

# Do You Hear What I See? Analyzing Visibility and Audibility in the Rock Art Landscape of the Alicante Mountains of Spain

MARGARITA DÍAZ-ANDREU, *Secció de Prehistòria i Arqueologia, Universitat de Barcelona, C/ de Montalegre, 6, 08001 Barcelona and ICREA,*

*Pg. Lluís Companys 23, 08010 Barcelona, Spain. Email: m.diaz-andreu@ub.edu*

GABRIEL GARCÍA ATIÉNZAR, *Universidad de Alicante*

CARLOS GARCÍA BENITO, *Centro de Estudios Turiasonenses*

TOMMASO MATTIOLI, *Universitat de Barcelona*

---

This article examines the relationship between rock art landscapes and perception. It pays particular attention to vision and hearing, the two key senses for landscape awareness. Given the importance of scale in the study of rock art landscapes, a distinction is made between the adjacent landscape and the broader territorial scale. Several methodological improvements are suggested, including the importance of clipping viewsheds in GIS analysis and measuring directionality instead of orientation of the rock art shelters. In our case-study we explore the rock art landscape of the Alicante Mountains (northeastern Spain) during the Neolithic period (ca. 5600 to 2800 cal BC). A new interpretation of how the cognitive and symbolic behavior of communities changed over time is offered. We argue that the analysis of perception in rock art landscapes can provide novel ways of understanding communities' distinctive appropriation of their landscapes, linking both the tangible and intangible aspects of their culture.

**Key words:** rock art, landscapes, acoustics, soundshed, viewshed, GIS

---

In the past thirty years, the field of rock art study has increasingly turned its attention to aspects beyond iconography and chronology, the two main traditional concerns on which experts had previously focused. Building on these concerns, in the 1980s scholars became interested in the analysis of rock art landscapes (Deacon 1988; Hood 1988; Sognnes 1987) and this was very soon complemented by a concern for the visual aspect of rock art landscapes. This focused on the relationship between visibility and audience, and the existence of an apparently consistent connection between extensive views and the most complex panels (Bradley 1991, 1997; Hartley 1992). However, the importance given to visibility in rock art landscapes contrasted with the scant attention paid to all the other human senses, reflecting a bias toward sight as a consequence of the

Submitted July 6, 2016; accepted September 19, 2017; published online April 17, 2017.

*Journal of Anthropological Research* (Summer 2017). © 2017 by The University of New Mexico.

All rights reserved. 0091-7710/2017/7302-00XX\$10.00

Western belief that humans are primarily visual beings (Classen 1993; Ingold 2000: 243–87). Nevertheless, in recent years a parallel line of research on musical instruments (e.g., conferences organized by the ICTM Study Group on Music Archaeology; see Hickmann and Hughes 1988; Lawson 1983; Lund 1986) included studies of prehistoric musical instruments—for the period dealt with in this article, mainly wind and percussion instruments, presumably in addition to vocal music—and soundscapes. Regarding audibility and vision we would like to stress recent research highlighting the role of hearing as the best counterpart of vision for creating spatial awareness (Letowski and Letowski 2012) and, in particular, for accomplishing localization tasks (Blessner and Salter 2007; Kells 2001; Neuhoff 2011).

Taking into account the new proposals regarding the importance of hearing for visual perception, in this article we analyze both audibility and visibility in rock art landscapes. We differentiate between what we call the adjacent landscape—an area within 1,150 m of the rock art site, or the Higuchi medium-distance threshold (see below)—and the broader territorial scale. With this distinction we implement Chipindale's (2004) suggestion regarding the importance of scale in the study of rock art landscapes. Distinct methodologies are used for each scale of analysis. In the adjacent landscape, where visibility does not represent a problem, we use the method developed by the team in earlier projects looking at the relationship between the rock art location and the presence of acoustic effects, such as echo and reverberation. For the study of the wider landscapes, GIS is employed. GIS has been used to examine the connection between visibility and rock art landscapes (Fairén 2007:293; Gaffney et al. 1995; Hartley and Vawser 1998; Mattioli 2008; Robinson 2010; Señorán Martín et al. 2014), but we are the first to use it to correlate rock art, landscape, and audibility. GIS also allows us to test whether the directionality of the view and hearing were factors the rock art artists considered to be relevant.

The aim of this article is to examine the importance of audibility and visibility for the perception of rock art landscapes, thus linking tangible archaeological aspects—landscape and rock art—with intangible elements such as vision and hearing. Instead of taking the landscape as a whole, our distinction between adjacent and wider areas reveals nuances that have thus far not been adequately dealt with in rock art studies.

The study area is the rock art landscape of the Alicante Mountains. This unique area contains three different post-Paleolithic rock art styles—Macroschematic (M), Levantine (L), and Schematic (S)—all of which were in existence during the Neolithic period (Martí Oliver and Juan-Cabanilles 2014). This enables us to compare them in the search for patterns.

#### THE STUDY AREA: ROCK ART LANDSCAPES IN THE ALICANTE MOUNTAINS

The Mediterranean coast of the Iberian Peninsula runs NNE-SSW, with a marked protuberance (Cabo de la Nao) in the northern part of Alicante province. It is created

by a series of SW-NE mountain ranges that disappear into the sea in the direction of the Balearic Islands. In this region rock art researchers have discovered a large number of sites with motifs that have been classified as belonging to three different rock art styles (Figure 1). The presence of the Levantine and Schematic has been known for many decades (Breuil 1933–1935 [4]:67–69; Jiménez de Cisneros 1922; Ponsell Cortés 1952; Visedo Moltó 1959), but the discovery of the Macroschematic rock art tradition only occurred in the late 1970s (Hernández Pérez and Centre d'Estudis Contestans 1982). Despite much searching, this unique style has only been found in a limited area in the mountain ranges of Alicante, with a buffer zone in which a few motifs may be related (Hernández Pérez 2009:68). This limited extent of the Macroschematic style clearly contrasts with those of Levantine art, which can be found over a wide area parallel to the Mediterranean coast, and Schematic art, which is found across most of the Iberian Peninsula and in southern France and Italy (de Marinis 2012; Hameau 2002; Mattioli 2007). A recent inventory of rock art sites in Alicante province identified 128 painted rock art sites (Hernández Pérez et al. 2014) (Figure 2). Most (105, or 82% of the total number of sites) only have one style—Macroschematic (10 sites), Levantine (17 sites), or Schematic (78 sites). In contrast, 23 sites (18%) have two or three styles: Macroschematic and Schematic (MS) (6 sites), Macroschematic and Levantine (ML) (2 sites), Levantine and Schematic (LS) (12 sites), and all three styles (MLS) (3 sites) (Table 1).

Macroschematic art is characterized by large, schematic motifs up to a meter high (Figure 3A). They represent anthropomorphs with raised arms, normally located in the center of the shelter; snake-like figures usually formed by a few parallel lines and sometimes surrounded by dots and short lines and other geometric motifs and also finishing

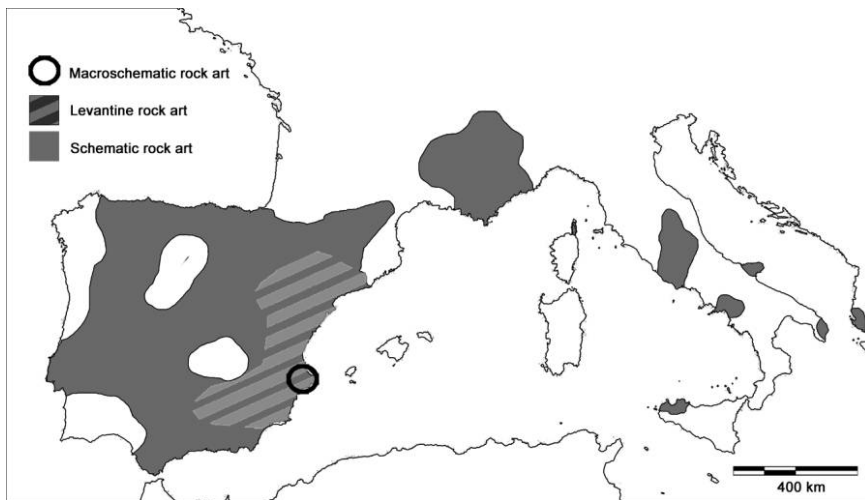


Figure 1. Areas where Macroschematic, Schematic, and Levantine rock art styles are found.

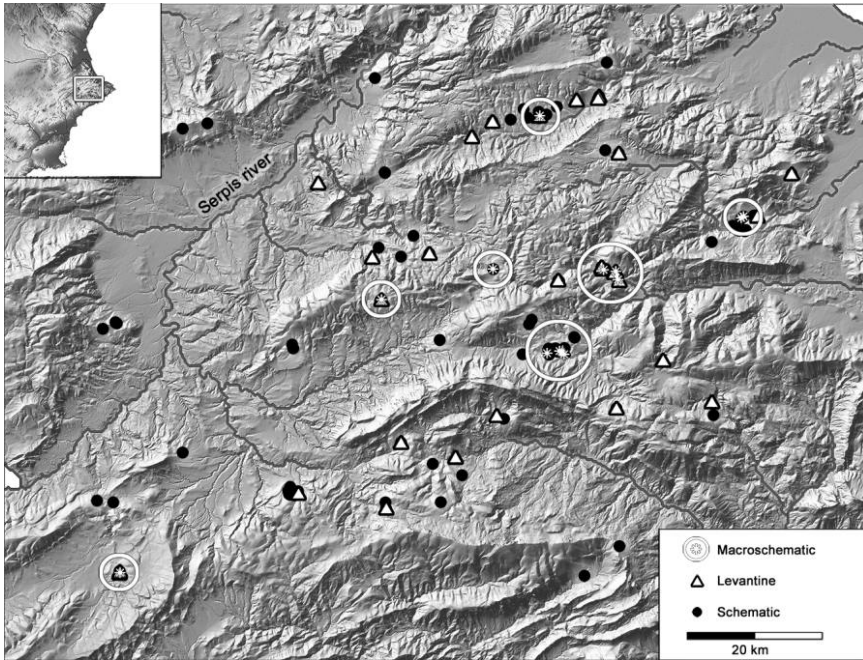


Figure 2. Map of the Alicante study area showing rock art sites and styles.

Table 1. Number and percentage of sites by style: Macroscopic (M), Levantine (L), Schematic (S), and combination. All M, All L and All S indicate the number of sites with M, L, or S motifs, both in isolation and in combination with other styles.

Style	<i>N</i> of sites	% of sites
M only	10	7.8
L only	17	13.3
S only	78	60.9
MS	6	4.7
ML	2	1.6
LS	12	9.4
MLS	3	2.3
Total		100.0
All sites with M	21	13.6
All sites with L	34	22.1
All sites with S	99	64.3
Total		100.0

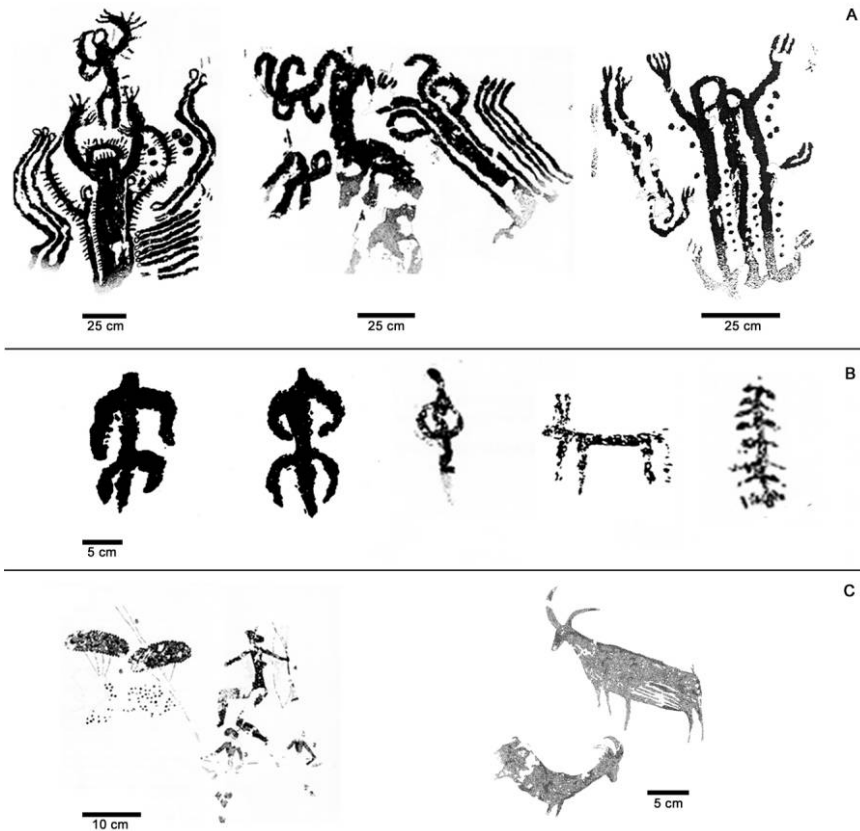


Figure 3. Rock art motifs in the Alicante study area: (A) Macroschematic, (B) Schematic, and (C) Levantine motifs.

with what look like fingers and other bars; and less easily identifiable geometric forms (Hernández Pérez and Centre d'Estudis Contestans 1982:64–69). Schematic art is composed of smaller, more basic figures of anthropomorphs, animals, geometric motifs (such as lines, zigzags, dots), and symbols (Martínez García and Hernández Pérez 2013) (Figure 3B). In contrast to the two previous styles, Levantine art has a more naturalistic and narrative nature (Figure 3C). The size of motifs varies, but in our area the figures are typically less than 10 cm in height and depict humans and animals, often in scenes. Most of these motifs are found in larger panels with one or more scenes, often depicting actions such as running, hunting, and warfare (García Arranz, Collado, and Nash 2012).

The chronology of these artistic manifestations has been the focus of fierce debate, partly because there are opposing views regarding the Neolithization process on the Iberian Peninsula (Cruz Berrocal and Vicent García 2007; McClure et al. 2008). Macroschematic rock art has been dated to the early Neolithic, mainly because of

the similarities of some of its motifs to those impressed on the Neolithic cardial pottery found in caves such as Cova de l'Or and Cova de la Sarsa (García Borja and López-Montalvo 2011; Martí Oliver and Hernández 1988:51–85). The earliest cardial pottery found in the area dates from ca. 5600 cal BC and was in use for 400 years until ca. 5200 cal BC, when the style gradually changed into the so-called Epicardial (García Atienzar 2010:44–45). Superimpositions show that Macroschematic motifs are always beneath either Schematic or Levantine motifs (Martí Oliver and Hernández 1988:51–85). It is thought that the Schematic tradition also originated in the earliest Neolithic but continued into the Chalcolithic and even later (Martínez García and Hernández Pérez 2013). Absolute radiocarbon dates have been obtained for the layer of calcium oxalates beneath and above some of the schematic paintings in the Abrigo de los Oculados rock shelter, producing a terminus ante quem date of 3520–3370 cal BC ( $1\sigma$ ) and a terminus post quem date of 890–595 cal BC ( $1\sigma$ ) (Ruiz López 2012: Table 4). Regarding Levantine art, most believe it has a Neolithic affiliation (Guillem Calatayud et al. 2011; Hernández Pérez 2009; Martí Oliver 2008), although some researchers have claimed that its origin may be in the final stages of the Upper Paleolithic (Viñas et al. 2010). However, superimpositions in our area seem to indicate that this was not the case, at least in the montane area of Alicante. Absolute radiocarbon dates have been obtained for the layer of calcium oxalate covering some paintings at the Marmalo III rock art site: 5890–5770 cal BC ( $1\sigma$ ) (Ruiz López 2012: Table 4, although see Mas et al. 2012). Another radiocarbon date has been reported for the Cueva del Tío Modesto site (5230–5010 cal BC), with both Levantine and Schematic motifs, plus some wavy parallel lines that have been compared with the serpent-like motifs of the Macroschematic style (Ruiz López et al. 2006). In summary, unless a future analysis of the microstratigraphic superposition of painting layers proves to the contrary, in the mountains of Alicante there is a general consensus that the earliest painted motifs were Macroschematic, followed by both Schematic and Levantine, all of them dating to the Neolithic period (ca. 5600 to 2800 cal BC). This means that, at least for a period of time, both Schematic and Levantine rock art styles were produced in the same area.

#### TESTING THE SONORITY OF THE LANDSCAPE ADJACENT TO ROCK ART SHELTERS

The first phase of our study of the acoustics in the Alicante Mountains followed the method we had previously developed to analyze other rock art areas in Spain and first tested in the Valltorta Gorge (Castellón Province) (Díaz-Andreu and García Benito 2012). This method is useful for measuring the sonority of the landscape adjacent to the rock art shelters. The test assesses the importance of echoes and reverberation, two types of acoustic effect that cannot be measured using GIS, as the tools currently available are unable to model sound reflections. The fieldwork for this phase, undertaken in May 2014, was carried out at a selection of rock art sites in the areas of Fomorca, Malafí (including the areas of Pla de Petracos, Sorellets, and Covalta), Infern,

and La Sarga. These areas are characterized by unimpeded visibility, a situation that may be generally similar to that of the Neolithic, although there was more vegetation at that time (Carrión et al. 2010). As in our previous work, in order to measure reverberation and echoes we used a low-tech device—an M-AUDIO MicroTrack II digital recorder with a T-shaped stereo electret microphone—which has the advantage of being efficient and cost-effective. The spectrograms resulting from the recordings in the field were later analyzed using the free Sonic Visualiser software ([sonicvisualiser.org](http://sonicvisualiser.org)). The results were converted, in the case of reverberation, into values of between 0 and 2: 0 (fair, no reverberation), 1 (good, meaning short and soft reverberation of one second duration or less), and 2 (excellent, longer reverberation). The number of echoes was also recorded and counted using both the device and the software mentioned above, for comparison with results that had been perceived in the field. In the field, reverberation and echoes were produced by six types of sound impulse in each test location: repeated clapping; two whistles with tones 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); a solo male voice; and, finally, a solo female voice. However, in the analysis of the results from other areas in Aragon, Catalonia, and the Valencian region, where we worked after completing our Alicante fieldwork (Díaz-Andreu and García Benito 2015), we realized that some of these measurements were largely redundant. For the sake of simplification, therefore, in this article we will only include the results of the tests of the sounds that, as explained in our previous articles, produced some of the most significant results: two whistles together and solo male voices for reverberation, and clapping for echo (Díaz-Andreu and García Benito 2013:237, 2015: 50–55). As in the previous experiments using this method, two types of tests were carried out. The first attempted to measure the sonority of the painted shelters themselves, in order to compare the values of each of the styles (Figure 4, Table 2). The second consisted of testing the sonority of the area around the sites and adjacent to them, with the purpose of checking whether the sections of the landscape with painted sites were special from an acoustic point of view. Tests were made at the lowest points in the landscape next to the rock layer; the shelters were at varying distances, depending on the landscape, but no more than 300 m away (Table 3).

The first experiment, that carried out in the shelters, generally showed good to excellent results for all the rock art styles. Excellent and good reverberation values and the presence of echoes were the norm (Table 2, Figures 5A, 6A). The comparison between the three styles in terms of what type of sound engendered longer reverberations showed that two whistles played together was usually the best method for obtaining higher reverberation values, although the male voice also produced very good results (Figure 5A). The highest reverberation values for whistles were obtained at Schematic and Macroschematic rock art sites, rather than at Levantine ones. At Levantine sites, however, a slightly higher number of echoes was achieved (Figure 6A). The second experiment consisted of tests undertaken in the area adjacent to the shelters, both in front of the decorated shelters (and, we could add, within their line-of-sight) and between

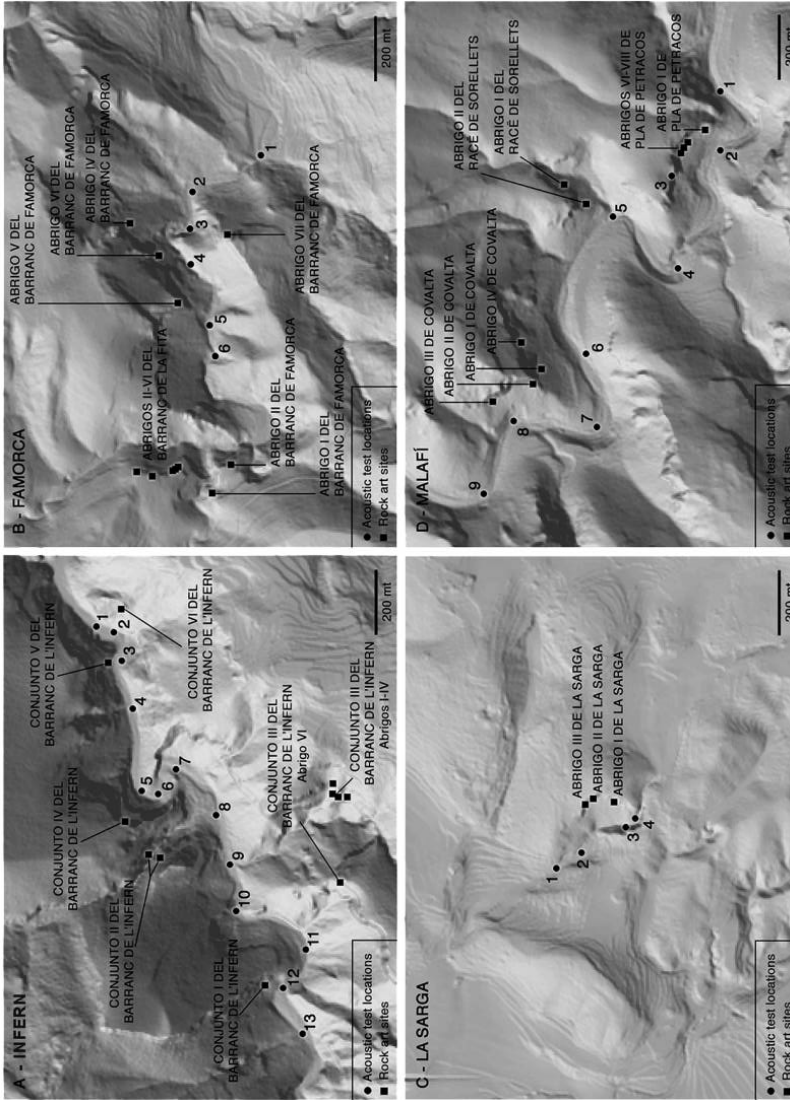


Figure 4. Test locations: (A) Infern, (B) Famorca, (C) La Sarga, (D) Malafi. See Table 3 for key.



Table 2. Results of acoustic tests at rock art shelters of the Alicante Mountains.  
 A: reverberation values for two whistles (0 = Fair, 1 = Good, 2 = Excellent);  
 B: male voice reverberation values (0 = Fair, 1 = Good, 2 = Excellent);  
 C: total number of echoes. For style abbreviations see Table 1.

	Style	Reverb Values		<i>N</i> of Echoes
		A	B	C
<b>Barranc de l'Infern</b>				
Conjunto I del Barranc de l'Infern (Abric I)	S	2	1	2
Conjunto II del Barranc de l'Infern (Abric I)	MS	2	2	1
Conjunto III del Barranc de l'Infern (Abric I)	S	2	2	3
Conjunto III del Barranc de l'Infern (Abric II)	S	2	2	3
Conjunto IV del Barranc de l'Infern (Abric I)	MS	2	2	5
Conjunto IV del Barranc de l'Infern (Abric II)	MS	2	2	5
Conjunto V del Barranc de l'Infern	S	2	2	2
Conjunto VI del Barranc de l'Infern (Abric I)	L	2	2	4
Conjunto VI del Barranc de l'Infern (Abric II)	LS	2	2	4
<b>Famorca</b>				
Abric V del Barranc de Famorca	MS	2	2	3
Abric VI del Barranc de Famorca	L	2	2	3
Abric VII del Barranc de Famorca	M	2	1	0
<b>La Sarga</b>				
Abric I de La Sarga	ML	2	1	2
Abric II de La Sarga	MLS	2	0	1
Abric III de La Sarga	MS	2	2	2
<b>Malafi</b>				
Abric I del Pla de Petracos	L	2	2	4
Abric III-VIII del Pla de Petracos	M	2	2	5
Abric I del Racó de Sorellets	ML	1	0	2
Abric II del Racó de Sorellets	L	1	1	2
Abric I de Covalta	MS	1	1	0
Abric II de Covalta	LS	1	1	1

them (in areas from which, although this was not our intention, we were unable to see the rock art shelters) (Figures 5B and C, and 6B). As was the case with the first experiment, the two whistles produced higher reverberation results than the male voices (Figure 5B). Measurements taken in the area adjacent to the rock art sites generally indicated that Schematic and Macroschematic sites had better acoustic qualities than Levantine sites, even if the last yielded slightly higher male voice reverberation values (Figure 5B). Echoes were likely to be present in every test performed in front of the

Table 3. Results of acoustic tests in the immediate vicinity of rock art and non-rock-art shelters in the Alicante Mountains.

A: reverberation values for two whistles (0 = Fair, 1 = Good, 2 = Excellent); B: male voice reverberation values (0 = Fair, 1 = Good, 2 = Excellent); C: total number of echoes. For style abbreviations see Table 1.

For locations see Figure 4.

Test number/Site name	Style	Test Type		
		A	B	C
<b>Barranc de l'Infern</b>				
1. (no rock art)		2	2	2
2. Conjunto VI	L	2	2	2
3. Conjunto V	S	2	2	1
4. (no rock art)		1	1	2
5. Conjunto IV	MS	2	1	1
6. Conjunto IV	MS	2	1	1
7. (no rock art)		1	1	1
8. Conjunto II	MS	1	1	3
9. (no rock art)		1	1	0
10. Conjunto III	S	2	1	1
11. (no rock art)		1	2	0
12. Conjunto I	S	2	1	0
13. (no rock art)		1	1	1
<b>Famorca</b>				
1. Abric VII	M	1	1	0
2. Abric VII	M	2	1	2
3. (no rock art)		2	1	2
4. (no rock art)		2	1	2
5. (no rock art)		2	1	2
6. Abric V	MS	2	1	2
<b>La Sarga</b>				
1. (no rock art)		0	0	0
2. (no rock art)		2	1	1
3. La Sarga II	MLS	2	1	2
4. La Sarga II	MLS	2	1	1
<b>Malafi</b>				
1. (no rock art)		1	1	0
2. Pla de Petracos IV-VI	M	2	1	2
3. (no rock art)		1	0	0
4. Racó de Sorellets II	L	1	1	1

Table 3 (Continued)

Test number/Site name	Style	Test Type		
		A	B	C
5. Covalta IV	S	1	1	0
6. Covalta I	MS	1	1	1
7. Covalta II	LS			
8. Covalta II-III	LS	1	1	2
9. (no rock art)		1	0	0

shelters (Figure 6B). Interestingly, the tests carried out in the sections of the valley in between rock art sites resulted in poorer values (Figures 5C and 6B). In conclusion, the outcome of the fieldwork acoustic tests in the adjacent area allows us to suggest that a connection can be established between acoustics and rock art in the Alicante Mountains. Looking at particular styles it can be argued that, although they all gave excellent results, those obtained from Macroschematic and Schematic rock art shelters were generally better than those of Levantine sites. This means that the most effective acoustic experience took place in Macroschematic and Schematic shelters. The connection between acoustics and rock art was further reinforced when the results obtained in the section of the valleys with no rock art were taken into account, as, although the values were still good, they were not as good as in the areas with rock art (Table 3).

The fieldwork in this first phase of our analysis only took into account the landscape adjacent to rock art shelters and the territory in between, and it focused on measuring the acoustic perception in the area where the sound was produced. The landscape in the Alicante Mountains made visibility unproblematic, as all the rock art sites are visible from the adjacent landscape. However, with the type of tests performed it was not possible to study the broader territorial scale in which sounds produced in the rock art shelters were likely to be heard. In order to undertake this analysis, it was decided to adopt a different approach, namely the use of GIS.

## GIS MODELING OF ROCK ART AUDIO-VISUAL PERCEPTION ON A TERRITORIAL SCALE

### *The Use of GIS in the Study of Perception in Rock Art Landscapes*

The first phase in the analysis of the perception of the adjacent rock art landscapes in the Alicante Mountains was followed by a second phase dealing with the larger territorial scale, which will be described in this section. By larger territorial scale we mean the soundshed—the wide area in which a sound produced in one location can be heard before it drops below the environmental noise—and the viewshed. Soundsheds have been modeled in archaeology with the help of GIS, which allows a raster map to be produced of the areas affected by sound waves coming from a sound source at a given

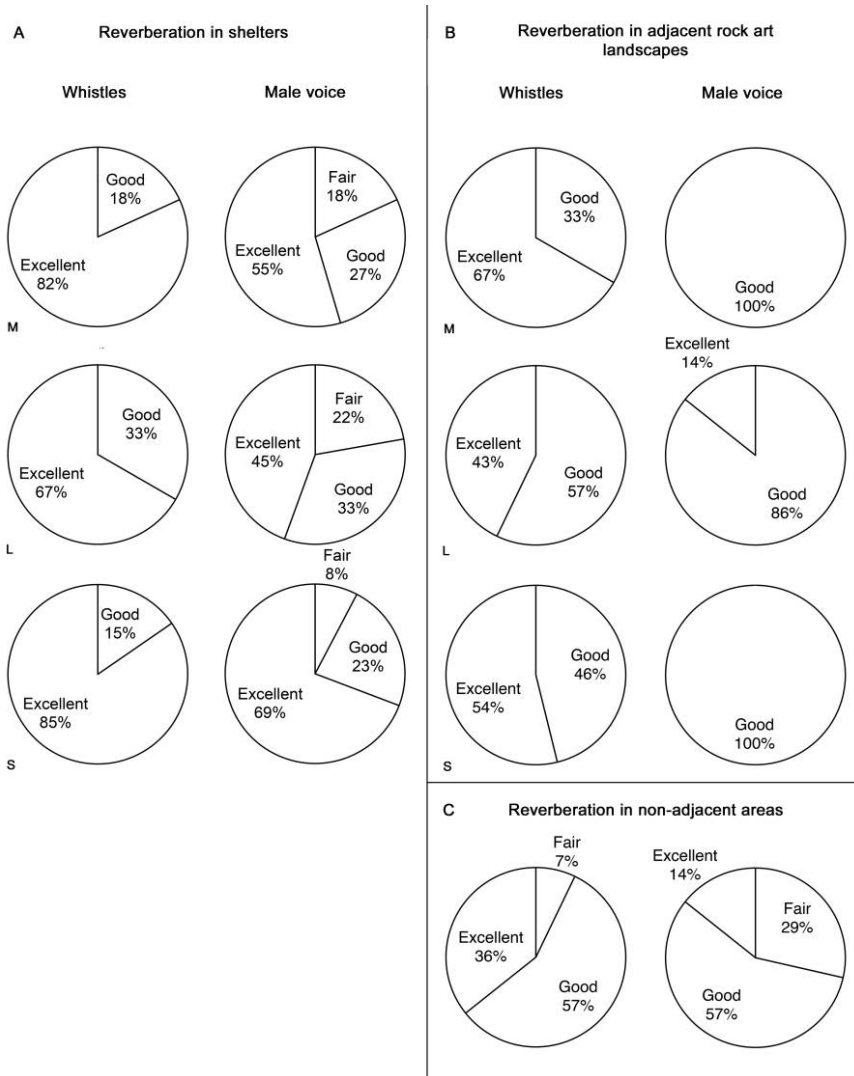


Figure 5. Weighted percentages of reverberation values measured (A) in the rock art shelters, (B) in the nearby area within line-of-sight, and (C) outside line-of-sight of the rock art shelters.

point in the landscape (Demers 2009:282). The increasing amount of scholarly literature on archaeological soundscapes has focused on a diverse range of topics, although prior to this article rock art was not included on the list. Constantidinis (2004), for example, investigated the way in which people at Mycenaean sites communicated with each other and their surrounding areas, and Mlekuz (2004) explored the sonorous space produced by church bells in Slovenia during the late medieval period. The effect produced by water in Sámi (“Lapp”) sacred ritual sites was the focus of a study by Äikäs

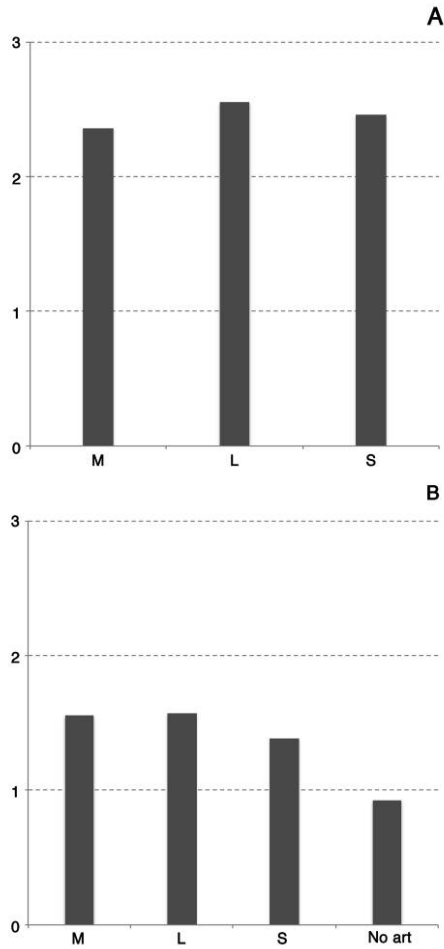


Figure 6. Weighted percentages of the number of echoes obtained (A) in the rock art shelters and (B) in the surrounding area.

(2015:112–19), and a final example is an investigation of the soundscapes of outdoor assembly sites in early medieval England (Baker and Brookes 2015). Our use of GIS to examine the soundscapes of the rock art in the Alicante Mountains is the first attempt to study audibility in rock art landscapes.

Our analysis of GIS audibility takes into account the influence of the natural ecosystem for sound propagation. Natural ecosystems not only are composed of landscape relief, but also vegetation and climate. In an ideal environment (one with no interference), sound waves spread geometrically and equally in all directions and the sound pressure level (SPL) decreases according to the inverse square law (ca.  $-6$  dB for each

doubling of distance from the sound source) (Rossing 2007:115). However, in natural environments sound propagation is affected by multiple factors, including ground effect, trees, foliage, wind, and temperature (Naguib and Wiley 2001; Neuhoff 2011; Rossing 2007:113–43; Zahorik 2002). The interference caused by these factors has not been taken into account in previous attempts to model soundsheds in archaeological contexts; our analysis is the first to do so.

The most common use of GIS methods to assess perception in archaeology is not related to audibility, but to visibility. Most commercial GIS software currently offers a set of standardized techniques allowing the exploration of sight. With techniques first developed in the 1990s (Baldwin et al. 1996), visual perception can be modeled through viewshed analysis, either via a raster binary map that represents the areas seen from a viewing location in the landscape or the degree of visibility of the given location from the surrounding areas (Kvamme 1999:177). As mentioned above, however, in localization tasks, visibility has been proved to be complementary to hearing (Blessner and Salter 2007; Kells 2001; Neuhoff 2011). This, together with the existence of previous work using GIS to analyze the visibility of the rock art in our study area, led us to add visual perception to our analysis, both on its own and in combination with audibility. In the field of rock art landscapes, viewshed analysis has been applied to the study of rock art in Britain (Fairén 2007:293; Gaffney et al. 1995), Italy (Mattioli 2008), the USA (Hartley and Vawser 1998; Robinson 2010), and Morocco (Señorán Martín et al. 2014).

In Spain, several authors have used GIS to assess visibility in rock art landscapes. In her work on the Valltorta and Gasulla areas in Castellón, María Cruz Berrocal argued that the visibility from the rock art sites, all of which had Levantine paintings, was local and only covered the territory adjacent to the sites (Cruz Berrocal 2004:55–56, fig. 5, 2005:266–69). Sara Fairén's research of the rock art of Alicante included sites with Macroschematic, Schematic, and Levantine styles. She began her study by dividing the sites into five types, regardless of the style painted in them, and only taking into account variables such as location, accessibility, and visibility. She then identified which styles were present at each site type. The results showed that the painters of each style had preferences in the selection of the sites to be decorated. Those sites with extensive views (Types 1, 4, and 5) were mainly used for the painting of Schematic motifs. In Type 2 and 3 sites it was also possible to find Schematic motifs, although they also contained Macroschematic and Levantine style paintings (Fairén 2004). In contrast to Cruz Berrocal and Fairén's results indicating low visibility levels for Levantine rock art in the areas of Castellón and Alicante, Manuel Bea's use of viewshed analysis in Aragón indicated the opposite. He demonstrated that in his study area at least some of the Levantine sites visually dominated the surrounding area (Martínez Bea 2006).

Visibility can range from 0 to infinity; in the latter case, this introduces analytical bias. In order to avoid this, Cruz Berrocal (2005:266) divided her study area into distances of 0–5 km and 5–20 km from the sites, although no apparent reason was given for this classification. In any case, she did not find a clear difference between the results

from the narrower and wider areas. Sara Fairén (2006:72–75) also considered the areas within 1 km, 5 km, and more than 5 km of the sites separately (0.6, 3.1, and >3.1 miles, respectively; see Fraser 1983). However, she then gave priority to the closest distance for her interpretation of, for example, the natural corridors, saying that the results if one considered the medium and longer distance were similar to those of the closest distance (Fairén 2006:222). Fairén referred to Wheatley and Gillings (2000) but did not follow their advice regarding how to analyze viewsheds. Instead of Fraser (1983), Wheatley and Gillings (2000) preferred to follow Japanese landscape planner Tadahiko Higuchi when they suggested replacing undifferentiated viewsheds with a field-of-view calculation structured around a number of quantifiable view-distance classes (visual ranges), which were based on Higuchi's proposal. Higuchi's visual ranges are based on the dimension of potential targets and the horizontal angle gaze, and they are structured into three components (short-, middle-, and long-distance; Higuchi 1983:13–14). In the short distance, potential targets are recognized as individual entities, immediate and close to the viewer. In the middle distance, targets are visible but not in detail. The long distance is the horizon, in which there is no more sense of depth and individual targets are not perceived. As shown in Ogburn (2006: Table 1), the Higuchi class distance can be calculated for targets with different sizes. In our study we also used Higuchi's proposals.

One of the factors that some authors have paid attention to when explaining the location of rock art has been the orientation of the shelter. Philip Hameau, for example, speaking about schematic art in southern France, pointed out that the shelters chosen to be painted were mainly south-facing (Hameau 1999:620–21, fig. 2). Most of the comments regarding the orientation of post-Paleolithic rock art in Spain underscore a similar preference to that observed in France, although the variation in choices usually ranges from east to south to west, depending on the area (Alonso Tejada and Grimal 1996:288; Martínez Bea 2006:174; Mateo Saura 2001; Soria Lerma et al. 2012:312; Utrilla Miranda 2000:26; Viñas and Morote Barberá 2011). The exception to this is Ladrufián, an area about 200 miles north of our study area where the sites appear to have faced north. Cruz Berrocal also indicated a preference for a northerly orientation of shelters in the Júcar basin, an area that includes the Alicante Mountains (Cruz Berrocal 2005:183, Map 11, 213, Graph 31), a result that contrasts with our observations in the field.<sup>1</sup> The orientation of the shelter, however, is not a good indication for analyzing perception—in particular, seeing and hearing—and therefore, in contrast to the authors mentioned above, we look instead at the directionality of the viewshed. A shelter in a gorge may be oriented toward the south but may have its visibility impeded by the cliff in front, and in this case it is likely that the best visibility—in other words, the directionality of the viewshed—will be toward the east and west. A review of the literature, including that in which GIS analysis has been used, reveals that, although it is a measurement known in other fields of archaeology (Gillings 2009), we are the first to use viewshed directionality in the study of rock art landscapes either in Spain or anywhere else.

## VIEWSHED AND SOUNDSHED ANALYSIS IN THE ALICANTE ROCK ART AREA

### *The Data Processing Phase*

For the GIS analysis of visibility and audibility in the rock art sites of the Alicante Mountains we used a Digital Elevation Model (DEM) with a cell size of 30.48 m (100 ft) obtained from the Comunitat Valenciana's Terrasit Geoportall (the region in which the province of Alicante is located) ([terrasit.gva.es/](http://terrasit.gva.es/)). The viewsheds were calculated using the ArcGIS 9.3 viewshed toolset. For each point we set a terrain offset of 1.6 m (5.24 ft) to simulate a viewpoint consistent with the average height of an adult. As explained above, we limited our analysis to an area of 1150 m (0.71 miles) around the site—the Higuchi medium-distance threshold for 1-m-high targets (Ogburn 2006: table 1). This means that visibility of rock art sites and even specific panels (but no motifs, unless they are made in Macroschematic style) is possible. For the soundsheds we used the full area, as there is no problem with values to infinity introducing bias. The full area was calculated using SPreAD-GIS 2.0 in ArcGIS 9.3 (Reed et al. 2010, 2012), one of the most versatile and ready-to-use GIS toolsets that takes into account the majority of the variables affecting sound propagation (Reed et al. 2012). This open-source toolset was originally developed for modeling noise propagation in natural environments. User-specific sound source characteristics and commonly available datasets on land cover, topography, and weather conditions allow the calculation of sound propagation patterns and excess sound above ambient conditions. This is done for one-third octave frequency bands (0.125 to 2 kHz) around one or multiple sound sources.

Some decisions needed to be made before the analysis of soundshed in a natural ecosystem could be undertaken. As explained earlier in the article, the difference in vegetation cover between the Neolithic and today was not very significant as shown by pollen analyses (Carrión et al. 2010). Nevertheless, we needed precise figures for the SPL and the frequency of the sound source. These are the two most crucial acoustic variables in sound modeling. Regarding SPL, the higher it is, the greater the area in which the sound impulse is likely to be heard before it drops below the environmental noise (Rossing 2007:115). In terms of the frequency of the sound source, the attenuation of sound waves is a dependent variable. Low frequencies can travel farther because they are less affected by atmospheric absorption, whereas for the propagation of sound over large outdoor distances, the atmospheric absorption is very significant and leads to the attenuation of higher frequencies (Rossing 2007: 116). We finally decided that the most suitable values were 90 dB at 1 m for SPL and a frequency of 1500 Hz, for this frequency is suitable for modeling prehistoric percussion instruments, a large number of wind instruments, and human voices (Aiano 2006; Hepp 1985; Ibáñez et al. 2015; Meyer 2005; Olsen 1998; Pearsons et al. 1977; Rainio and Mannermaa 2012; Reznikoff 2014).

In addition to deciding about SPL and frequency values, a second decision was how to deal with the decrease in SPL from the source point due to ground and veg-



etation absorption. For this we used the SPreAD-GIS tool, which calculates absorption on the basis of the rate of foliage and ground cover loss, computing absorption as a function of the predominant land cover type (conifer, hardwood, shrub, grass, barren, water, or urban) and distance from the sound source. The vegetation cover considered in our analysis was derived from the Corine Land Cover 2006 of the Terrasit-WebGIS of the Comunitat Valenciana, whose methodology can be found on the web (<http://www.eea.europa.eu/publications/COR0-part1>, accessed June 2016). It was reclassified as shown in Table 4. The decrease in sound level can also be affected

Table 4. Table showing the correspondence between the Corine Land Cover and SPreAD-GIS values for vegetation cover.

Corine Land Cover 2006		SpreadGIS	
Code	Description	Code	Description
111	Zonas urbanas – Tejido urbano continuo	URB	Urban or developed area
112	Zonas urbanas – Tejido urbano discontinuo	URB	Urban or developed area
121	Zonas industriales, comerciales y de transportes	URB	Urban or developed area
131	Zonas de extracción minera	URB	Urban or developed area
133	Zonas en construcción	URB	Urban or developed area
211	Tierras de labor en secano	BAR	Barren land
212	Terrenos regados permanentemente	HEB	Herbaceous or grassland
213	Arrozales	WAT	Water
221	Cultivos permanentes – Viñedos	HWD	Hardwood or deciduous forest
222	Cultivos permanentes – Frutales	HWD	Hardwood or deciduous forest
223	Cultivos permanentes – Olivares	HWD	Hardwood or deciduous forest
242	Zonas agrícolas heterogéneas – Mosaico de cultivos	HEB	Herbaceous or grassland
243	Zonas agrícolas heterogéneas	HEB	Herbaceous or grassland
311	Bosques – Bosques de frondosas	HWD	Hardwood or deciduous forest
312	Bosques – Bosques de coníferas	CON	Coniferous forest
313	Bosques – Bosque mixto	HWD	Hardwood or deciduous forest
321	Espacios de vegetación arbustiva y/o herbácea	SHB	Shrubland
323	Matorrales esclerófilos.	SHB	Shrubland
324	Matorral boscoso de transición.	SHB	Shrubland
332	Rocas desnudas	BAR	Barren land
333	Espacios con vegetación escasa	BAR	Barren land
411	Humedales y zonas pantanosas	WAT	Water
512	Láminas de agua	WAT	Water

by the atmospheric absorption variables, and these relate to the time of the year in which the analysis takes place. We decided to provide values corresponding to a typical summer day in July with no wind. Air temperature, humidity, and prevailing wind direction data were taken from the Spanish National Meteorology Agency ([www.aemet.es](http://www.aemet.es)), which resulted in the following values: temperature 25.5 °C (77.9 °F), humidity 65%, and no prevailing wind.

Soundshed and viewshed binary maps of each rock art site were intersected to create a new raster map showing only their overlapping areas (Figure 7). However, since we had used the Higuchi medium area for viewshed and the full area for soundshed, in order to make the intersection possible we had to clip the soundshed area by the same Higuchi medium area previously used for viewshed. This final map represents the portions of landscape in which rock art sites are likely to be visible and audible at the same time. We worked with this new map in two ways: first considering it as a full surface and second in order to check the directionality of the viewshed in relation to the cardinal direction, which we deemed to be important, as reclassified surfaces according to four directional cardinal points.

### *The Post-Processing Data Phase*

In the post-processing data phase we began by analyzing the soundshed area and the clipped viewshed area of each site expressed in hectares. In order to verify whether audio and/or visual patterns were linked to each of the rock art styles (M, S, and L), the central tendency and variability of each style was determined using MiniTab v. 17.1 statistical software. The central tendency of each style refers to the mean values of the geographical area in which each of the shelters was visible and/or a sound made in it was audible. The variability for each style refers to the range covered by 95% of sites. The central tendency and the variability are represented as interval plots: a graphical summary of the distribution of each of the three style groups and combinations of styles (Figure 8). The exception to the latter are ML sites ( $n=2$ ) and sites with all three styles ( $n=3$ ), whose low numbers make any calculation statistically unreliable. For this reason they have not been included in the graphics.

A second step in the post-processing phase was to verify whether different viewshed directionality patterns might have existed for each of the rock art groups. To accomplish this task, we performed the same statistical calculations on weighted surfaces reclassified according to the four directional zones of interest, centered on the main cardinal points (Figure 9).

### *Interpreting the GIS Results*

GIS was used in the study of the Alicante rock art landscapes to assess both acoustic and visual perception. In the first, the soundshed analysis showed a clear difference between Macroschematic rock art sites, on the one hand, and Schematic sites on the other, with values ranging from 12–33 ha at Macroschematic sites to 33–44 ha at Schematic sites. These results indicate that Schematic rock art artists appear to have

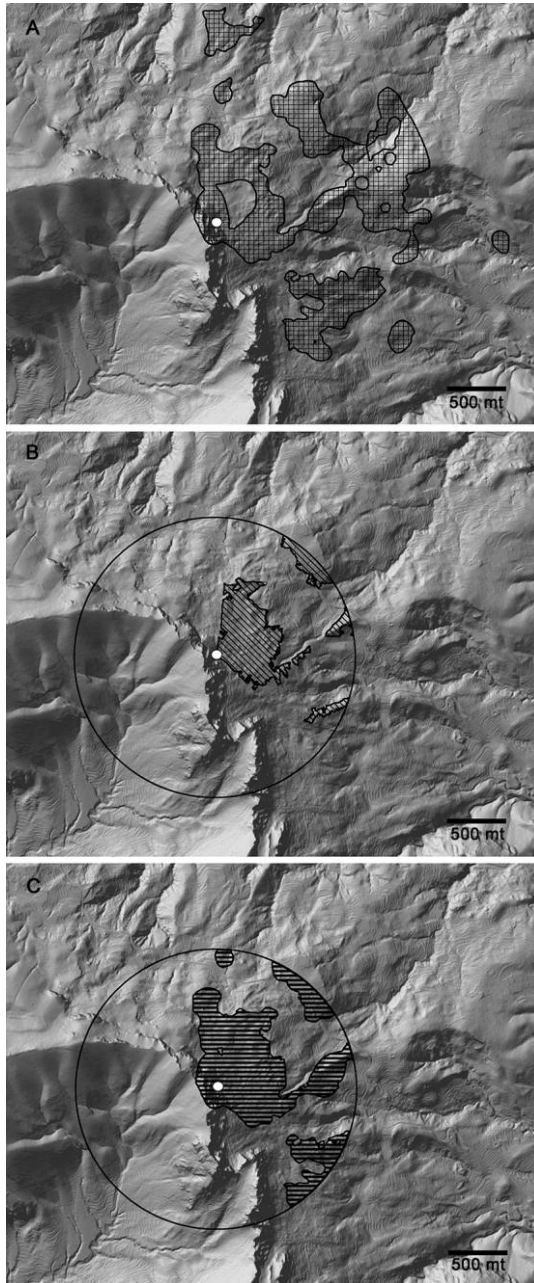


Figure 7. Raster maps of Site 109 (Barranc de l'Arc): (A) soundshed binary map, (B) viewshed binary map, (C) intersection of soundshed and viewshed binary maps within the Higuchi medium-distance threshold.

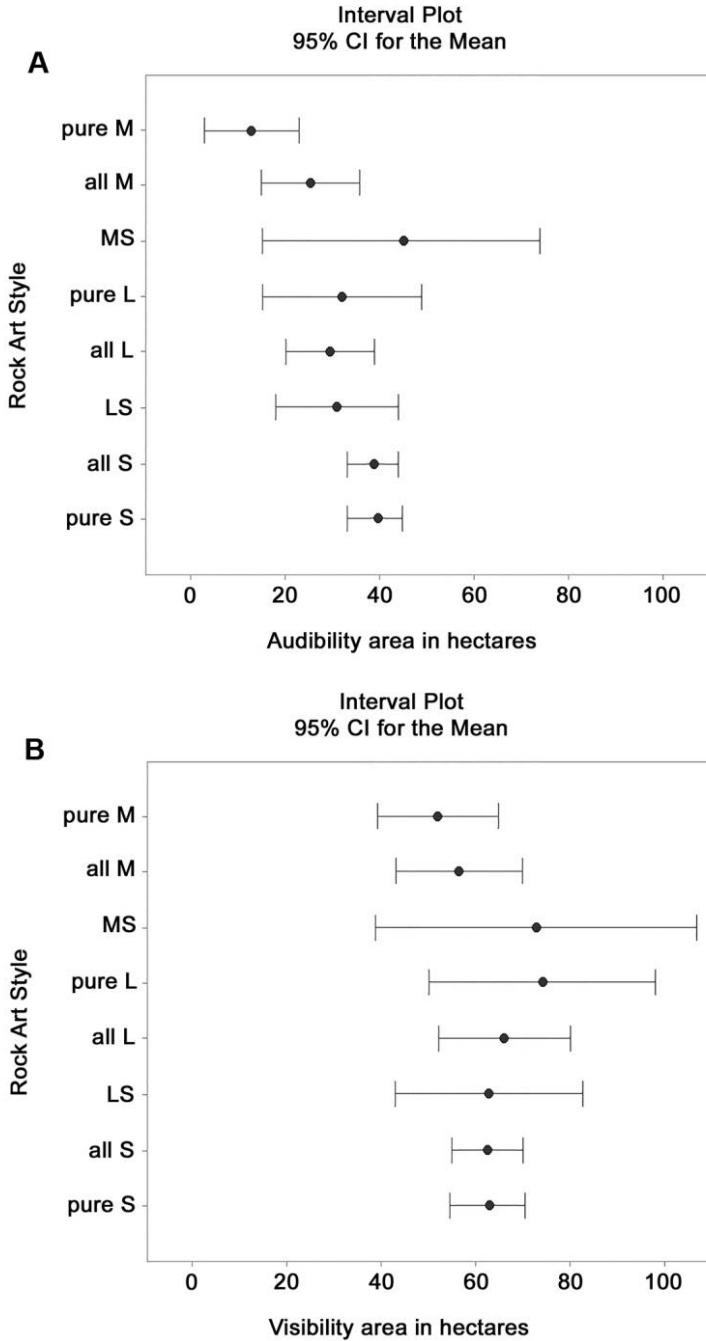
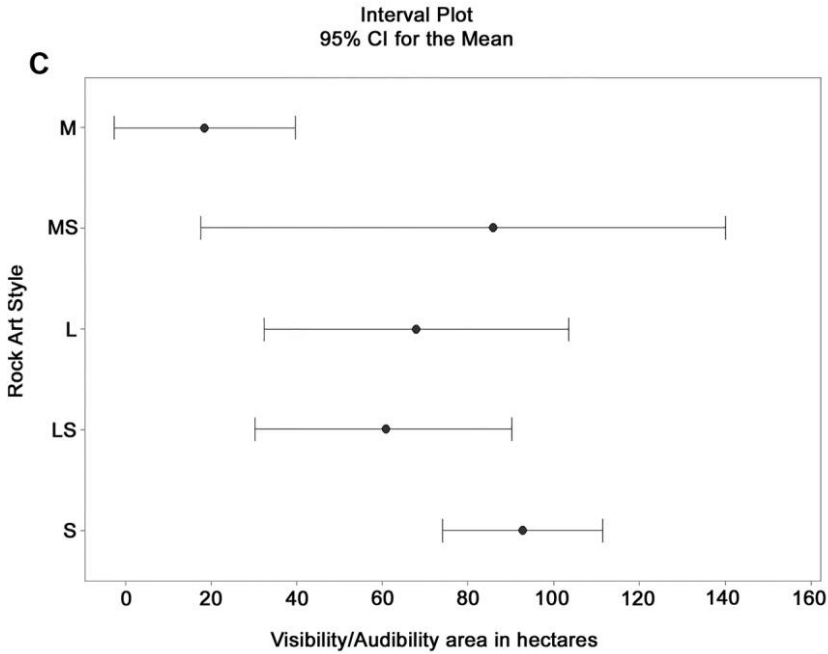


Figure 8. Interval plot (central tendency and variability of the data) of sites with Macroschematic (M), Macroschematic and Schematic (MS), Levantine (L), Levantine and Schematic (LS), and Schematic rock art styles (S): (A) audibility area in hectares in the buffer zone, (B) clipped visibility area in hectares, (C) intersection of clipped audibility/visibility areas in hectares.

Figure 8 (*Continued*)

taken great interest in audibility in the wider landscape, whereas Macroschematic artists were less interested. This contrasts with our previous findings in the adjacent landscape which showed an interest in close-range audibility on the part of both Schematic and Macroschematic artists. Levantine artists, who appeared not to be very interested in close range audibility, seemed to have more value for the wider landscape, with a range in between that of the Schematic and Macroschematic sites (20–39 ha). A close inspection of sites with two or more styles draws interesting results in the case of sites with both Macroschematic and Schematic: among all sites previously painted in the Macroschematic style, Schematic artists tended to choose those that had higher audibility. The values for the combination of Levantine and Schematic styles are less defined, perhaps because these two styles were contemporary, at least during the Neolithic, and the results may reflect the relative irrelevance of audibility for Levantine artists (Figure 8A).

As regards visibility, all the styles showed similar values, with Levantine rock art sites having the highest mean value, but also the widest value range, followed by Schematic, with a lesser mean value but closer homogeneity, and with Macroschematic sites yielding the lowest results, which, in any case, were better than those for audibility. Generally speaking, the values for the three styles were higher than those for the whole surface of audibility, thus confirming previous authors' emphasis on this type of perception (Figure 8B). The analysis of the audibility and visibility intersection reflects the findings

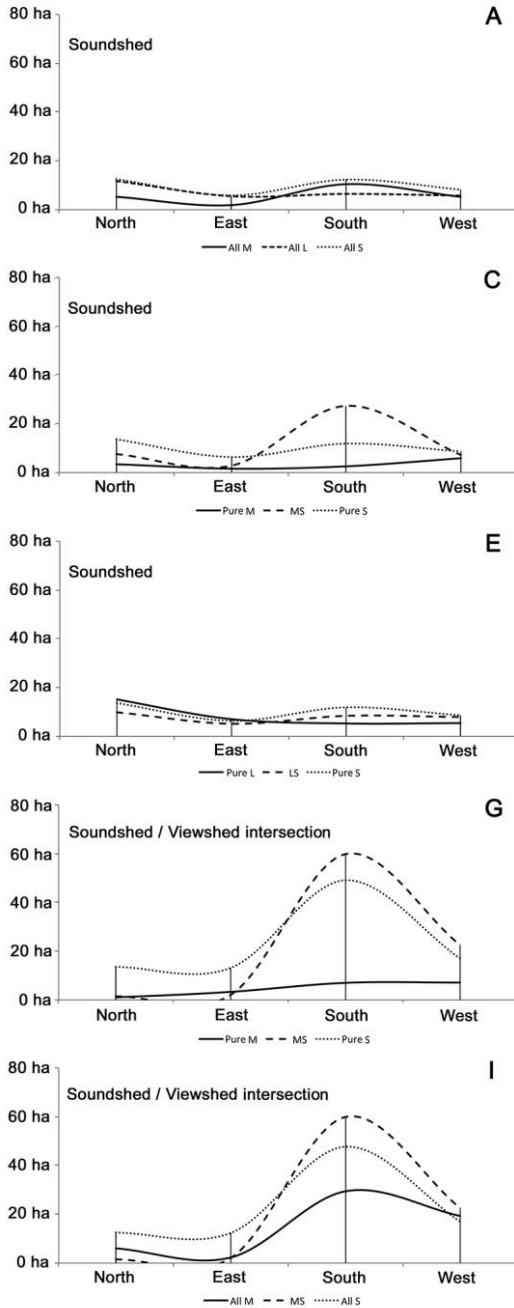


Figure 9. Mean values of the directionality of the viewshed, soundshed, and their intersection by style: (A, C, E) audibility area in hectares in the buffer zone; (B, D, F) visibility area in hectares in the buffer zone; (G, H, I, L) intersection of audibility/visibility areas in hectares.

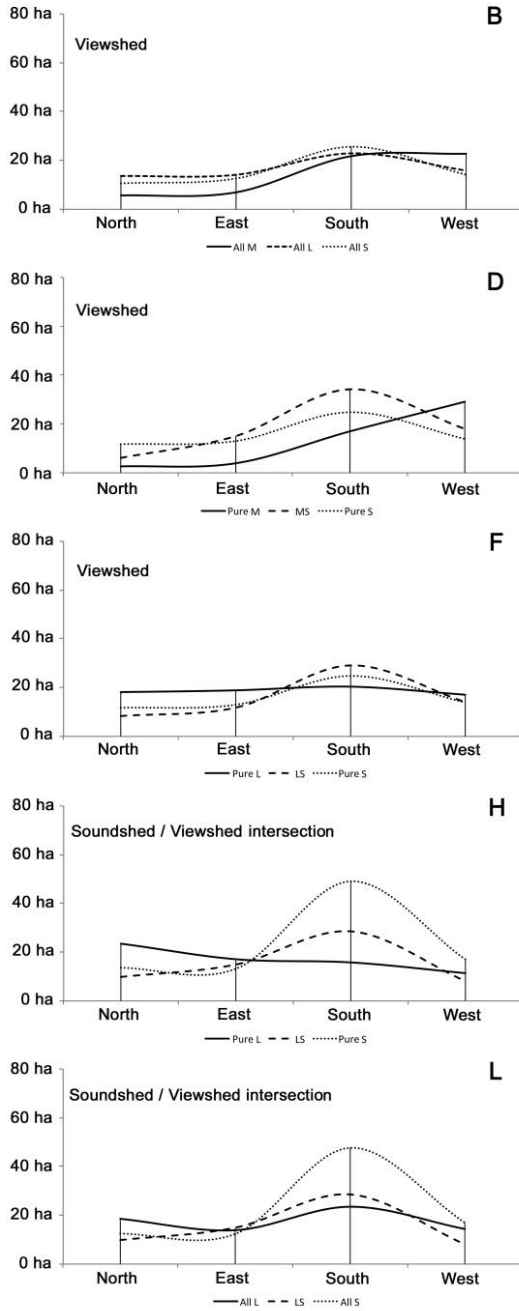


Figure 9 (Continued)

for audibility—Schematic artists were more interested in this combination (choosing sites with both high visibility and high audibility) than Macroschematic ones, with Levantine artists somewhere in the middle (Figure 8C). In conclusion, the higher values for visibility toward the wider landscape than those obtained for audibility seem to indicate that, generally speaking, prehistoric artists were more interested in visibility than audibility, with Schematic artists being most interested in both seeing and hearing, followed by Levantine and then Macroschematic artists.

The analysis of soundshed and viewshed directionality and the area encompassing the intersection of both provides interesting results. Regarding soundshed, both Macroschematic and Schematic rock art sites have better results in southerly directions, and sites with both styles repeat this predilection (Figure 9A and C), contrasting with the northerly direction of Levantine rock art sites (Figure 9A). However, when Schematic artists chose sites already painted with Levantine motifs, the results do not show any preference (Figure 9C). The analysis of the viewshed is again the most significant. Whereas Levantine artists did not have any preferences (Figure 9B and F), Macroschematic artists favored sites looking both southward and westward (Figure 9B and F). In turn, Schematic artists clearly preferred south-facing sites, and when Schematic artists decided to paint in shelters that had already been decorated with either Macroschematic or Levantine motifs, they tended to select only those facing in that direction (Figure 9F). The examination of directionality in the soundshed and viewshed intersection area confirms that Macroschematic and Levantine sites do not have any marked preferences whereas Schematic sites prioritize those that are south-facing. In sites where Schematic motifs are found together with either Macroschematic or Levantine ones, this trend is also present, seemingly indicating a selection by Schematic artists of sites that fulfilled their perceptual requirements (Figure 9G and H).

#### DISCUSSION: THE CHANGING PERCEPTION OF THE ROCK ART LANDSCAPES IN THE ALICANTE MOUNTAINS

The analysis of the perception of rock art landscapes in the Alicante Mountains examined audibility and visibility and the connection between them in an area in which three rock art styles were produced during the Neolithic period (ca. 5600 to 2800 cal BC). These styles were only partially contemporaneous, as the analysis of superimpositions has demonstrated (Martí Oliver and Hernández 1988:51–85): an earlier Macroschematic (M) style was followed by the overlapping Levantine (L) and Schematic (S) styles. Our study looked at perception in both the adjacent and the wider landscapes, comparing the results obtained in the tests undertaken for each of the styles. The relative chronology established for these three styles allows us to propose that throughout the Neolithic period intangible aspects of the landscape—vision and hearing—had a changing role in the Alicante Mountains.

The acoustic analysis of the adjacent landscape followed the method we had already applied in other rock art areas (Díaz-Andreu and García Benito 2012, 2015),



looking at the degree of reverberation and the number of echoes. The results showed a relationship between acoustics and rock art both in the painted shelters and in their surrounding areas, and that it was particularly significant in both Macroschematic and Schematic rock art shelters. This means that when the first Neolithic artists (those painting Macroschematic motifs) decided to decorate the landscape, they were interested in the acoustic effects of intentionally produced sounds in the rock art shelters and their adjacent areas. Later in the Neolithic, the communities living in the region changed styles, with Levantine (L) and Schematic (S) motifs being produced, at least partially, in the same period. Despite being more interested in visibility, the artists of both were also interested (although not as much) in acoustics, although Levantine painters slightly less so. Nevertheless, the results from the Levantine sites are good enough to verify the outcome of the tests made in the other Levantine areas we examined in our previous work in the Mortero Gorge, the Godall Mountains, and the Valltorta Gorge, which are located 218, 162 and 145 miles, respectively from the current project area (Díaz-Andreu and García Benito 2015). Also, as observed in those areas, tests undertaken in Alicante in places with rock art produced better results than those where no rock art was present. Since there are no known hidden rock art shelters in Alicante, regardless of the style painted in them, it is possible to say that visual perception at close range was important for the whole of the Neolithic period.

Interestingly, the GIS analysis undertaken to examine the perception of rock art landscapes in a wider area provided a slightly different picture. The results indicate that when Macroschematic artists first approached a landscape, although they were interested in shelters with good close-range acoustic phenomena, as seen above, they paid little attention to audibility in the wider landscape. Although slightly more attention was paid to visibility in this wider landscape, this did not seem to have been a key issue for the selection of rock art to paint. In fact, the opposite may be true, as the comparison with the later styles makes it clear that the Macroschematic rock art sites have the lowest values for both types of perception—audibility and visibility—in the wider landscape. Nevertheless, it is extremely interesting to note that the Macroschematic creators were very concerned with the directionality of the site viewshed, preferring those sites with better views toward the west and south. It seems remarkable that the literature thus far produced on this rock art style has ignored this pattern. In our opinion, it is very significant, as it is the only style that favors this type of viewshed directionality, a subject that may be worth developing in future research.

In a later period, when the Neolithic artists painting in Levantine and Schematic styles had to decide where to paint, their choices were different than those of the preceding Macroschematic painters. Both paid greater attention to wider audibility, and especially wider visibility. Levantine artists appear to have been less interested in the directionality of the site viewshed. Schematic rock art creators, however, showed a definite preference for the south, and they clearly selected—among shelters that had already been painted with Macroschematic and Levantine motifs—those with a south-facing viewshed. In the case of Levantine and Schematic shelters, it is also possible to

interpret the data as the result of Levantine artists deciding to paint in shelters already decorated by Schematic artists that happened to favor south-facing viewsheds. The analysis of the combination of audibility and visibility shows that audibility, despite its lower values, is in fact a key element when audibility and visibility are analyzed together, especially in the case of Schematic rock art landscapes.

The analysis of how visibility and audibility were used by each of the groups that produced the three rock art styles in the Alicante Mountains during the Neolithic period shows that the cultural differences were not only tangible—the different styles and different places in the landscape chosen for decoration—but also intangible. This is because each community valued visual and hearing perception, as well as the directionality of the view and soundshed, in distinct ways.

Throughout the Neolithic there was an interest in both audibility and visibility at close range. However, when the perceptual values in the wider landscape are examined, it becomes clear that the cognitive maps of the communities who produced each of these styles were different, especially in terms of audibility and the intersection between audibility and visibility. This is because of the striking differences in the choices made by Macroschematic and Schematic artists. The former were notably less concerned with their perceptual presence in the wider landscape, whereas Levantine painters were somewhere in the middle. This has implications for how we are to understand the continuity between the communities that produced Macroschematic and Schematic rock art proposed by Valencian scholars (Hernández Pérez 2009; Martí Oliver and Juan-Cabanilles 2014:36–41). Cultural transformation in this area was not, however, related to a change in populations, as DNA analyses have indicated a continuity between early and later Neolithic communities in areas farther to the north, in Mediterranean Spain, in Aragon and Catalonia, and, at the same time, a genetic break with previous populations (Fernández et al. 2010; Gamba et al. 2012).

## CONCLUSION

This article has examined rock art landscapes, paying particular attention to visibility and audibility, the key senses for landscape awareness. These intangible aspects may have a major influence on the way tangible landscapes are experienced and considerable impact on the selection of places to produce and experience rock art. Archaeologists have thus far studied each of these perceptions separately, and this article has endeavored to fill the resulting gap in our knowledge. This has been done taking into account Chippindale's (2004) suggestion regarding the importance of scale in the study of rock art landscapes. Consequently, our analysis distinguished between the adjacent landscape and the broader territorial scale, using the Higuchi (1983) medium-distance threshold—1150 m (0.71 miles)—as the dividing line between them.

In comparison with previous studies, this work represents a twofold qualitative step forward, in both methodology and interpretation. Methodologically, three different proposals have been made. First, it has been argued that clipping viewsheds in

a meaningful manner should become standard practice in GIS analyses of visibility. Related to this, we have suggested that the use of the Higuchi medium-distance threshold—the area within 1150 m (0.71 miles) of the site—brings a higher degree of confidence in the results. Second, we have also contended that measuring the directionality of the viewshed is more significant than measuring the orientation of the rock art shelters because directionality is a better reflection of actual visibility. Third, since research indicates that senses other than vision are used for the spatial perception of place, and that hearing is, after vision, the next most important sense, we have devised an innovative method not only to analyze audibility in the wider landscape thanks to GIS but, more important, to examine both visibility and audibility together. We have done this by intersecting the viewshed and soundshed and undertaking the same studies we had previously carried out separately.

Our study has also shown that the investigation of perception can provide new perspectives for understanding the different ways in which communities appropriated their surroundings, paying attention to both tangible and intangible aspects. In our case study we have shown that the way in which landscape was perceived by the Neolithic communities living in the mountains of Alicante went through changes revealed by the diverse perceptual patterns exhibited by each of the three rock art styles in the area. DNA analysis seems to indicate that these transformations were not related to a change in population, which led us to conclude that communities may decide at a certain point in their history to make radical changes to their cultural traditions. The reasons behind this major makeover of their cognitive and symbolic behavior open up new questions for scholars to investigate in the future, hopefully not only in our study case area but also in other rock art landscapes around the world.

#### NOTES

The research reported in this article has been partly undertaken within the framework of the People Programme (Marie Curie Actions) grant of the European Union's Seventh Framework Programme FP7/2007-2013/ under REA Grant Agreement No. 627351. Thanks to Laura Sirvent for her assistance in the field, to Manuel Bea for his suggestions, to Craig Alexander for his help with statistics, and to Apostolos Sarris for sharing his knowledge of GIS to complement ours. Fieldwork in Alicante was undertaken with permission from the Conselleria d'Educació, Cultura i Esport, Generalitat Valenciana, Exp. 2013/0656-A (SS. TT.).

1. There may be several ways to explain this difference. First, Cruz Berrocal was taking into account a larger area, including other rock art areas to the north in the Valencian region that we have not considered. Second, a comparison between Cruz Berrocal (2004:48) and Hernández Pérez et al. (2014: fig. 1) makes it evident that Cruz Berrocal was using the coordinates submitted for the UNESCO file when the ARAMPÍ nomination was proposed in 1998 (see [whc.unesco.org/en/list/874](http://whc.unesco.org/en/list/874)). Unfortunately, the list contained a few serious errors (Fernández López de Pablo 2009:133; Hernández Pérez et al. 2014:171, fig. 1), which sheds doubt on any analyses based on it.

## REFERENCES CITED

- Aiano, L. 2006. Pots and drums: An acoustic study of Neolithic pottery drum. *EuroREA – Journal of (Re)construction and Experiment in Archaeology* 3:31–42.
- Äikäs, T. 2015. *From boulders to fells: Sacred places in the Sámi ritual landscape*. MASF 5. Helsinki: Archaeological Society of Finland. Available online at [http://www.sarks.fi/masf/masf\\_5/masf\\_5.html](http://www.sarks.fi/masf/masf_5/masf_5.html).
- Alonso Tejada, A., and A. Grimal. 1996. El arte rupestre prehistórico de la cuenca del río Taibilla (Albacete y Murcia): Nuevos planteamientos para el estudio del arte levantino. Barcelona: self-published.
- Baker, J., and S. Brookes. 2015. Identifying outdoor assembly sites in early medieval England. *Journal of Field Archaeology* 40:3–21.
- Baldwin, J., P. Fisher, J. Wood, and M. Langford. 1996. Modeling environmental cognition of the view with GIS. Paper presented at the Third International Conference on Integrating GIS and Environmental Modeling, January 21–25, Santa Fe, New Mexico.
- Blessner, B., and L.-R. Salter. 2007. *Spaces speak: Are you listening?* Cambridge: MIT Press.
- Bradley, R. 1991. Rock art and the perception of landscape. *Cambridge Archaeological Journal* 1: 77–101.
- . 1997. *Rock art and the prehistory of Atlantic Europe: Signing the land*. London: Routledge.
- Breuil, H. 1933–1935. *Les peintures rupestres schématiques de la Péninsule Ibérique*, 4 vols. Lagny: Fondation Singer-Polignac.
- Carrión, J. S., S. Fernández, P. González-Sampériz, G. Gil-Romera, Ernestina Badal, Yolanda Carrión-Marco, L. López-Merino, J. A. López-Sáez, E. Fierro, and F. Burjachs. 2010. Expected trends and surprises in the Late Glacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands. *Review of Palaeobotany and Palynology* 162(3): 458–75.
- Chippindale, C. 2004. “From millimetre up to kilometre: A framework of space and of scale for reporting and studying rock-art in its landscape,” in *The figured landscapes of rock-art: Looking at pictures in place*. Edited by C. Chippindale and G. Nash, pp. 102–13. Cambridge: Cambridge University Press.
- Classen, C. 1993. *Worlds of sense: Exploring the senses in history and across culture*. London: Routledge.
- Constantinidis, D. 2004. “The interconnectivity of cultural sites: Sights and sounds across a landscape,” in *Enter the past: The e-way into the four dimensions of cultural heritage*. Edited by K. Fischer-Ausserer, W. Börner, M. Goriany, and I. Karlhuber-Vöckl, pp. 258–62. CAA 2003: Computer Applications and Quantitative Methods in Archaeology, Vienna. Oxford: BAR International Series S1277.
- Cruz Berrocal, M. 2004. La investigación del arte rupestre desde la geografía: La pintura neolítica del ámbito mediterráneo de la península ibérica. *Trabajos de Prehistoria* 62:41–62.
- . 2005. *Paisaje y arte rupestre: Patrones de localización de la pintura levantina*. Oxford: Archaeopress.
- Cruz Berrocal, M., and J. M. Vicent García. 2007. Rock art as an archaeological and social indicator: The Neolithisation of the Iberian Peninsula. *Journal of Anthropological Archaeology* 26:676–97.
- de Marinis, R. 2012. A che punto è lo studio dell’arte rupestre della Valcamonica. *Preistoria Alpina* 46:17–43.

- Deacon, J. 1988. The power of a place in understanding southern San rock engravings. *World Archaeology* 20:129–40.
- Demers, M. 2009. *Fundamentals of Geographic Information Systems*, 4th edition. Hoboken, NJ: John Wiley & Sons.
- Díaz-Andreu, M., and C. García Benito. 2012. Acoustics and Levantine rock art: Auditory perceptions in La Valltorta Gorge (Spain). *Journal of Archaeological Science* 39:3591–99.
- . 2013. “Sound and ritual in Levantine art: A preliminary study,” in *Music and ritual: Bridging material and living cultures*. Edited by R. Jiménez Pasaolodos, R. Till, and M. Howell, pp. 227–56. Berlin: Ekho Verlag.
- . 2015. Acoustic rock art landscapes: A comparison between the acoustics of three Levantine rock art areas in Mediterranean Spain. *Rock Art Research* 32:46–62.
- Fairén Jiménez, S. 2004. Rock art and the transition to farming: The Neolithic landscape of the central Mediterranean coast of Spain. *Oxford Journal of Archaeology* 23:1–19.
- . 2006. *El paisaje de la Neolitización. Arte rupestre, poblamiento y mundo funerario en las comarcas centro-meridionales valencianas*. Alicante: Universidad de Alicante.
- . 2007. British Neolithic rock art in its landscape. *Journal of Field Archaeology* 32:283–95.
- Fernández, E., C. Gamba, D. Turbón, and E. Arroyo. 2010. “ADN antiguo de yacimientos Neolíticos de la cuenca mediterránea: La transición al Neolítico desde una perspectiva genética,” in *Os últimos caçadores-recolectores e as primeiras comunidades produtoras do sul da Península Ibérica e do norte de Marrocos*. Edited by J. F. Gibaja and A. F. Carvalho, pp. 205–12. Faro: Universidades do Algarve.
- Fernández López de Pablo, J. 2009. “Arte rupestre, sistemas de información geográfica e infraestructuras de datos espaciales,” in *El arte rupestre del Arco Mediterráneo de la Península Ibérica: 10 años en la lista del Patrimonio Mundial de la UNESCO*. Edited by J. A. López Mira, R. Martínez Valle, and C. Matamoros de Villa, pp. 131–38. Actas IV Congreso (Valencia, 3, 4 y 5 de diciembre de 2008). Valencia: Generalitat Valenciana.
- Fraser, D. 1983. *Land and society in Neolithic Orkney*. Oxford: Archaeopress.
- Gaffney, V., Z. Stancic, and H. Watson. 1995. Moving from catchments to cognition: Tentative steps towards a larger archaeological context. *Scottish Archaeological Review* 9/10:41–64.
- Gamba, C., E. Fernández, M. Tirado, M. F. Deguilloux, M. H. Pemonge, P. Utrilla, M. Edo, M. Molist, R. Rasteiro, L. Chikhi, and E. Arroyo-Pardo. 2012. Ancient DNA from an Early Neolithic Iberian population supports a pioneer colonization by first farmers. *Molecular Ecology* 21: 45–56.
- García Arranz, J. J., H. Collado, and G. Nash (eds.). 2012. *The Levantine question: The development of Spanish Levantine rock art*. Budapest: Archaeolingua.
- García Atienzar, G. 2010. Las comarcas centromeridionales valencianas en el contexto de la Neolitización de la fachada noroccidental del Mediterráneo. *Trabajos de Prehistoria* 67:37–58.
- García Borja, P., and E. López-Montalvo. 2011. “Decoración cerámica y representaciones parietales de la cova de la Sarsa,” in *Las primeras producciones cerámicas*. Edited by J. Bernabeu Aubán, M. A. Rojo Guerra, and L. Molina Balaguer, pp. 231–34. El VI milenio CAL AC en la península ibérica. Valencia: Universitat de València.
- Gillings, M. 2009. Visual affordance, landscape, and the megaliths of Alderney. *Oxford Journal of Archaeology* 28:335–56.

- Guillem Calatayud, P. M., R. Martínez Valle, and V. Villaverde Bonilla. 2011. *Arte rupestre en el Riu de les Coves*. Valencia: Generalitat Valenciana, Instituto Valenciano de Conservación y Restauración de Bienes Culturales (IVACOR).
- Hameau, P. 1999. Héliotropisme et hygrophile des abris à peinture schématique du Sud de la France. *L'Anthropologie* 103:617–31.
- . 2002. Passage, transformation et art schématique: L'exemple des peintures néolithiques du sud de la France. Oxford: British Archaeological Reports S1044.
- Hartley, R. 1992. *Rock art on the northern Colorado Plateau*. Aldershot, Avebury.
- Hartley, R., and A. M. W. Vawser. 1998. "Spatial behaviour and learning in the prehistoric environment of the Colorado River drainage (southeastern Utah), western North America," in *The archaeology of rock art*. Edited by C. Chippindale and P. S. C. Taçon, pp. 185–211. Cambridge: Cambridge University Press.
- Hepp, B. H. 1985. The sound of two hands clapping: An exploratory study. *Journal of the Acoustical Society of America* 81:1100–1109.
- Hernández Pérez, M. S. 2009. "Arte rupestre postpaleolítico en el ArcoMediterráneo de la Península Ibérica: Balance de 10 años de descubrimientos y estudios," in *Actas IV Congreso el arte rupestre del arco mediterráneo de la península ibérica: 10 años en la lista del patrimonio mundial de la UNESCO*, Edited by J. A. López, R. Martínez, and C/ Matamoros, pp. 59–80. Valencia: Generalitat Valenciana.
- Hernández Pérez, M. S., and Centre d'Estudis Contestans. 1982. Consideraciones sobre un nuevo tipo de arte rupestre prehistórico. *Ars Praehistorica* 1:179–87.
- Hernández Pérez, M. S., G. García Atienzar, V. Barciela González, X. Martorell Briz, and F. J. Molina Hernández. 2014. Actualización y realización del inventario de los yacimientos arqueológicos con arte rupestre de la comunidad valenciana. Provincia de Alicante. MARQ, Arqueología y Museos [Dossier: Manuel H. Olcina Doménech & Jorge A. Soler Díaz (ed.) Arqueología en Alicante en la primera década del siglo XXI. II Jornadas de Arqueología y Patrimonio Alicantino] extra 1, 170–75.
- Hickmann, E., and D. W. Hughes (eds.). 1988. *The archaeology of early music cultures*. 3rd International Meeting of the ICTM Study Group on Music Archaeology, Hannover-Wolfenbüttel-Hildesheim, November 1986, Orpheus 31. Bonn: Verlag für Systematische Musikwissenschaft.
- Higuchi, T. 1983. *The visual and spatial structure of landscapes*. Cambridge: MIT Press.
- Hood, B. C. 1988. Sacred pictures, sacred rocks: Ideological and social space in the north Norwegian Stone Age. *Norwegian Archaeological Review* 21:65–84.
- Ibáñez, J. J., I. Clemente, N. Soler, and J. Salius Guma. 2015. Use and sonority of a 23,000-year-old bone aerophone from Davant Pau Cave (NE of the Iberian Peninsula). *Current Anthropology* 56:282–89.
- Ingold, Tim. 2000. *The perception of the environment: Essays on livelihood, dwelling and skill*. London: Routledge.
- Jiménez de Cisneros, D. 1922. La peña escrita de Tárben. *Ibérica* XVI:319–20.
- Kells, K. 2001. Ability of blind people to detect obstacles in unfamiliar environments. *Journal of Nursing Scholarship* 33:153–57.
- Kvamme, K. L. 1999. Recent directions and developments in Geographical Information Systems. *Journal of Archaeological Research* 7:153–201.

- Lawson, G. (ed.). 1983. European archaeomusicology: A summary and abstracts of a seminar on the archaeology of musical instruments. 1st International Meeting of the ICTM Study Group on Music Archaeology, Cambridge, December 1982. Music-Archaeological Report 6. Cambridge: Cambridge Music-Archaeological Research Project.
- Letowski, T. R., and S. T. Letowski. 2012. *Auditory spatial perception: Auditory localization*. Washington, DC: US Army Research Laboratory.
- Lund, C. S. (ed.). 1986. *Second conference of the ICTM Study Group on Music Archaeology, Stockholm, November 19–23, 1984*, 2 vols. Study Group on Music Archaeology. Kungl. Musikaliska Akademiens Skriftserie 53. Stockholm: Royal Swedish Academy of Music.
- Martí Oliver, B. 2008. “Cuevas, poblados y santuarios neolíticos: una perspectiva mediterránea,” in *Actas del IV congreso del neolítico peninsular*, vol. I. Edited by M. S. Hernández Pérez, J. A. Soler Díaz, and J. A. López Padilla, pp. 17–27. Alicante: Diputación Provincial de Alicante, Museo Arqueológico de Alicante.
- Martí Oliver, B., and M. S. Hernández. 1988. *El neolítico Valencià: Art rupestre i cultura material*. Valencia: Diputació de València.
- Martí Oliver, B., and J. Juan-Cabanilles. 2014. “Los primeros agricultores neolíticos mediterráneos (VI–V milenios a.C.),” in *Protohistoria de la península ibérica: Del Neolítico a la Romanización*. Edited by Almagro Gorbea, pp. 19–41. Burgos: Universidad de Burgos, Fundación Atapuerca.
- Martínez Bea, M. 2006. “Arte rupestre y SIG en los alrededores de Santolea (Teruel),” in *La aplicación de los SIG en la arqueología del Paisaje*. Edited by I. Grau, pp. 171–80. Alicante: Servicio de Publicaciones de la Universidad de Alicante.
- Martínez García, J., and M. Hernández Pérez (eds.). 2013. *Arte rupestre esquemático en la península ibérica*. Actas del II Congreso. Vélez Blanco: Ayuntamiento de Vélez Blanco.
- Mas, M., R. Maura, and M. Solís. 2012. “Absolute chronologies and relative chronologies: On the initial sequences of post-Palaeolithic rock art in the Mediterranean arc,” in *The Levantine question: The development of Spanish Levantine rock art*. Edited by J. J. García Arranz, H. Collado, and G. Nash, pp. 187–208. Budapest: Archaeolingua.
- Mateo Saura, M. A. 2001. Arte Levantino adversus pintura esquemática. Puntos de encuentro y divergencias entre dos horizontes culturales de la prehistoria peninsular. *Quaderns de Prehistòria i Arqueologia Castellonencs* 22:183–211.
- Mattioli, T. 2007. L’arte rupestre en l’Italia centrale: Umbria, Lazio, Abruzzo. *Quaderni di Protostoria* [Perugia] 4.
- . 2008. “Landscape analysis of a sample of rock art sites in central Italy,” in *Layers of perception: Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA)*. Edited by A. G. Posluschny, K. Lambers, and I. Herzog, pp. 342–43. Bonn: Dr. Rudolf Habelt.
- McClure, S. B., L. Molina Balaguer, and J. Bernabeu Auban. 2008. Neolithic rock art in context: Landscape history and the transition to agriculture in Mediterranean Spain. *Journal of Anthropological Archaeology* 27:326–37.
- Meyer, J. 2005. Description typologique et intelligibilité des langues sifflées: Approche linguistique et bioacoustique. PhD dissertation, Université Lumière Lyon 2.
- Mlekuz, D. 2004. Listening to the landscapes: Modelling soundscapes in GIS. *Internet Archaeology* 16. [http://intarch.ac.uk/journal/issue16/mlekuz\\_toc.html](http://intarch.ac.uk/journal/issue16/mlekuz_toc.html)

- Naguib, M., and R. H. Wiley. 2001. Estimating the distance to a source of sound: Mechanisms and adaptations for long-range communication. *Animal Behaviour* 62:825–37.
- Neuhoff, J. G. 2011. “Perception, cognition and action in auditory displays,” in *The sonification handbook*. Edited by T. Hermann, A. Hunt, and J. G. Neuhoff, pp. 63–86. Berlin: Logos Verlag.
- Ogburn, D. E. 2006. Assessing the level of visibility of cultural objects in past landscapes. *Journal of Archaeological Science* 33:405–13.
- Olsen, W. O. 1998. Average speech levels and spectra in various speaking/listening conditions: A summary of the Pearson, Bennett, & Fidell (1977) report. *American Journal of Audiology* 7:1059–89.
- Pearsons, K. S., R. L. Bennett, and S. Fidell. 1977. *Speech levels in various noise environments*. Washington, DC: Office of Health and Ecological Effects, Office of Research and Development, US Environmental Protection Agency.
- Ponsell Cortés, F. 1952. El hallazgo de las pinturas rupestres de La Sarga. *Revista de la Fiesta de Moros y Cristianos de Alcoi*.
- Rainio, R., and K. Mannermaa. 2012. “Bird calls from a Middle Neolithic burial at Ajvide, Gotland? Interpreting tubular bird bone artefacts by means of use-wear and sound analysis, and ethnographic analogy,” in *Sounds like theory: XII Nordic Theoretical Archaeology Group Meeting in Oulu April 25–28, 2012*. Edited by A.-K. Salmi and T. Äikäs, pp. 85–100. Helsinki: Archaeological Society of Finland.
- Reed, S. E., J. L. Boggs, and J. P. Mann. 2012. A GIS tool for modeling anthropogenic noise propagation in natural ecosystems. *Environmental Modelling & Software* 37:1–5.
- Reed, S. E., D. H. Smith, and J. L. Boggs. 2010. SPreAD-GIS: An ArcGIS toolbox for modeling the propagation of engine noise in a wildland setting, version 2.0. San Francisco: The Wilderness Society. Available online at <http://warnercnr.colostate.edu/~sereed/publications/ReedBoggsMann2010.pdf>
- Reznikoff, I. 2014. “On the sound related to painted caves and rocks,” in *Sounds like theory: XII Nordic Theoretical Archaeology Group Meeting in Oulu April 25–28, 2012*. Edited by A.-K. Salmi and T. Äikäs, pp. 101–9. Helsinki: Archaeological Society of Finland.
- Robinson, D. W. 2010. Land use, land ideology: An integrated Geographic Information Systems analysis of rock art within south-central California. *American Antiquity* 75:792–818.
- Rossing, T. D. (ed.). 2007. *Springer handbook of acoustics*. New York: Springer.
- Ruiz López, J. F. 2012. “Del macro-estilo al micro-estilo: Análisis de la técnica del arte levantino como factor discriminante estilístico,” in *The Levantine question: The development of Spanish Levantine rock art*. Edited by J. J. García Arranz, H. Collado, and G. Nash, pp. 323–44. Budapest: Archaeolingua.
- Ruiz López, J. F., M. Mas, A. Hernanz, M. W. Rowe, K. L. Steelman, and J. M. Gavira. 2006. First radiocarbon dating of oxalate crusts over Spanish prehistoric rock art. *International Newsletter on Rock Art (INORA)* 46:1–5.
- Señorán Martín, J. M., P. de la Presa, M. Ruiz-Gálvez Priego, and J. de Torres Rodríguez. 2014. Connecting data: GIS and the human history of the Oukaïmeden Valley. *Complutum* 25:211–25.
- Sognnes, K. 1987. Rock art and settlement pattern in the Bronze Age: Example from Stjørdal, Trøndelag, Norway. *Norwegian Archaeological Review* 20:29–50.



- Soria Lerma, M., M. Gabriel López Payer, and D. Zorrilla Lumbreras. 2012. "El arte rupestre levantino en Andalucía: Nuevas aportaciones," in *The Levantine question: The development of Spanish Levantine rock art*. Edited by J. J. García Arranz, H. Collado, and G. Nash, pp. 299–322. Budapest: Archaeolingua.
- Utrilla Miranda, P. 2000. *El arte rupestre en Aragón*. Zaragoza: Caja de Ahorros de la Inmaculada de Aragón.
- Viñas, R., and J. G. Morote Barberá. 2011. *Arte rupestre de Valltorta-Gassulla*. Museo y Parque Cultural—Art rupestre de Valltorta-Gassulla. Museu i Parc Cultural—Rock art of Valltorta-Gassulla. Museum and Cultural Park. Poble de Benifassà: Asociación de Amigos del Parque Cultural de La Valltorta y su Museo.
- Viñas, R., J. M. Vergès, M. Fontanals, and A. Rubio. 2010. Análisis de una figura de arquero de tradición levantina del Abric I del Barranc de Fontscaldes (Cornudella de Montsant, Tarragona). Datos para una aproximación cronocultural. *Cuadernos de Arte Rupestre* 5:53–61.
- Visedo Moltó, C. 1959. *Alcoy: Geología, prehistoria*. Alcoy: Publicaciones del Instituto Alcoyano de Cultura "Andrés Sempere."
- Wheatley, D., and M. Gillings. 2000. "Vision, perception and GIS: Developing enriched approaches to the study of archaeological visibility," in *Beyond the map: Archaeology and spatial technologies*. Edited by G. Lock, pp. 1–27. Amsterdam: IOS Press.
- Zahorik, P. 2002. Assessing auditory distance perception using virtual acoustics. *Journal of the Acoustical Society of America* 111:1832–46.