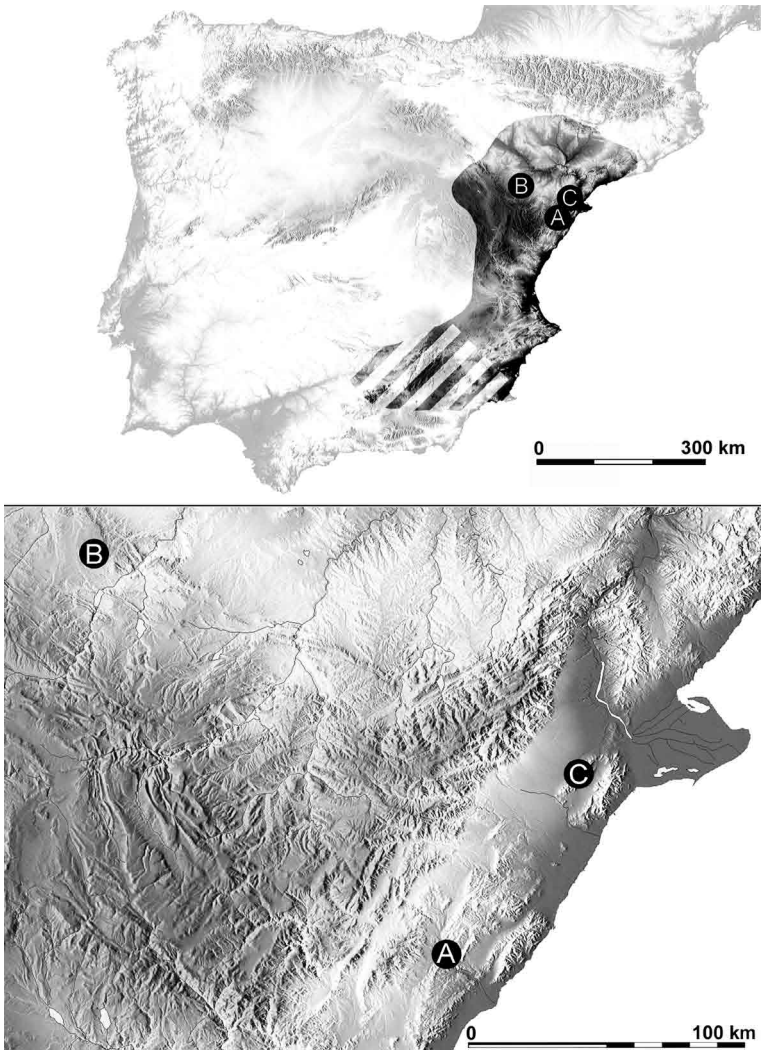

Figure 1. Map of the Iberian Peninsula with the Levantine rock art area shaded. A. Valltorta; B. Mortero Gorge: C. The Godall mountains rock art area.

although they differed in their approach, as they investigated the acoustics of the space where the art had been produced, studying echoes, resonance and tonality. Reznikoff and another researcher who had taken some measurements at Upper Palaeolithic art sites, Steve Waller, were the first to realise that art from other periods and chronologies could also be worth studying from the point of view of acoustics (Dayton 1992; Waller 1993; Reznikoff 1995; Waller et al. 1999: see also Ouzman 2001). Waller also innovated in the field by focusing on the iconography of rock art. Since the mid-1990s many other researchers have added their work to this expanding field of research. Among the latest work published we find studies not only of rock art (Rifkin 2009; Mazel 2011; Garfinkel and Waller 2012; Lahelma 2012; Williams 2012), but also of megalithic art and architecture (Watson 2006; Till 2009). There have also been new research into musical instruments (Higham et al. 2012) and novel experimental studies with them (Buisson and Dartiguepeyrou 1996; Dauvois 2005; Conard et al. 2009).

This article aims to test whether Levantine rock art in Spain was located in places with good acoustics, comparing three different rock art landscapes. The Levantine rock art tradition is dated to the Epipalaeolithic/Mesolithic/Neolithic[2] period, and paintings have been 'dated' from 8000 to 4000 BCE on the basis of superimpositions and stylistic comparisons (Viñas 2012: 75–78). Levantine art is characterised by motifs representing naturalistic animals and stylised humans, often composing scenes painted on hilly landscapes (García Arranz et al. 2012). This project stems from our initial work in 2011 at the Valltorta Gorge rock art area, where we undertook an experiment on the relationship between acoustics and the location of Levantine rock art. Despite the positive results we obtained, we finished our article by warning that 'the extent to which the model proposed for the Valltorta rock art area can be extrapolated to other Levantine rock art areas is, however, unknown and should be the focus of future research' (Díaz-Andreu and García Benito 2012: 3597). That is precisely our aim in this article: to investigate whether the association between Levantine rock art and acoustics is repeated in other areas with a similar concentration of decorated sites. The areas we selected to work in were the Mortero Gorge and the Godall mountains rock art area (Fig. 1).

Methodology

In order to compare the results obtained in the Valltorta Gorge with other rock art areas we first had to decide on what we were searching for. We knew that trying to find other fully comparable rock art areas was not possible, as each landscape is unique. It was helpful to remind ourselves of the reason we had chosen Valltorta in the first place — mainly because of the high concentration of rock art sites in a limited space.

2 The dating of Levantine rock art has been a matter of fierce debate. Some authors argue that the fine engravings of zoomorphs and signs that precede the Levantine paintings, but have the same style, should be dated to the end of the Palaeolithic (Martínez Valle et al. 2009; Mateo Saura 2011; Viñas 2012). Regarding the painted motifs, although most still believe in a Neolithic chronology (Guillem Calatayud et al. 2011; Hernández Pérez 2009; Martí Oliver 2008) , others see their origin in the Mesolithic (Viñas et al. 2010). Epipalaeolithic is a term used in Spain to denote archaeological complexes that have many points in common with the Late Palaeolithic techno-typological tradition (Aura et al. 2009). Radiocarbon dates have been obtained for the layer of calcium oxalate covering some paintings of the Marmalo rock art site with a date of 5890–5770 cal BCE (Ruiz et al. 2012), and further results have been promised for several years (Viñas et al. in press), but not everybody agrees with the method used to obtain the dates (Mas et al. 2012).

We decided this was an essential feature for the new test areas. Scholars repeatedly agree that Levantine rock art extends over an area of about 100 000 square kilometres along the Mediterranean coast between eastern Andalusia and the Pyrenees, with some incursions inland (Cruz Berrocal 2005: Map 1; Domingo Sanz 2008: Fig. 5.1; Moure 1999: Fig. 7.1). However, a review of the published literature soon made us realise that concentrations of rock art shelters with Levantine art do not appear in large zones to the south — Jaén and Almería — where, in addition, the paintings are less naturalistic than the Levantine art produced in the area between Alicante and the Pyrenees. The discussion as to whether there is a need to redefine what constitutes the Levantine style is beyond the remit of this article, but what is clear is that a more standardised type of Levantine art only appears further north, from the area of Albacete and Murcia, precisely the area originally considered as Levantine (Beltrán 1982: 10–11).

Partly for geographical convenience, from the various areas with a concentration of Levantine rock paintings (for example, towards the south of the Levantine area, Taibilla [Alonso and Grimal 1996] and Moratalla [Mateo Saura 2005]), we decided to choose the two rock art landscapes of the Mortero Gorge in Alacón (Teruel province) and the Godall mountains in Ulldecona (Tarragona province) (Fig. 1). The distance between these two areas is about 140 km, approximately the same as that between Mortero and Valltorta, whereas there are only about 50 km between Valltorta and Ulldecona. The distances do not mean that these communities did not know each other. Group territories during the Mesolithic have been calculated as having been between 25 and 35 square kilometres (Martí Oliver et al. 2009). However, analyses of different types of materials show that objects — and therefore some community members — travelled longer distances during the Epipalaeolithic/Mesolithic and Neolithic. For example, the Epipalaeolithic site of Baños in the Mortero Gorge area has perforated *Columbellae rusticae* shells that come from coastal areas (Beltrán and Royo 2008: 75). Adjacent to the Levantine area in Catalonia, beyond the north-east end of the Levantine area, the hammers used in the Neolithic salt mine of Cardona came from Collserolla, and variscite from Gavà is found in some of the Cardona burials. Moreover, in that whole area of Catalonia, honey flint from Provence (France) and obsidian from Sardinia was being used, and shell pendants, probably from the River Ebro delta were also deposited in burials (Terradas et al. 2014; Weller and Fíguls 2008). Studies of a variety of polished stones, including bracelets and polished axes, also show the movement of these objects across large distances (Harrison and Orozco Köhler 2001). These examples demonstrate that, despite the distances between the three areas, throughout the period in which the rock art was being produced, their communities may well have known each other and in any case, broadly speaking shared a symbolic universe to which the paintings testify.

Using the methodology developed in Valltorta (Díaz-Andreu and García Benito 2012: 3593), the examination of the acoustics in the three rock art areas described in this study was undertaken in three stages: fieldwork, analysis and interpretation. The methodology was as follows. The first stage was fieldwork, but it began with a thorough study of the published literature on the rock art in the area to be analysed and a careful design of the experiment adapted to the peculiarities of each of the rock art landscapes to be tested. In order to make the comparison possible, we decided to keep the focus of our study on reverberations and echoes. These were recorded with an M-AUDIO MicroTrak II digital recorder and comments on the results were noted in situ in a purpose-built acoustics recording form. As can be seen in all the tables included in this article, reverberation was measured as 0 (meaning no reverberation), 1 (indicating short and soft reverberation of one second duration or less), and 2 (longer reverberation). The number of echoes was also recorded. On the basis of the types of musical instruments known from the Upper Palaeolithic up to the beginning of the Bronze Age, we chose a series of sounds that represented wind and percussion instruments, as well as vocal music. Thus, in each test location we took six measurements: repeated clapping; two whistles with frequencies of C7/C#7 and G7/G#7 played together; the G7/G#7 whistle played at intervals; male and female voices together using the 'a' sound (as in mat) (the pitch was not controlled); a solo male voice and a solo female voice.

In addition, to assess reverberation and echoes with different sounds, we also decided to include a method of examining whether the acoustic properties were taken into account when deciding which shelters to paint in. Accordingly, we resolved not only to check locations where rock art had been created but, when possible and following a purposive survey, also other places in the landscape of an apparently similar geological nature (i.e. shelters in our case study) where, despite their relatively high number, no rock art has been found. Although we had not undertaken this type of test at Valltorta, we were intrigued about what results we could obtain. Yet, in practice we encountered the problem that the area where the pre-Historic communities decided to paint was not that large and this limited the selection of undecorated shelters. Also, in order to answer the question of who may have made up the audience the music was aimed at and where that audience would have been, we decided to carry out two series of tests, one at the sites themselves and another in nearby areas where large groups could be accommodated, i.e. the bottom of the gorge or the foot of the hill below the rock art shelters. Finally, to answer this question in a different way, we undertook two series of tests in the shelters, one facing towards the rock art panel and the other facing away from it.

After the fieldwork, the second phase of the project was a desktop analysis. We inspected the spectrogram

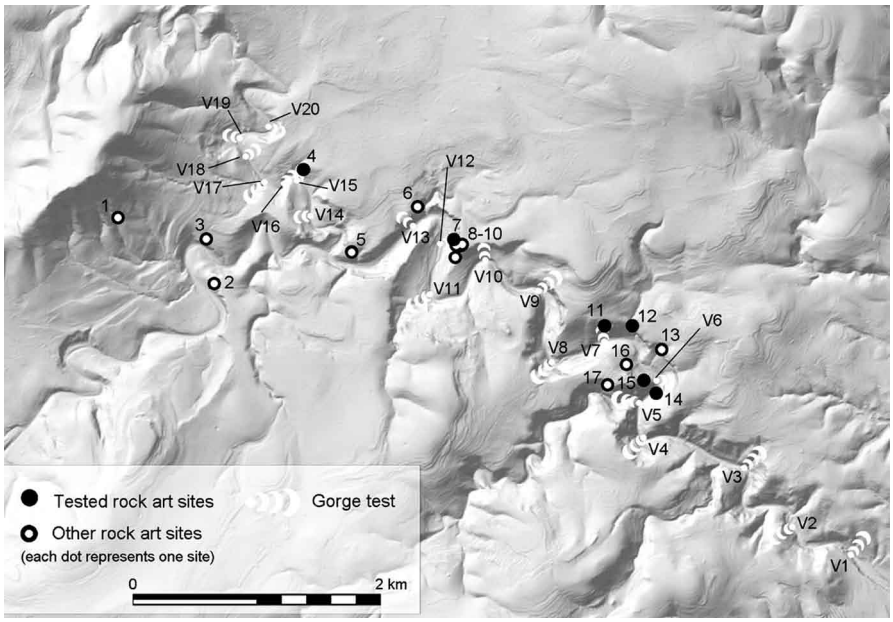

Figure 2. *Map of the Valltorta rock art area with indication of test locations.*

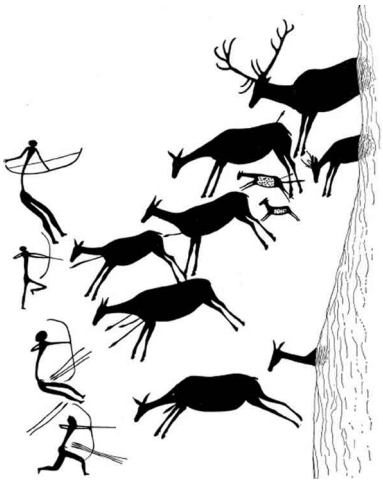

Figure 4. *Rock art paintings at Cavalls (Obermaier and Werner 1919).*

results from the fieldwork phase using free software developed at the Centre for Digital Music at Queen Mary, University of London, obtained with Sonic Visualiser. The results were noted in a database that we then queried to answer the questions posed and to allow us to make a series of interpretations.

Testing the acoustics at three Levantine rock art areas

The Valltorta Gorge

The rock art area of Valltorta was most likely 'discovered' in 1916, coming to scholarly attention in 1917, and it has been the focus of much research (Obermaier and Wernert 1919; Cabré 1925; Viñas 1982; Martínez Valle and Villaverde 2002; Viñas and Morote 2011; Guillem Calatayud et al. 2011). In a limestone gorge of about 10 km length, in which the rock art is concentrated in a stretch of 6 km, there are seventeen known sites (Figs 2 and 3). Three of them — Saltadora, Cavalls and Civil — are exceptional because of the large number of motifs painted in them. However, there are no apparent differences between the types of 'scenes' painted at these mega-sites and those at the minor sites. Generally speaking, 'scenes' with 'archers' predominate, while clearly identifiable women are in the minority. 'Deer', 'mountain goats' and 'cattle' represent the highest percentage of zoomorphs depicted. Some of them are painted with 'arrows' stuck in their bellies, necks and backs.

Our fieldwork in Valltorta Gorge took place in July 2011 (Díaz-Andreu and García Benito 2012). It first focused on the acoustics of the rock art sites themselves (fieldwork phase 1) and then on the acoustics of the gorge (phase 2). For the former we decided to test all three mega-sites and three selected minor sites (Lledoner, Mas d'en Josep and Tolls del Puntal). The results showed that reverberation was excellent at the minor sites, especially when facing the panel, and very good at the mega-sites. All types of sound gave excellent results when looking towards the shelter and very good results when facing away from it, when clapping and the female voice gave poorer results. Regarding echoes, more were obtained at the mega-sites, with the best results being those of clapping when looking towards the shelter and one intermittent whistle when facing the gorge. The poor results obtained at Mas d'en Josep for most of the tests were not corroborated in an informal test made during a later visit; this discrepancy seems to be linked to the strong wind at the time of our original experiment. This experience is

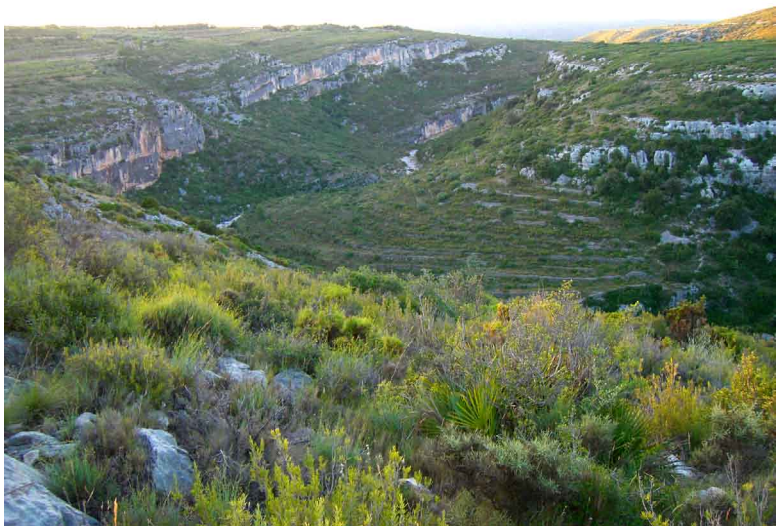

Figure 3. *The Valltorta rock art landscape (photo by M. Díaz-Andreu).*

an indication of the effect of the weather on the sonority of a site and of the need to take more account of the weather conditions in tests (Tables 1A–1D). Further experimentation has shown that results are significantly affected when the wind speed is over 5 km/h (García Benito in prep.).

In the second phase of the fieldwork, the auditory properties of the bottom of the gorge were tested. For this, twenty test locations were chosen at varied intervals less than one kilometre apart. The first four test locations were in the area downstream from the painted area and the last four were in the area upstream, beyond the decorated shelters. The remaining twelve were in the decorated section of the gorge, of which six were in front of rock art sites and the other six were in areas without known rock art sites. In the latter, the tests were made facing the side of the gorge from which we thought the best results would be obtained. The results of the tests clearly identified the decorated sector of the gorge as having the best acoustics, and in that sector the results obtained in decorated areas were better than those from the control locations with no art in the decorated area of the gorge. Echoes followed this trend even more clearly, as none were detected in the undecorated areas and the best results were obtained at the mega-sites and at the largest of the minor sites, Mas d'en Josep. The longest reverberation was obtained from voices, followed by the intermittent whistle. The largest number of echoes, however, resulted from clapping (Tables 1E–1F).

A. Reverberation (towards shelter)	**Mega-sites**				**Minor sites**		
	Saltadora (S)	Saltadora (N)	Cavalls	Civil	Lledoner	Mas d'en Josep	Tolls del Puntal
Clapping	2	2	1	2	2	2	2
Both whistles	2	2	2	1	2	2	2
One intermittent whistle	2	2	2	1	2	2	2
Voices	1	2	2	1	2	2	2
Male Voice	1	2	2	1	2	2	2
Female Voice	1	2	2	1	2	2	2

B. Reverberation (towards gorge)	**Mega-sites**				**Minor sites**		
	Saltadora (S)	Saltadora (N)	Cavalls	Civil	Lledoner	Mas d'en Josep	Tolls del Puntal
Clapping	1	1	1	1	1	1	2
Both whistles	2	2	2	2	2	1	2
One intermittent whistle	2	2	2	2	2	2	2
Voices	1	2	2	1	2	1	2
Male Voice	2	2	2	2	2	1	2
Female Voice	1	2	1	2	2	1	2

C. Echo (towards shelter)	**Mega-sites**				**Minor sites**		
	Saltadora (S)	Saltadora (N)	Cavalls	Civil	Lledoner	Mas d'en Josep	Tolls del Puntal
Clapping	2	3	0	0	3	0	0
Both whistles	0	0	0	0	0	0	0
One intermittent whistle	1	0	2	0	0	0	0
Voices	0	0	0	1	0	0	0
Male Voice	0	0	0	1	0	0	0
Female Voice	0	0	1	1	0	0	0

D. Echo (towards gorge)	**Mega-sites**				**Minor sites**		
	Saltadora (S)	Saltadora (N) *1	Cavalls *2	Civil *3	Lledoner	Mas d'en Josep	Tolls del Puntal
Clapping	0	0	2	0	1	0	0
Both whistles	0	3	0	1	0	0	0
One intermittent whistle	0	2	1	0	1	0	0
Voices	0	0	0	1	0	0	0
Male Voice	1	0	1	1	0	0	0
Female Voice	0	0	0	0	0	0	0

*1 The echo comes from the left. *2 The eco produces an effect stereo. *3 The echo comes from the right.

Table 1a. *Valltorta (V). Fieldwork phase 1. Reverberation A/ when facing the back wall of the shelter; B/ when facing the gorge; echoes (number of) C/ when facing the back wall of the shelter; D/ when facing gorge.*

E. Reverberation (from the gorge)	V1*[1]	V2	V3*[2]	V4	V5-Matamoros	V6-Saltadora	V7-Mas d'en Josep	V8*[3]	V9	V10	V11	V12-Cavalls	V13	V14	V15-Civil	V16-Civil II*[4]	V17	V18	V19	V20
Clapping	0	0	1	1	0	1	0	0	0	0	0	2	0	1	0	1	0	0	0	0
Both whistles	1	1	1	1	1	2	0	0	0	0	0	2	0	1	1	1	0	0	0	0
One intermittent whistle	1	1	1	1	2	2	0	0	2	0	1	2	0	1	0	1	0	0	0	0
Voices	1	1	1	1	1	2	1	0	0	0	0	2	0	1	1	1	0	0	0	0
Male Voice	1	1	1	1	1	2	0	0	1	0	1	2	0	1	1	1	0	0	0	0
Female Voice	1	1	1	1	1	2	0	0	1	0	0	2	0	1	1	1	0	0	0	0

*[1] Sound is transmitted upwards the Gorge. *[2] Sound is transmitted upwards the Gorge with clapping and downwards with Male voice. *[3] Strange place. Not well defined echo or reverberation. *[4] Sound is transmitted upwards the Gorge with whistle and male voice.

F. Echo (from the gorge)	V1	V2	V3	V4	V5-Matamoros	V6-Saltadora	V7-Mas d'en Josep	V8	V9	V10	V11	V12-Cavalls	V13	V14	V15-Civil	V16-Civil II	V17	V18	V19	V20
Clapping	0	0	0	0	2	2	2	0	1	0	0	1	1	0	0	1	0	0	0	0
Both whistles	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	1	0	0	0	0
One intermittent whistle	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0
Voices	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	1	0	0	0	0
Male Voice	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0
Female Voice	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Table 1b. *Fieldwork phase 2. E/ reverberation from the bottom of Valltorta Gorge; F/ number of echoes from the bottom of Valltorta Gorge. See Figure 2 for site and test point locations.*

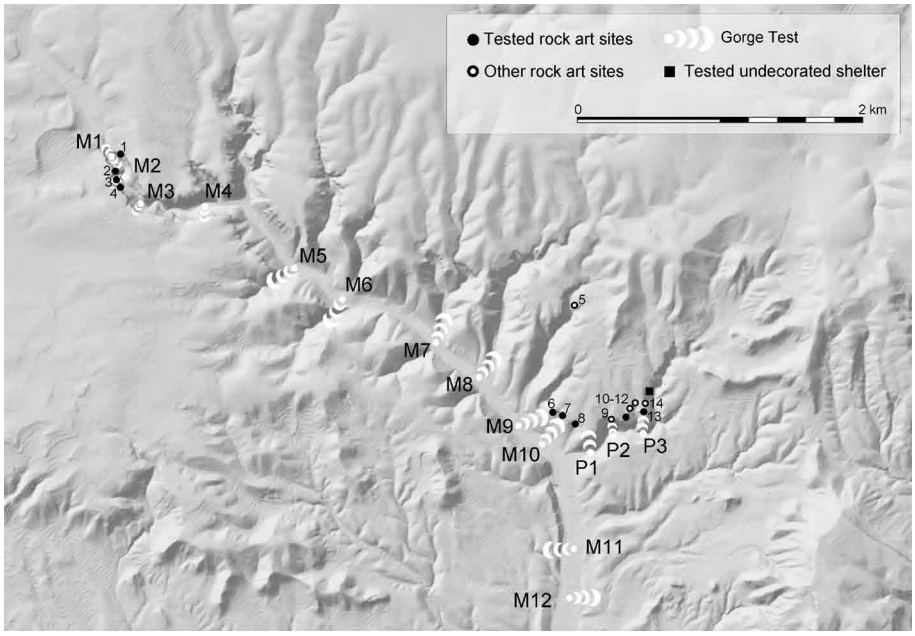

Figure 5. *Map of the Mortero Gorge rock art area indicating the test locations. A. Head of the Mortero Gorge area. B. Cerro Felío area. M indicates Mortero Gorge and P indicates Pellejas Gorge.*

The Mortero Gorge

The Mortero Gorge is a limestone gully that flows into the Martín River in the province of Teruel, in the Autonomous Region of Aragón (Fig. 5). Known as a rock art area since 1948 (Ortego 1948), the Martín River area is now known to have one of the highest concentrations of rock art sites in Spain, thanks to the late Antonio Beltrán and the unremitting work of his team (Beltrán 1961, 2005). It is about 10 km long, although the paintings are concentrated in two main sectors separated by about 3.5 km, one at the head of the gorge (Fig. 6) and the other at the western and southern ends of Cerro Felío hill, in the calcite shelters aligned along its edge. The Cerro Felío hill

sites are clustered in two groups, one to the west, facing the Mortero Gorge, and the other to the south, facing the Pellejas Gorge.

Out of the nine published sites at Cerro Felío, one has only the remains of paint, perhaps of 'schematic style' (unnamed shelter shown as No. 1 in Fig. 5), and three others have 'schematic' paintings (Encebros, Eudoviges and Esquemático, the latter exclusively), probably indicating a later production date for the paintings. The sites with the largest number of paintings are those at the ends: El Garroso (Fig. 7) and Covacha Ahumada. The Arqueros Negros site has at least two anthropomorphs displayed horizontally, interpreted as representations of dead people; they are surrounded by other human figures painted in the later, 'nematomorph style' (Obermaier and Wernert 1919: 95; Beltrán 1982: 38–40), also known more recently as the 'lineal style' (Domingo Sanz 2008: 113). The meaning of most of the 'scenes' is unclear, but there are many 'archers' depicted with 'deer' and some 'goats'. At the head of the Mortero Gorge there are four rock art sites, all profusely decorated (Beltrán 2005). No previous mention of the acoustic properties of the Mortero Gorge rock art sites can be found in the literature, although about 40 km away, in the Guadalope River basin, rock art expert Manuel Bea published a comment on the good acoustic properties of the site of Barranco Hondo (Martínez Bea 2004: 99) and in conversation made a similar comment to us about La Vacada, in the same basin (M. Bea, pers. comm.)

Figure 6. *Head of the Mortero Gorge area (photo courtesy of Manuel Bea).*

Figure 7. *Detail of Levantine painting at El Garroso. Photo digitally manipulated to slightly raise the contrast of colours (original photo courtesy of Manuel Bea).*

The fieldwork was undertaken by Carlos García Benito, assisted by María Sebastián López and Paloma Lanau Hernáez, between October 2011 and March 2012. As in the Valltorta Gorge, the fieldwork was divided into two main phases, the first testing the acoustics of rockshelters and the second those of the gorge. In acoustics test 1, aimed at measuring the acoustics of the sites, the decision was taken to test all four sites at the head of the Mortero Gorge. In contrast, in order to avoid testing adjacent sites, a selection of five sites was made at Cerro Felío hill: El Garroso, Frontón de los Cápridos, Eudoviges, Tía Mona and Covacha Ahumada. In this case a novelty was introduced with respect to the tests undertaken at Valltorta: sound was also measured in a shelter without rock art, located contiguous to the painted area to the east of the line of shelters in the Pellejas Gorge.

The results obtained in acoustics test 1 showed a clear contrast between the shelters with rock art and those with none, as the latter had practically no reverberation and echoes, whereas most of the tests undertaken in the shelters with rock art provided positive results (Table 2). The shelter without rock art is at the eastern end of the area to the south of Cerro Felío and is geologically of a similar nature as the others (shelters of about 10–12 m wide by 5 m deep, high enough for people to stand up). However, given that

only one test was made in only one shelter without rock art, further tests may be needed to verify the difference between painted and unpainted shelters in the Mortero Gorge. Regarding the results obtained in tested rock art shelters, no apparent differences were found between Eudoviges, which was probably painted later, and the other four shelters, painted in a more typical Levantine style. In contrast to Valltorta, the tests carried out facing the shelter (Tables 2B and 2D) were less effective than those facing the gorge (Tables 2A and 2C), both at the head of the Mortero Gorge and at Cerro Felío. In both areas whistles, closely followed by voices, gave the best results when testing reverberation, although clapping produced a higher number of echoes. The sites of Covacho Ahumado at the head of the Mortero Gorge and Tía Mona in Cerro Felío had the highest number of echoes. It is particularly interesting to note that the Covacho Ahumado site showed some peculiar acoustic properties as, when facing the shelter, the echoes came from different directions, depending on the sound produced (Table 2D). Although Covacho Ahumado is the shelter with the most motifs at the head of the Mortero Gorge, at Cerro Felío there are fewer in Tía Mona than in the neighbouring shelter of Covacha Ahumada. Both gave similar results when facing the shelter, but the results from Covacha Ahumada fell dramatically when making sounds while facing the gorge.

Regarding the examination of the acoustics produced at the gorge, sixteen test locations were chosen for acoustics test 2, some of them in sections of the gorge with rock art and others in those with none (Tables 2E and 2F). For the former, the test locations were placed as follows: three in the area at the head of

A. Reverberation (towards shelter)	**Head of Mortero Gorge**				**Cerro Felío**					
	Covacho Ahumado	Los Trepadores	Los Borriquitos	Recolectores	Covacho Ahumado	Tía Mona	Eudoviges	Frontón de los Cápridos	El Garroso**	Shelter without art
Clapping	0	0	0	2	0	0	0	0	0	0
Both whistles	2	1	2	2	2	2	2*1	1	1	0
One intermittent whistle	2	1	2	2	2	2	2	2	1	0
Voices	1	1*1	1	2	2*2	2	2*2	1	1	0
Male voice	2	1	1	1	1	1*2	2*2	1	1	0
Female voice	2	1	1	2	1	1*2	2*2	1	1	0

Notes: ** For all tests in this place the sound bounces in a shelter located in front of it.
*1 The reverberation comes from downstream. *2 The reverberation comes from behind the emitter, from the other side of gorge.

B. Reverberation (towards gorge)	**Head of Mortero Gorge**				**Cerro Felío**					
	Covacho Ahumado	Los Trepadores	Los Borriquitos	Recolectores	Covacho Ahumado	Tía Mona	Eudoviges	Frontón de los Cápridos	El Garroso**	Shelter without art
Clapping	0	0	1	2	0	0	0	0	0	0
Both whistles	2	1	2	2	2	2	2	1	2	1
One intermittent whistle	2	2	2	2	2	2	2	2	2	0
Voices	2	1	2	1	1	2	2	2	1	0
Male voice	2	1	2	2	2	1	2	1	2	0
Female voice	2	1	1	2	2	1	2	1	1	0

Note: **For all tests in this place the sound bounces in a shelter located in front of it.

C. Echo (towards shelter)	**Head of Mortero Gorge**				**Cerro Felío**					
	Covacho Ahumado	Los Trepadores	Los Borriquitos	Recolectores	Covacho Ahumado	Tía Mona	Eudoviges	Frontón de los Cápridos	El Garroso**	Shelter without art
Clapping	1	1	1	1	1*2	3	1	2*3	1*3	0
Both whistles	1*1	0	0	0	2	0	1	0	0	0
One intermittent whistle	1*2	0	0	0	2*2	2	0	0	0	0
Voices	1*3	0	0	0	0	0	0	1	1	0
Male voice	1*4	1	1	0	1*2	0	0	0	0	1
Female voice	0	0	0	0	0	0	0	0	0	0

Notes: ** For all tests in this place the sound bounces in a shelter located in front of it.
*1 The echo comes from two directions: downstream and upstream, a stereo mode. *2 The echo comes from down stream. *3 The echo comes from upstream. *4 The echo comes of in front of the shelter.

D. Echo (towards gorge)	Head of Mortero Gorge				Cerro Felío					
	Covacho Ahumado	Los Trepadores	Los Borriquitos	Recolectores	Covacho Ahumado	Tía Mona	Eudoviges	Frontón de los Cápridos	El Garroso**	Shelter without art
Clapping	2*1	2*1	2*2	1	1*1	3	1	1	1	0
Both whistles	0	0	0	0	1	2	1	0	0	0
One intermittent whistle	1*1	0	0	0	0	2	0	2	1	0
Voices	1*2	0	0	0	0	2	2*4	1	1	0
Male voice	1*3	1	0	0	0	1	0	1	1	1*5
Female voice	0	0	0	0	0	0	0	0	0	0

Notes: ** For all tests in this place the sound bounces in a shelter located in front of it.
*1 The echo comes from downstream. *2 The echo comes from upstream. *3 The echo comes of in front of the shelter.
*4 The echo comes form two directions: downstream and upstream, a stereo mode. *5 The echo comes from Pellejas gorge.

E. Reverberation (from the gorge)	Mortero Gorge													Pellejas Gorge		
	M1-Head		M2-Borriquitos	M3	M4	M5	M6	M7	M8	M9-Ahumada-Tía Mona	M10-Eudoviges	M11	M12	P1	P2-Frontón Cápridos	P3-Garroso
	TT	TG														
Clapping	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Both whistles	2	2	2	1	1	1	1	0	0	1	1	0	0	1	1	2
One intermittent whistle	2	2	2	1	1	1	1	1*2	1	1	2	0	0	1	2	2
Voices	1	2	1	0	1	0	0	0	1	2	2	0	0	1	1	2
Male voice	1	2	2*1	1	0	0	0	0	1	2	1	0	0	0	1	0
Female voice	1	1	1	0	0	0	0	0	0	2	1	0	0	0	1	1

Notes: TT: (towards theatre) looking at the natural theatre; TG: (towards gorge) looking at the gorge.
*1 The reverberation goes to downstream. *2 The reverberation comes from downstream.

F. Echo (from the gorge)	Mortero Gorge													Pellejas Gorge		
	M1-Head		M2-Borriquitos	M3	M4	M5	M6	M7	M8	M9-Ahumada-Tía Mona	M10-Eudoviges	M11	M12	P1	P2-Frontón Cápridos*3	P3-Garroso*3
	TT	TG														
Clapping	1	0	1	0	0	0	0	0	1	2	2*2	0	0	1	1*4	1
Both whistles	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
One intermittent whistle	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Voices	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1	1*1
Male voice	0	1*1	3	0	0	0	0	0	1	1	0	0	0	1	0	1*1
Female voice	1	0	2	0	0	0	0	0	1	0	0	0	0	1	0	0

Notes: TT: (towards theatre) looking at the natural theatre; TG: (towards gorge) looking at the gorge. *1 The echo comes from downstream. *2 The echo comes from Pellejas Gorge. *3 The dam of the gorge can influence these tests.
*4 The echo comes from upstream.

Table 2. *Mortero Gorge. Fieldwork phase 1. Reverberation A/ when facing the back wall of the shelter; B/ when facing the gorge; echoes (number of) C/ when facing the back wall of the shelter; D/ when facing gorge. Fieldwork phase 2. E/ reverberation from the bottom of Valltorta Gorge; F/ number of echoes from the bottom of Mortero Gorge.*

the Mortero Gorge, two to the west of Cerro Felío, next to the Covacha Ahumada and Tia Mona sites, and two to the south of Cerro Felío, next to the rock art sites of Frontón de los Cápridos and Garroso. Six test points were established in areas without rock art between the two major areas and two downstream from the Cerro Felío area. In addition we have to point out that test location P1 was located in an area between the southern and western sides of Cerro Felío, where no rock art has been found. The tests were always made in the centre of the gorge and therefore the distance to the sites varied from 200 m to about 30 m.

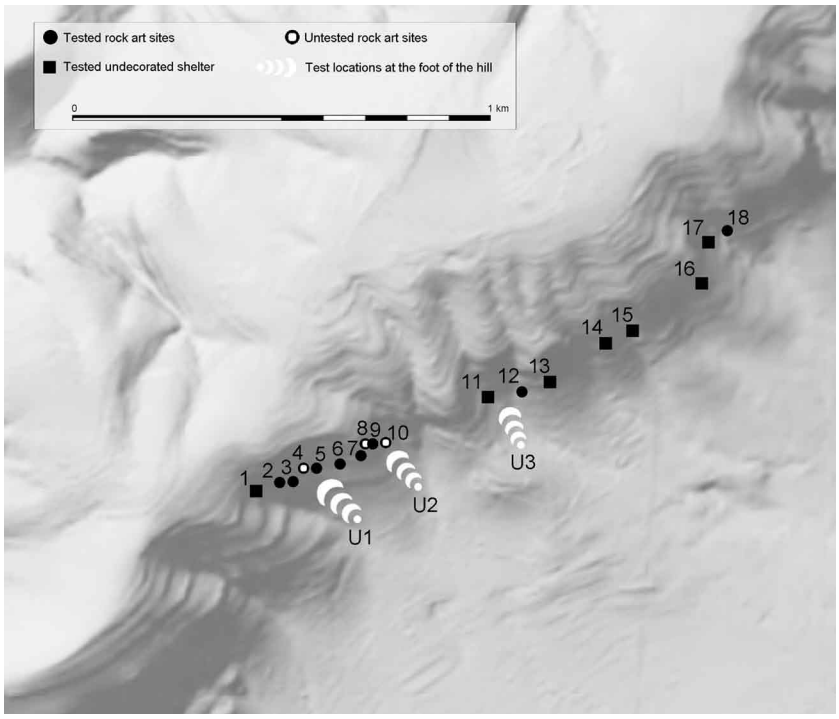

Figure 8. *Map of the Godall mountains rock art area with indication of test locations. Black circle: tested rock art sites. Empty black circles: non-tested rock art sites. Square: tested shelter without rock art. White circle with waves: location of tests at the bottom of the hill. Ermites area: 2. Ermites I; 3. Ermites II; 4. Ermites III; 5. Ermites IV or Cova Fosca; 6. Ermites V; 7. Ermites VI; 8. Ermites VII: 9. Ermites IX. Escuarterades area: 12. Escuarterades II; 18. Escuarterades I. U means Ulldecona, bottom of the hill.*

The results of acoustics test 2 indicated the good auditory nature of the sectors of the gorge with rock art. The best results for reverberation and echoes were clearly found in the sectors of the gorge at the foot of the two decorated areas (see Tables 2E and 2F). Significantly, the results of test location P1 showed intermediate values between those of the decorated and undecorated sectors of the gorge. Intermittent whistles obtained the longest resonance and clapping the highest number of echoes. In these two areas the rock art sites with better acoustic properties were at the head of the Mortero Gorge next to the Borriquitos site (which is about 100 m from Covacho Ahumado) and Tía Mona at Cerro Felío.

The rock art of Godall mountains in Ulldecona

The third area selected for acoustics testing was Godall mountains in Ull-decona (Tarragona province) (Figs 8 and 9). Since its 'discovery' in 1975, the literature has remained silent about the area's excellent auditory properties, which are the reason concerts are regularly held at the local hermitage. In contrast to the wider variety of themes at Valltorta and Mortero, in the Ermites area 'goat', 'deer' and 'horse hunting' clearly predominate in the paintings (Fig. 10). The area's most prominent rock art expert attributes this to it being the most common activity in the area (Viñas 1986, Viñas et al. 2009). As is usual in Levantine rock art, the paintings are found in limestone rockshelters at relatively high locations with respect to the surrounding area, in this case about 100–150 m above the valley floor. The sierra or mountain range where the shelters are located has an elongated, narrow shape, 13 km long and 4 km wide and is orientated NE–SW. The range is parallel to the coastline, which is only 9 km away, although it is separated from it by a parallel elevation (the Serra de Montsià), where no rock art has been found (García Rubert 2005; Viñas 1986; Viñas et al. 2009: 50).

A total of fourteen rock art sites have been identified; twelve of them at the centre of the elevation (the sites of Ermites and Escuarterades) and two close to the north-eastern end (Masets and Llibreres). They are all on the south-eastern slope of the sierra. Those in the centre are located near the Ermita de la Pietat, a hermitage with architectural remains dating to the early Middle Ages and whose associated church is still occasionally used. The Ermita I to IX sites are located to the south-west of the hermitage. Altogether they cover a line of c. 280 m length and from the last of them it is only c. 30 m to the Rock Art Interpretation Centre museum next to the hermitage. Continuing from the hermitage, but still staying at approximately the same height, we find the two Escuarterades sites. The first of them is about 400 m to the north-east of the hermitage and the second c. 250 metres further on. The Ermites and Escuarterades sites are located at an absolute height of 265–275 m above sea level and about 25 m above the hermitage (Viñas et al. 2009: 50), in rockshelters formed in the continuous calcareous crust in the upper section of the elevation.

Access to the shelters presents some difficulty, as to reach most of them it is necessary to climb steeply about five to seven metres (Viñas et al. 2009: 51). The only exception is the unusually large rock art shelter of Cova Fosca or Ermita IV, which is at the bottom of the calcareous layer. It is large enough for a group to live in and would have also allowed for inter-group meetings, and, as Viñas has mentioned on several occasions, may have been an aggregation site (Viñas et al. 2009: 50, 57; cf. Conkey 1980). There is some evidence that Cova Fosca had stratigraphy in the form of archaeological material found in the cracks in the floor, but the earth of the shelter floor was removed some decades ago to level the terraces in front of the site and any archaeological layers were thus destroyed (Viñas et al. 2009: 50). Stone artefacts were recovered from the shelter talus range

Figure 9. *The Ermites rock art landscape. Rock art sites Ermites I–V and the Ermita de la Pietat hermitage (photo by Margarita Díaz-Andreu).*

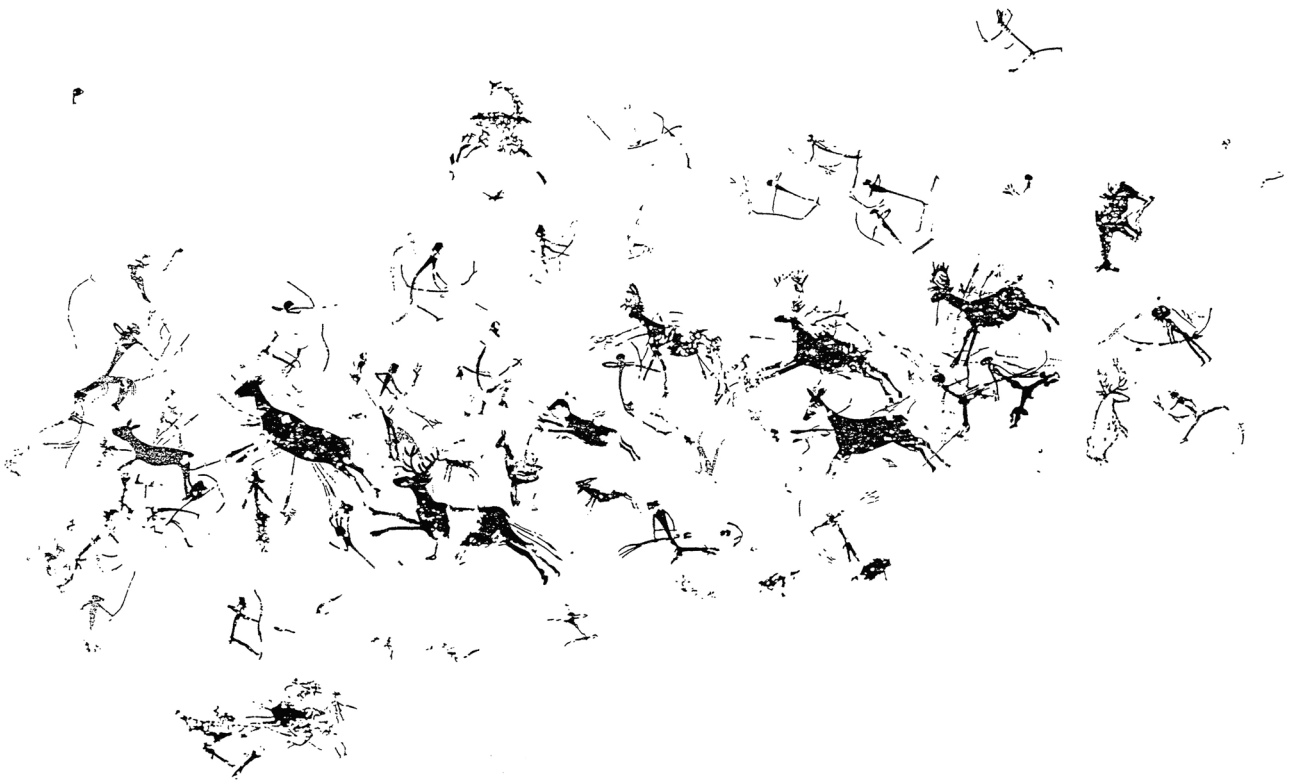

Figure 10. *Ermites I. Recording by Ramón Viñas (Viñas et al. 2009: Fig. 4).*

— about 400 pieces of retouched stone implements — in the mid-1970s. Typologically they show a chronology from the Magdalenian in the Upper Palaeolithic to the Mesolithic and 'Late Prehistory' (Viñas et al. 2009: 54, 57). Cova Fosca is also different to the others, not only because of its size and the likely use as a dwelling or aggregation site, but also its paintings seem schematic and also of a Historical date (Viñas 1986: 118–135).

The acoustics tests in the Godall mountains rock art area were carried out on 31 January 2013 by the authors of this article, assisted by Agustí Vericat, Director of the Abrics de l'Ermita Interpretation Centre. As with the Valltorta and Mortero gorges, the results of acoustics test 1 (Tables 3A–3D) clearly showed better acoustic properties in the shelters with rock art, especially those of Ermita, which provided consistently higher values for the acoustics produced in them than Escuarterades and the undecorated shelters. Regarding the latter,

the results obtained at the Cossis shelter were similar to the nearby Escuarterades II. The sound with the best reverberation was that produced with either two whistles or one intermittent whistle, both when facing the shelter or looking away from it. This phenomenon was observed in both the decorated and undecorated areas, although the values were higher in the first. Clapping was not effective at all and voices gave much poorer results than whistles, although only in the decorated area, mainly when looking towards the shelter and more so in Ermites than in Escuarterades. Clapping, however, was more effective in producing echoes, especially in the decorated area, both facing towards and away from the back of the shelter. The results of acoustics test 2 (Tables 3E–3F), made at a distance of 300 m to the line of decorated shelters, showed that the acoustics were better at the foot of the hill when facing the sites of Ermites than when facing Esquarterades. Once again whistles were the most effective in producing reverberation and clapping in producing echoes.

Conclusions

In this article we have endeavoured to answer the question with which we finished a previous study of the acoustics of the Valltorta rock art area (Díaz-Andreu and García Benito 2012). We wondered then whether or not the positive results we obtained were exceptional

A1. Reverberation (towards Shelter)	**Decorated area**							
	Ermita I	Ermita II	Ermita IV	Ermita V	Ermita VI	Ermita VIII	Escuar-terades I	Escuar-terades II
Clapping	0	0	0	0	0	0	0	0
Both whistles	2	2	2	2	2	2	1	2
One intermittent whistle	2	2	2	2	2*	2	2	2
Voices	0	1	1	1	1	1	0	0
Male voice	0	1	1	1	1	1	0	0
Female voice	1	0	0	0	0	1	0	0

Note: *The reverberation comes from the right.

A2. Reverberation (towards Shelter)	**Non-decorated area**							
	Ermita A	Escuar-terades A	Escuar-terades B	Escuar-terades C	Escuar-terades D	Escuar-terades E	Cossis	
							Test 1	Test 2
Clapping	0	0	0	0	0	0	0	0
Both whistles	1	1	1	1	1	1	2	2
One intermittent whistle	1	2	1	1	1	1	2	2
Voices	0	0	0	0	0	0	0	0
Male voice	0	0	0	0	0	0	0	0
Female voice	0	0	0	0	0	0	0	0

B1. Reverberation (outward)	**Decorated area**							
	Ermita I	Ermita II	Ermita IV	Ermita V	Ermita VI	Ermita VIII	Escuar-terades I	Escuar-terades II
Clapping	0	0	0	0	0	0	0	0
Both whistles	2	2	2	2	2	2	2	2
One intermittent whistle	2	2	2	2	2*	2	2	2
Voices	0	1	0	1	1	2	0	0
Male voice	0	1	1	1	1	2	0	0
Female voice	1	0	0	1	0	1	0	0

Note: *The reverberation comes from the left.

B2. Reverberation (outward)	**Non-decorated area**							
	Ermita A	Escuar-terades A	Escuar-terades B	Escuar-terades C	Escuar-terades D	Escuar-terades E	Cossis	
							Test 1	Test 2
Clapping	0	0	0	0	0	0	0	0
Both whistles	1	1	1	2	1	2	2	2
One intermittent whistle	1	2	1	1	1	2	2	2
Voices	0	0	0	0	0	0	0	0
Male voice	0	0	0	0	0	0	0	0
Female voice	0	0	0	0	0	0	0	0

C1. Echo (towards Shelter)	Decorated area							
	Ermita I	Ermita II	Ermita IV	Ermita V	Ermita VI	Ermita VIII	Escuar-terades I	Escuar-terades II
Clapping	1	2	3	1	2*[1]	3	0	1
Both whistles	0	0	0	0	0	0	0	0
One intermittent whistle	0	0	0	0	0	0	0	0
Voices	1	1	0	1	0	1	0	1*[2]
Male voice	1	1	0	1	0	1	0	1
Female voice	0	0	0	0	0	0	0	1

Notes: *[1] The echo comes from the left. *[2]The echo comes from the right.

C2. Echo (towards Shelter)	Non-decorated area							
	Ermita A	Escuar-terades A	Escuar-terades B	Escuar-terades C	Escuar-terades D	Escuar-terades E	Cossis	
							Test 1	Test 2
Clapping	1	0	0	0	0	0	1	2*
Both whistles	0	0	0	0	0	0	0	0
One intermittent whistle	0	0	0	0	0	0	0	0
Voices	0	0	0	0	0	0	0	1
Male voice	0	0	0	0	0	0	0	1*
Female voice	0	0	0	0	0	0	0	0

Note: * The echo comes from the right.

D1. Echo (outward)	Decorated area							
	Ermita I	Ermita II	Ermita IV	Ermita V	Ermita VI	Ermita VIII	Escuar-terades I	Escuar-terades II
Clapping	1	2	3	1	0	3	0	0
Both whistles	0	0	0	0	0	0	0	0
One intermittent whistle	0	0	0	0	0	0	0	0
Voices	1	0	0	1	1	1	0	1
Male voice	0	0	0	1	1	1	1	1
Female voice	0	0	0	0	0	0	0	1

D2. Echo (outward)	Non-decorated area							
	Ermita A	Escuar-terades A	Escuar-terades B	Escuar-terades C	Escuar-terades D	Escuar-terades E	Cossis	
							Test 1	Test 2
Clapping	1	0	0	0	1	0	0	1
Both whistles	0	0	0	0	0	0	0	0
One intermittent whistle	0	0	0	0	0	0	0	0
Voices	0	0	0	0	0	0	0	1
Male voice	0	0	0	0	0	0	0	1*
Female voice	0	0	0	0	0	0	0	0

Note: * The echo comes from the right.

E. Reverberation (from outside at the bottom)	Ermites		Escuarterades
	U1	U2	U3
Clapping	0	0	0
Both whistles	2	2	2
One intermittent whistle	2	2	2
Voices	2	1	1
Male voice	1	1	1
Female voice	1	2	1

F. Echo (from outside at the bottom)	Ermites		Escuarterades
	U1	U2	U3
Clapping	2	1	0
Both whistles	0	0	0
One intermittent whistle	1	0	0
Voices	0	1	0
Male voice	0	1	1
Female voice	0	0	0

Table 3. *Godall mountains. Fieldwork phase 1. Reverberation A1, A2/ when facing the back wall of the shelter; B1, B2/ when facing the gorge; echoes (number of) C1, C2/ when facing the back wall of the shelter; D1, D2/ when facing the gorge. Fieldwork phase 2. E/ reverberation from the foot of the hill; F/ number of echoes from the foot of the hill.*

in the context of similar rock art areas of Levantine paintings. In order to answer this question we have tested two further areas, the Mortero Gorge and the Godall mountains. Our results strongly indicate that acoustics was a feature that the late hunter-gatherers/early agriculturalists of Mediterranean Spain deemed essential in considering areas and shelters appropriate for decoration.

In order to undertake the comparison we decided to follow the low-tech methodology devised at Valltorta to examine other apparently geologically similar areas with rock art and neighbouring areas without rock art (or, as in Godall, with much lesser presence of it). As it had happened in Valltorta, in the areas without rock art or with little rock art, we obtained scores significantly less remarkable than in the decorated areas. The comparison between the three areas in terms of what type of sound engenders longer reverberations and a higher number of echoes proved that whistles, either two in conjunction or only an intermittent whistle, were usually the best for obtaining higher reverberation values, although voices, especially the male voice, also produced very good results (the only exception to this was Valltorta, where this order was inverted). In order to generate echoes, however, clapping was found to be the most effective sound. The tests undertaken at Mortero and in the Godall mountains were inconclusive as regards to whether it was better to face towards or away from the back wall of the shelter, contrasting with the results at Valltorta. The three areas coincide in general terms in having the largest number of painted motifs in shelters with high acoustic values.

Our proposal that there is a positive relationship between Levantine rock art and acoustics does not mean that we discard that there may have been other factors that influenced the location of rock art. In this respect, we have argued elsewhere that particular geological features in the landscape may have also influenced the selection of shelters to be decorated (Díaz-Andreu 2011). However, a systematic study of this, and how to interrelate both factors, is still to be done. We should also stress that we do not discard that the sound qualities of the rock art landscapes may have played alternative roles to those proposed in the next paragraph in the everyday life of pre-Historic societies, for example in hunting activities, as suggested by Viñas and others (Viñas et al. 2009).

How can we interpret this pattern of acoustics and rock art obtained at the three Levantine areas of Valltorta, Mortero and the Godall mountains? There are several possible answers to this. One has already been proposed: past communities considered the acoustics of the landscape in order to select where to make the paintings. We can also say that percussion instruments produced better echoes and wind instruments and vocal music generated the best reverberation, and we can argue that they may have been used in the past. However, beyond the level of signification that refers to shared perceived experience (outward meaning in Quine [1960] and Layton's [2001: 315] terms), there is another level — inward meaning — which is more difficult to access for those studying societies that no longer exist and about which we have no source of information other than archaeology. Inward meaning is defined by Layton, following Quine, as that related to the cultural and social conventions in which cultural practices are created (for example, the dove motif representing the Holy Spirit in a church). However, we would like to argue that, although we cannot hypothesise the specific practices that may have taken place in any of these three rock art areas, we can still advocate that they were sacred landscapes. Being sacred is not related to experience, it is cultural; but still the data seem to point to this, as special acoustics were sought, which is not an obviously functional element. In addition, the lack of stratigraphy makes it evident that none of the painted shelters were used as settlements — with the exception of Eudoviges, which has a site of an earlier chronology (Barandiarán 1975–76), and perhaps Cova Fosca, which has paintings that seem later than all the others at Ermites. Also, the many repaints of the panels indicate that these places were important to the communities who repeatedly used them. We would like to argue, as some authors have proposed for earlier periods (Morley 2009; Reznikoff and Dauvois 1988: 228), that their function was mainly ritual and that music was a component of the spiritual practices carried out in them. This proposal is also in tune with the relationship between the use of music in ritual practices among small-scale societies (Cross and Morley 2008), the type of societies which produced Levantine art. We would like to finish this study by proposing that the acoustic aspect of landscapes should be integrated as a necessary element in future studies of rock art, as it seems clear that senses other than sight were inextricably linked to their creation and later use by the communities that gave meaning to them and the reverberation and echoes that emanated from the art.

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Professor Margarita Díaz-Andreu
Departament de Prehistòria, H. Antiga i Arqueologia
Facultat de Geografia i Història,
ICREA-Universitat de Barcelona, Carrer de Montalegre, 6
08001 Barcelona
Spain
m.diaz-andreu@ub.edu

Carlos García Benito
Departamento de Ciencias de la Antigüedad
Facultad de Filosofía y Letras
Universidad de Zaragoza
c/ Pedro Cerbuna, 12
50009 Zaragoza
Spain
cgb@unizar.es

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