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Motion and Gesture: Analysing Artistic Skills in Palaeolithic Art

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Abstract
The development of artistic abilities in Upper Palaeolithic societies has been analysed in recent years from the perspective of learning and transmission of artistic know-how, from both technical and formal points of view. Recent analyses, based on the study of the operational chains involved in engraving, have shown different levels of acquisition of technical knowledge among Magdalenian artists in Western Europe. This study presents the results of an experimental programme based on the analysis of the physical actions performed while executing artistic motifs. Different patterns of movement and orientation were analysed within a large group of engravers with different levels of technical ability in order to determine the gestural parameters that characterize the different stages of artistic learning. The results, which have been processed with statistical analysis tools, make it possible to differentiate with greater precision the different actions required to engrave on hard materials with lithic implements, as well as the different stages of acquisition of technical knowledge linked to the production of artistic motifs by engraving.

Keywords Artist · Learning · Upper Palaeolithic · Portable art · Technology · Knowledge · Engraving

Introduction

The study of technical actions and the learning process associated with their acquisition and assimilation were originally approached mainly by Mauss (1997[1950]) and Leroi-

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Gourhan (1964, 1965). In the case of prehistoric research in the francophone literature, this approach has been utilized to understand the development of human motor and cognitive skills, along with the sociocultural determinants to which they correspond.

Following the introduction of the *chaîne opératoire* concept to prehistoric research (Pelegrin et al. 1988), technical learning by Palaeolithic knappers was first proposed by Pigeot (1988). Numerous studies have since continued that line of research to understand the mental processes involved in the creation of lithic implements, and which of these may be related to the cognitive development of Palaeolithic humans (Karlin 1991a, b; Ellen 2009; Mesoudi and Aoki 2015; Klaric 2018; Roux and Bril 2005; Stout 2002). These studies have been based on ethnological, ethnoarchaeological, neurobiological, and anthropological data in attempts to understand aspects of the development of cognitive skills and how technical innovations occurred and were perpetuated during the Palaeolithic.

In recent years, evidence of technical training in the Palaeolithic has extended beyond lithic reduction and has been attested within the production of artistic motifs (Fritz 1999; Rivero 2011, 2015, 2016, 2018). In the case of art, the study of the *chaînes opératoires* that occur in the production of decorated objects allows researchers to overcome the restrictions often suffered by studies of the symbolic behaviour of Palaeolithic societies. The technical analysis and reconstruction of the sequence of actions involved in creating artistic works can link art with the rest of the archaeological record, which helps to furnish the study of Palaeolithic art with social and cultural meaning (Rivero 2016).

The reconstruction of the actions of the engraver, analysed with technical parameters established by an experimental methodology, can provide data about the mode of interaction with the surface that is being decorated and the engraver's degree of control over the tool. These factors can help to establish a scale of expertise, based on the presence or absence of certain errors and accidents due to the engraver's level of experience. In this way, it is possible to address certain aspects of the transmission of graphic codes and the techniques involved in artistic production (Rivero 2016).

However, whereas the first experiments in lithic reduction date back to the beginnings of the discipline, experimental research in Palaeolithic art began much later, during the late twentieth century (Lorblanchet 1973, 1995; Féruglio 1993; D'Errico 1994; Fritz 1999), and today we are still far from understanding the technical requirements implied in the production of artistic motifs, the complexity of the *chaînes opératoires*, and the characterization of the skill of the Palaeolithic artists.

Research studies carried out by Bril et al. (2000, 2005) on the control of lithic implements and the associated technical actions have shown that they are conditioned by society and that the acquisition of technical know-how necessarily involves both perception and action. In other words, to comprehend an action, it is necessary to perform it. As those authors have demonstrated in the case of lithic reduction, to learn percussion techniques, what is necessary is not to learn the movements but rather the ability to control the mechanical determinants implied in the task: kinetic energy, direction of the percussive tool, and precision in the point of impact (Lorblanchet 1995; Bril et al. 2000, 2005; Nonaka et al. 2010). This line of research has been continued by numerous authors who, from an experimental viewpoint, have studied in detail the technical actions employed to produce lithic tools and the differences between categories of knappers according to expertise (Stout 2002; Roux and David 2005;

Lorblanchet 1995; Stout and Chaminade 2007; Geribàs et al. 2010; Magnani et al. 2014; Rivero 2015).

The present study uses a similar approach to understand the production of artistic motifs and particularly of Palaeolithic engravings. Just as the fabrication of lithic tools is subject to the control of functional parameters, engraving also involves a series of determinants which must be controlled and learned by the artists to obtain effective results in their work. This study is therefore based on the hypothesis that the mistakes seen in the production of motifs in the archaeological record are attributable to specific gestural sequences that occur in the first stages of learning. As pointed out by Roux et al. (1995), elementary movements must be controlled before a plan of action can be carried out. In the case of engraved motifs, more or less innate skill in drawing does not imply that novice artists do not need to master basic technical actions in order to create a motif correctly.

In this regard, this research has been based on the people who carry out the 'technical actions' and their relationship with their materials: the engraving tool and the object being engraved. Thus, first of all, we must define the type of action implied in Palaeolithic engraving—the functional constraints that come into play when engraving an object. As stated by Bril (2019), the aim is to analyse the action from a physical point of view, without any social or cultural dimensions.

If Palaeolithic engraving is reduced to the essential aspects of the task, the main point that should be borne in mind is the need for the engraving to be visible. It is necessary to apply considerable pressure to achieve visibility when making incisions into hard materials. In the case of engraving on bone, the biomechanical characteristics of the bone create significant difficulty, hindering progress when cutting in the opposite direction to the fibres in the bone (Koester et al. 2008). Mineral objects, such as limestone, also offer considerable resistance to incisions.

Along this line, an engraving is the result of applying pressure on a passive surface. However, it should also be noted that this work does not only consist of applying a force, but the direction of the tool must also be taken into account as engraving also requires precision in movement, especially bearing in mind that it does not only involve straight lines but also curves.

From the physical point of view, a series of mechanical parameters are, to a certain extent, comparable with the parameters of orthogonal cutting (Groover 2007). However, some of these parameters are likely to be nuanced depending on the difference in materials, especially in the case of engraving on bone, where the biomechanical complexity of the osseous tissue is greater than that of most materials used in engineering (Guede et al. 2013; Caeiro et al. 2013). Thus, in terms of the mechanical parameters in the action of engraving, a series of geometric, kinematic, and dynamic or kinetic variables come into play from the strictly physical point of view of the interaction between the materials and the different forces exercised on them. In turn, the resistance of the material (force) and its rigidity equally influence those parameters. In the case of bone, for example, the force is measured in megapascals or MPa (between 238 and 65 MPa depending on the different biomechanical resistance tests) (Caeiro et al. 2013).

From a theoretical point of view, the action of engraving a surface with a burin is an orthogonal incision (*i.e.* an incision in which the tool is placed perpendicularly to the direction of movement). This type of incision, when analysed geometrically in two dimensions, is distinguished by three characteristic angles and the depth of the incision ($T = E - e$, where E is the initial thickness and e is the final thickness of the object).

These angles are the rake angle (γ), the clearance angle (α), and the angle of the cutting edge (β). The sum of the three angles can be positive or negative depending on the position of the tool as regards the object (Fig. 1). When engraving, the position of the hand generates the positive or negative angle and this factor has significant consequences when creating a deep groove effectively.

Unlike a mechanical incision, the position of the hand, inclined to the right or the left, may have certain consequences when engraving. Therefore, the angles generated by the lateral inclination of the tool (to the right or to the left) must be taken into account.

Regarding the kinematics of the incision, the velocity of the incision should be considered. This represents the speed in which the tool advances and is expressed in mm/min.

Finally, the dynamic factors that influence engraving must also be considered. This is a force (R) measured in newtons that can be divided into two depending on the axes of the abscissas in the direction of the movement. Thus, the force corresponding to the X axis will be the direction force (F_x), whereas the force corresponding to the Y axis will be the thrust force (F_y) (Fig. 1). They can also be divided into F, the force that acts in the plane of the incision, and N, the force that acts in a plane at right angles to the incision. The two forces allow the friction coefficient (μ) to be calculated as the result of dividing the tangential force by its corresponding normal force.

Additionally, connected with the force, the cutting pressure (p) should be taken into account. This will vary depending on the hardness of the material being engraved, the characteristics of the material, and the geometry of the tool. For instance, the hardness of bone is measured as about 2.5 in the Mohs scale, whereas flint has a hardness of between 3.5 and 4. The harder the object, the greater the pressure required. However, this will also depend on the raw material of the tool and its geometry.

These physical parameters can be analysed in the case of Palaeolithic engraving in order to determine how their variability influences the final result, along with the differences that are derived from the mechanical actions carried out by expert and inexpert engravers.

Here, the geometric parameters will be analysed, without considering the kinematic and dynamic parameters of engraving in this first approach. The force exercised will only be measured here indirectly, by calculating the depth of the incision. However, it

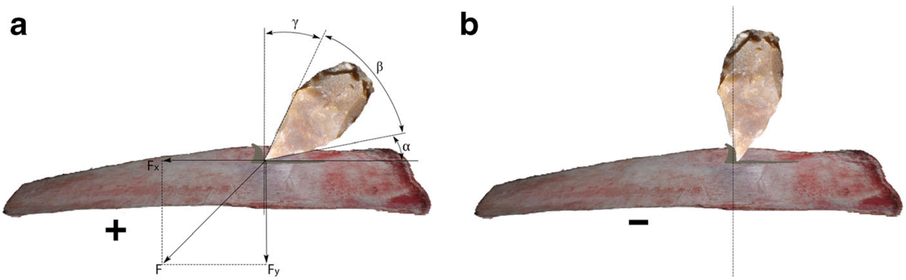

Fig. 1 Positive and negative rake and clearance angles of the tool on the object and the division of the forces exercised in the direction of movement

should be noted that the force exercised and the depth of the incision are not always correlated linearly as, in the case of Palaeolithic engraving, force is not the only determinant factor to obtain a deep engraving.

The aim of this research is to determine the functional principles that are necessary to obtain a correct result from a technical point of view when engraving on hard surfaces. To do this, a series of analytical criteria will be used, including the geometric parameters of the mechanics of orthogonal incision (*e.g.* cutting angles, depth of the incision), but behavioural units will also be taken into account, in a manner similar to how they have been applied to lithic assemblage analyses (Geribàs et al. 2010). These will allow a determination of the dynamic actions needed for the correct production of Palaeolithic engravings.

To understand how these physical and behavioural determinants come into play in the production of engraved motifs, we have carried out experimentation with a group of 26 individuals with different levels of experience. Their actions and motifs have been analysed in order to establish which technical actions are implicated in the production of an engraving. The results show that, despite the small size of the sample, a series of factors clearly separate the gestural dynamics of expert and inexpert engravers.

Materials and Methods

Experimentation

For this experimental process, 26 individuals have taken part: 11 women and 15 men in various age groups, with different handedness and with different degrees of expertise (Table 1).

The artists' degree of expertise has been determined *a priori* by their previous experience/inexperience in the use of burins to create either artistic motifs or osseous artefacts. The expert engravers possessed over 10 years of experience in the use of burins to create osseous objects and to produce engravings.

The participants in the experimental programme engraved on gypsum and bovine ribs, using dihedral burins, as this kind of utensil is associated archaeologically with engraving artistic motifs (Venditti et al. 2016) (Fig. 2). Gypsum is a soft material that facilitates the work of engraving and deepening the groove, while cow ribs are

Table 1 Participants in the experiment, according to their laterality, expertise, and age group

Number	Sex	Laterality	Expertise	Age
9	Female	Right-handed	Novice	18–38
1	Female	Left-handed	Novice	19
1	Female	Right-handed	Intermediate	40
11	Male	Right-handed	Novice	18–70
1	Male	Left-handed	Novice	43
1	Male	Right-handed	Intermediate	33
2	Male	Right-handed	Expert	45–53

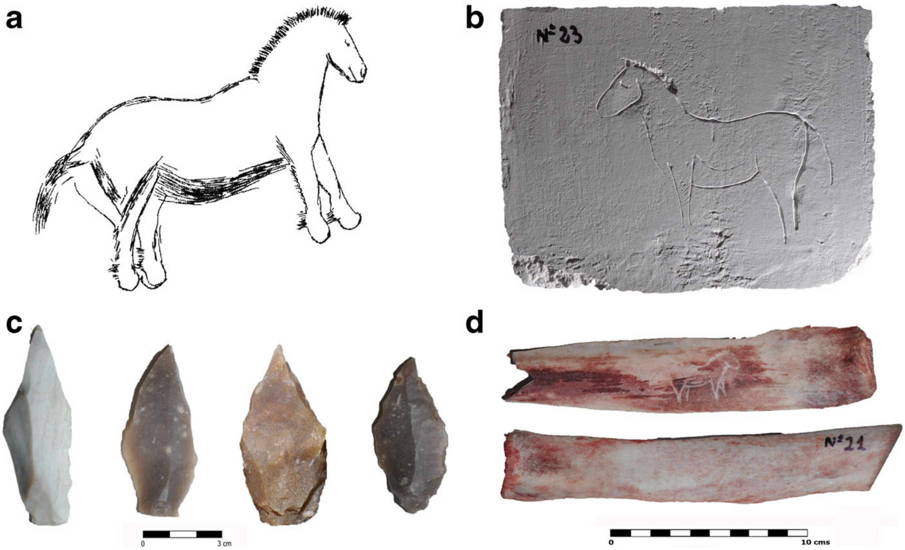

Fig. 2 Materials used in the experimentation. **a** Copy of the engraved horse in the cave of La Pasiega (after C. González Sainz). **b** Gypsum plaque. **c** Straight dihedral burins in flint. **d** Cow rib

significantly resistant to engraving, as bone displays a very particular combination of stiffness, hardness, and toughness (Koester et al. 2008).

None of the participants possessed previous notions of the process. They were not given any verbal instructions, and the time for producing the motifs was not restricted. The experimental programme consisted of two stages.

The participants first were asked to draw a horse in gypsum. A figurative motif was chosen as this involved a complex *chaîne opératoire* that would provide sufficient information about the sequence of actions involved.

During the second stage, the participants were asked to reproduce the image of an Upper Palaeolithic horse on a bovine rib, which had previously been scraped to remove the periosteum, or outer layer. For this task, a figure from La Pasiega Cave (Cantabria, Spain) was chosen because of the large quantity of anatomical details it contains.

The process was recorded with two cameras: a Panasonic HC-V110 video camera with full HD quality and 72× intelligent zoom, with a 34.4-mm angle of vision and 25 f/s, and a Nikon D90 camera, to obtain detailed images of the hands and body posture, following a methodology used in experimentation into the processes of lithic reduction (Geribàs et al. 2010).

Analytical Methodology

A double methodology was applied to analyse the data. First, the videos of the participants were examined to obtain a repertoire of their actions and a series of criteria about the artistic production sequences. We also analysed the motifs produced by each participant with microscopic and microphotogrammetric observation, in order to identify the characteristics of the engraving (mistakes in drawing, depth of the incision, and traits of the lines).

Video Analysis

As mentioned above, a series of behavioural units were established through the method of video observations (Martin and Bateson 2007). These units are defined as each one of the minimal elements into which a sequence of actions can be divided. To analyse the videos, the speed was reduced to 75% in the VLC player in order to identify the different actions involved. Analysis of the video recordings consisted first of defining each of the behavioural units and then, in a second viewing, of codifying them by the presence or absence of qualitative criteria and quantifying the number of actions in the case of quantitative criteria. The total time used by each engraver was also measured.

Criteria Referring to the Dynamics of Engraving

Unlike the situation in lithic reduction, no previous studies have been carried out regarding the dynamics implicated in engraving artistic motifs. Therefore, to create our repertoire of behavioural units (Geribàs et al. 2010), we have followed lithic reduction studies but adapted them to fit the nature of the processes of engraving.

In the case of lithic reduction, such criteria as percussion, rotation (Geribàs et al. 2010), strength (Magnani et al. 2014), and kinetic energy (Nonaka et al. 2010) are taken into account; in the case of engraving, the parameters that have been established are based on qualitative and quantitative criteria observed among the participants. These criteria concern the position of the burin in the hand, the angle of the implement, the point of contact of the burin with the object, the dynamics of turning and rotating the hand and the object, and the changes that occur during the sequence of actions (Table 2).

Regarding the variables that have been analysed, the different behavioural units were defined by the action dynamics observed through experimentation seen in the video. Therefore, these variables were not established beforehand.

In this way, different body postures, the position of the object with regard to the legs, and the way of holding it (horizontally or vertically) have been discriminated. Similarly, the different ways of holding the burin in the working hand and the object in the other hand were observed. It should be stressed that burin positions 5 to 11 were only observed in one participant, and therefore, they are not regarded as representative of engraving action dynamics.

Additionally, as explained above, the angles of the position of the tool as regards the object, both orthogonal and lateral, have been considered. The point in which the burin makes contact with the object has also been analysed, along with the place in which the tool is held in the hand.

Regarding the quantitative variables, these take into account both the movement of the engraving action (in the sense of the direction of movement) and the dynamics in the changes between the different qualitative variables. In this regard, referring to the position of the wrist and the hand, a turn has been distinguished when the movement starts at the elbow towards the right or the left (normally with an angle of 45°), and a rotation when the wrist moves to the right or the left (also in an angle of 45°). Similarly, the rotation of the object has been analysed depending on the angles (in this case without distinguishing between a rotation towards the left or the right).

The total time has been measured according to the observations of the videos.

Table 2 Quantitative and qualitative analytical criteria for the dynamics of the engraving process used by the participants in the experimentation

Gestural attributes	
Qualitative variable	Quantitative variable
Corporal position	Movement of the burin making the engraving
Sitting with both feet on the floor	From top to bottom
Sitting with 1 foot on the floor and the other over the knee	From bottom to top
Sitting crossing the legs	From left to right
	From right to left
Object position	Backwards and forwards
Horizontal	Rotation
Vertical	
	Engraving dynamic
Situation of the object on the legs	Stops
On one leg	Change of the point of contact of the burin
On both legs	Change of the position of the burin in the hand
	Change of the position of the blade
Position of the burin in the main hand	Change of corporal position
Burin between thumb and index finger supported on middle finger (burin position 1)	Change of the object position on the leg
Burin between thumb and index finger (index finger bent, not gripping) (burin position 2)	Cleaning object and/or burin
Burin gripped between thumb and index finger (burin position 3)	
Burin gripped between thumb, index finger, and middle finger (burin position 4)	Positions of the wrist and the hand
All fingers pressing against the palm (burin position 5)	Turn 45° to the left
Burin between thumb, index finger, and middle finger, with middle finger pressing against the palm (burin position 6)	Turn 45° to the right
Burin gripped with the whole hand (like a dagger) (burin position 7)	Rotation 45° to the left
Burin between index finger bent and thumb pressing against the edge of the object (burin position 8)	Rotation 45° to the right
Burin gripped between thumb and middle finger (burin position 9)	
Burin between thumb and ring finger with thumb under index finger and middle finger (burin position 10)	Rotation of the object
Burin between thumb, index finger, and middle finger, supported on ring finger (burin position 11)	45°
	90°
Position of the support in the passive hand	180°
Pushing the burin with the thumb or the index finger	
Holding the support	Time (min)
Making a clamp between index finger and thumb on the burin	
Moving the support helping the burin movement	Depth of a single incision (mm)

Table 2 (continued)

Gestural attributes	
Qualitative variable	Quantitative variable
Burin inclination	
To the left	
To the right	
Negative rake angle	
Positive rake angle	
Contact point of the burin with the object	
Left facet (burin point of contact 1)	
Right facet (burin point of contact 2)	
Dorsal arris (burin point of contact 3)	
Ventral arris (burin point of contact 4)	
Bit of the edges (burin point of contact 5)	
Another part of the blade (burin point of contact 6)	
Part of the burin gripped in the hand	
Mesial	
Proximal	

Finally, the depth of the incision in a single hand movement has been calculated by the depth established in the microphotogrammetry models produced, divided by the number of movements observed in the engraver's actions.

In the present study, we only use the data gathered from the experimental engraving on ribs (Figs. 3, 4, 5, and 6).

Microscopic Analysis and Identification of the Technical Quality Index

In addition to characterizing the actions made by examining the videos, the motifs produced by the participants have been analysed from a technical point of view. The motifs were observed with a Leica MZ16 with 16:1 apochromatic zoom, 7.1× to 115× magnification, using an added-on Leica IC90E, and a Dino-Lite AD-7013MZT version 1.3.2 digital microscope, with 5 megapixel resolution and 10× to 250× magnification. The microscopic analysis of the lines was based on previous work (Rivero 2016) which determined a series of technical indices or stigmas that are indicative of greater or lesser motor control of the tool and the engraver's actions. There are six stigmas in the case of inexperience (difficulty in deepening a single groove; the tool going outside the line; inflexions in curved or straight lines; slips; and rectifications) and six in the case of expertise (depth of the incision; use of combined profiles; precision in the actions; differential relief; combination of techniques; and preparation of the surface) (Table 3).

With these indices of inexperience and expertise, a database (LiveCode© software) has been generated to describe the motifs engraved by the 26 participants. The inexperience indices have been quantified negatively and the expertise indices positively, in such a way that the 'average quality index' for each motif will be between −

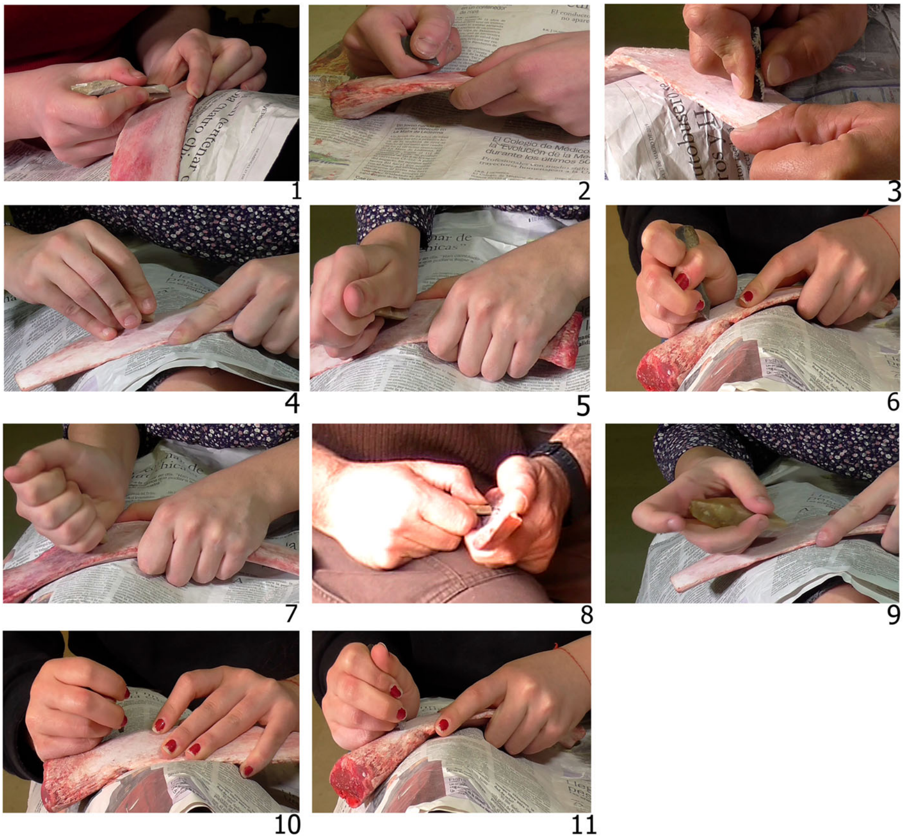

Fig. 3 Actions represented by the different qualitative variables. Position of the burin in the main hand. 1, burin between thumb and index finger, supported on middle finger; 2, burin between thumb and bent index finger; 3, burin gripped between thumb and index finger; 4, burin gripped between thumb, index finger, and middle finger; 5, all fingers pressing against the palm; 6, burin between thumb, index finger, and middle finger, with the middle finger pressing against the palm; 7, burin gripped in the whole hand; 8, burin between bent index finger and thumb levering against the edge of the rib; 9, burin gripped between thumb and middle finger; 10, burin between thumb and ring finger with thumb under index finger and middle finger; 11, burin between thumb, index finger, and middle finger, supported on ring finger

10 and + 10, depending on the degree of expertise of each engraver (Figs. 7 and 8), following a methodology applied to the archaeological record (Rivero 2016).

As previous studies have found, the determination of the 'average quality index' in Palaeolithic portable art has shown that motifs can be grouped into three categories based on the predominance of the indices: one group characterized by a predominance of negative indices (*Neg*) that must correspond to inexpert or novice artists; an intermediate level (*Low*), between 0 and 3; and a superior level (*Hig*) characterized by positive or expert indices (Rivero 2016). These three categories correspond to the different levels of expertise in Palaeolithic art. However, in the experimental programme, no engraver reached the high index—above 3. In our case, the 'expert' engravers have not scored more than 0 in the technical index and would be classed in the intermediate category of Palaeolithic artists. In a similar way, whereas no

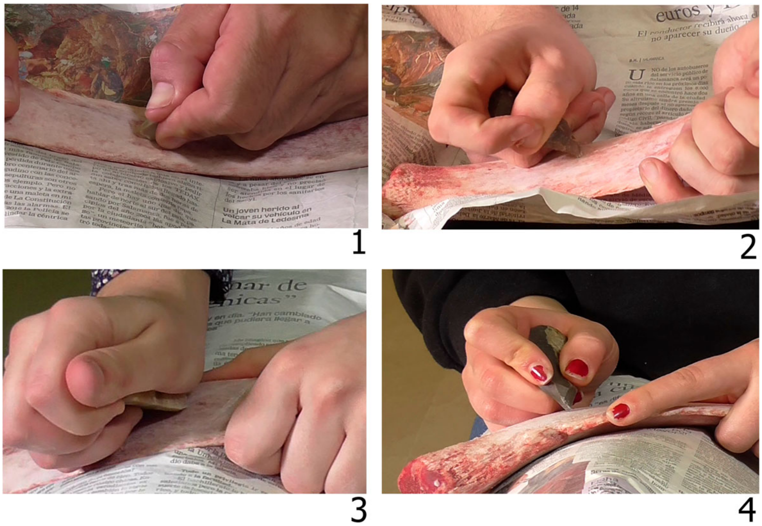

Fig. 4 Qualitative variables taken into account in the analysis of the gestural dynamics. Burin inclination. 1, burin tilted towards the left; 2, burin tilted towards the right; 3, negative rake angle; 4, positive rake angle

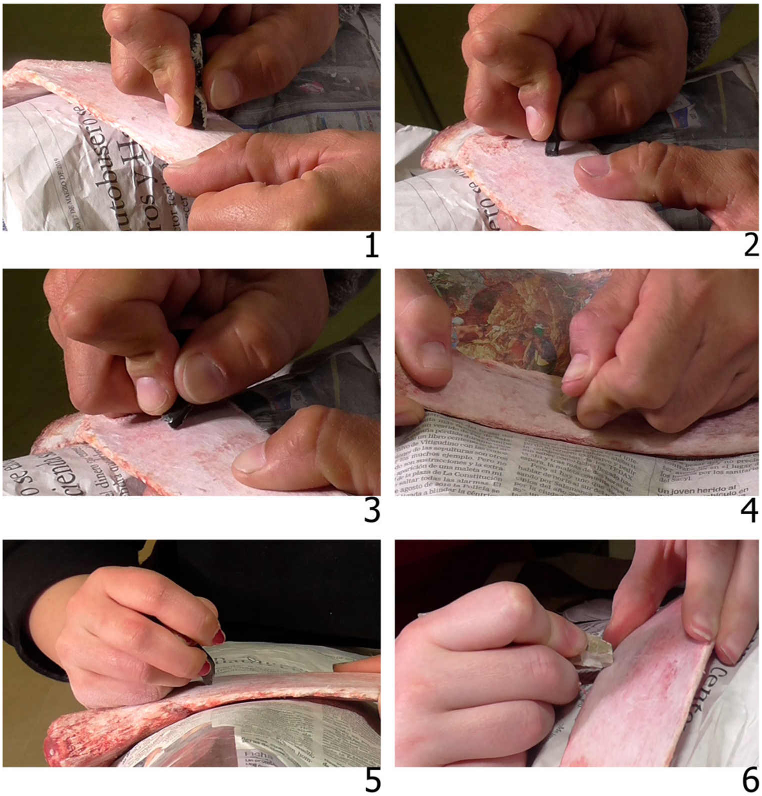

Fig. 5 Qualitative variables referring to the point of contact of the burin on the media surface. 1, left facet; 2, right facet; 3, dorsal arris; 4, ventral arris; 5, bit of the edges; 6, other part of the blade

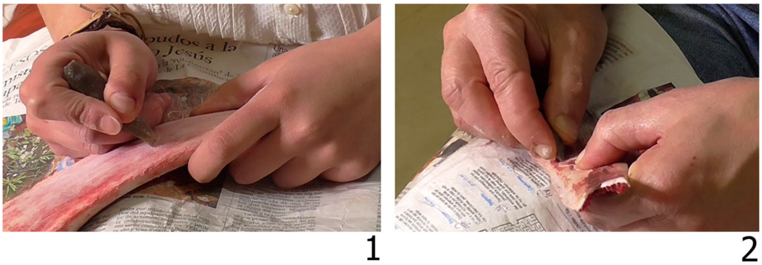

Fig. 6 Qualitative variables referring the part of the burin gripped in the hand. 1, gripped in the mesial part of the blade; 2, gripped in the proximal part of the blade

Palaeolithic engraver possesses a technical index under − 6, indices of − 7 and − 8 have been scored among the experimental engravers.

Microphotogrammetry and the Morphological Analysis of the Lines

The microscopic analysis of the motifs was complemented by the three-dimensional restitution of the engraved objects. In recent years, digital photogrammetry of close objects has developed considerably because of lower costs and greater accessibility of photographic equipment, along with software based on the SIFT and similar algorithm (González-Aguilera et al. 2009; Azéma et al. 2010; Feruglio et al. 2013; Richardson et al. 2013; Domingo et al. 2013; Rivero 2014). Thus, close-range photogrammetry can currently be considered the standard methodology for recording rock art (Rivero et al. 2019), while 3D reproduction techniques have enabled analytical approaches, for example, in the field of traceology (Zotkina and Miklashevich 2016; Plisson and Zotkina 2015) and 3D analysis of cut marks (Maté González et al. 2015, 2018).

In the present case, microphotogrammetry has been applied to the engraved figures, using the images obtained with the Dino-Lite AD-7013MZT series digital microscope,

Table 3 Traces of experience or inexperience with possible values, so that the quantitative 'technical quality index' may vary between − 10 and + 10

Trace	Values
Difficulty of deepening	0/− 1/− 2
Tool escaping	0/− 1/− 2
'Hooking' (straight line)	0/− 1
'Hooking' (curved line)	0/− 1/− 2
Stick-slip oscillations	0/− 1
Drawing correction	0/− 1/− 2
Exact deepening	0/+ 2
Combination of profiles	0/+ 2
Differential relief	0/+ 2
Combination of techniques	0/+ 2
Precision of gesture	0/+ 1
Preparation of support	0/+ 1

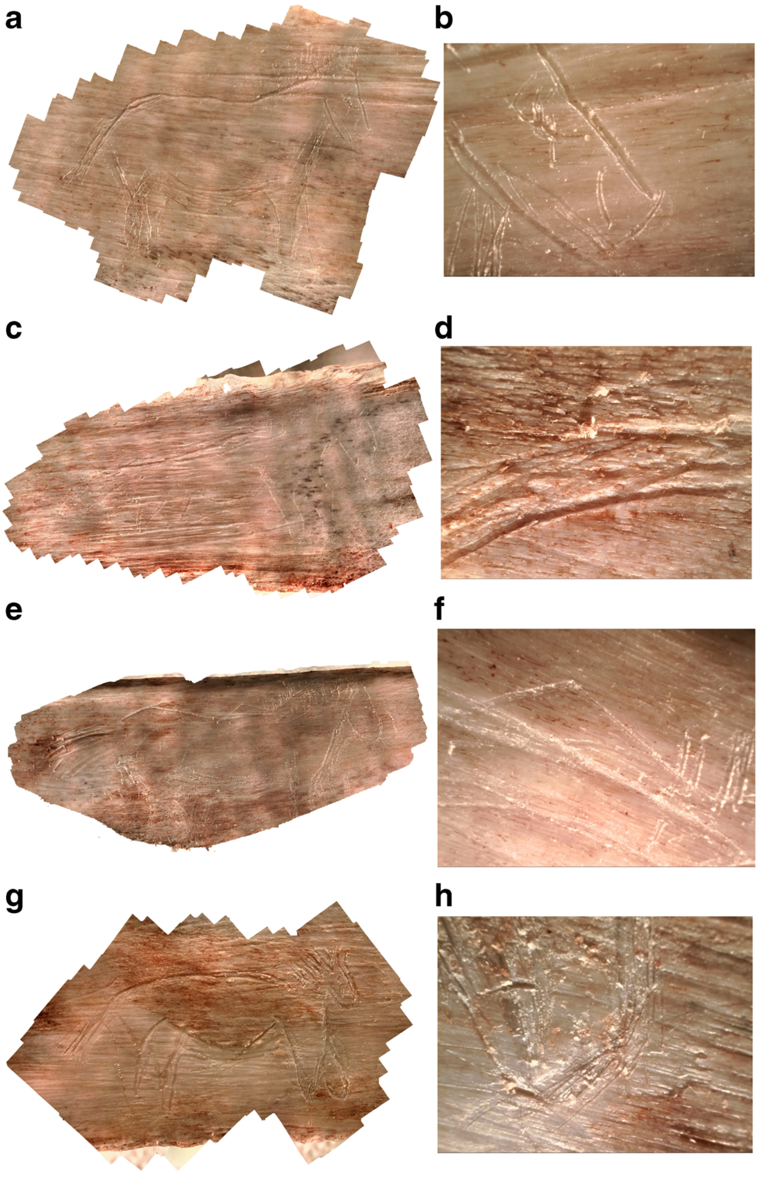

Fig. 7 Some examples of motifs on ribs by novice engravers. **a** Orthoimage of an engraving with a technical index of −4. **b** Micrograph at 30× where difficulties in deepening the groove can be seen as well as the tool going outside the line and inflexions in a straight line. **c** Orthoimage of an engraving with a technical index of −6. **d** Micrograph at 30× where difficulties in deepening the groove can be seen. **e** Orthoimage of an engraving with a technical index of −8. **f** Detail of an inflexion in a curved line. **g** Orthoimage of an engraving with a technical index of −5. **h** Detail of difficulties in deepening a single line and the tool going outside the line

to generate precise metrical models. The images were processed with Agisoft Professional version 1.4.0 software. The scaled 3D restitutions have made it possible to view the cross-sections of the engraved grooves and calculate the depth, breadth, and length

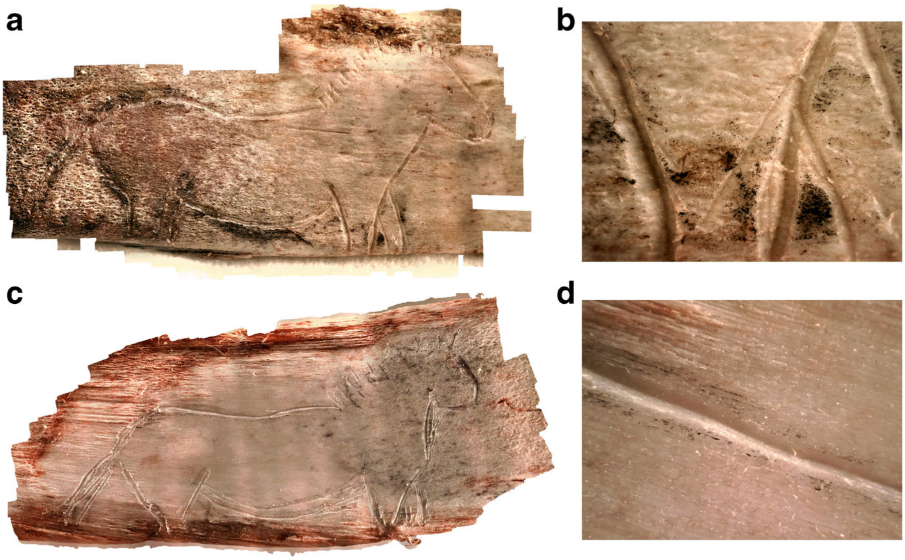

Fig. 8 Examples of drawings on ribs produced by intermediate and expert engravers. **a** Orthoimage of an engraving with a technical index of 0. **b** Micrograph at 30× where the depth of the line can be appreciated, although some problems persist, such as the tool going outside the groove. **c** Orthoimage of an engraving with a technical index of 0. **d** Micrograph at 30× where it can be seen that a single groove was deepened without difficulty

of the lines (Fig. 9). When combined with the information obtained from the videos, this has provided data about the depth of the incision achieved by the engraver in a single movement of the tool.

Data Analysis

Multivariate statistical tools have been used to analyse the qualitative and quantitative variables and other data such as the technical quality indices. These variables have been correlated to test the hypotheses posed by the experimentation.

In the case of the actions involved in the engraving dynamics, such as the movements of the burin and changes in the point of contact of the burin, the time effect has been weighted and eliminated by dividing each one of the measurements by time, thus obtaining the number of burin movements per minute and the changes in the point of contact per minute.

To analyse all the variables, multivariate tools have been used: factorial correspondence analysis (FCA) (Benzecri and Benzecri 1980–1984), using the STAT2 programme designed by Prof. Dr. G. Sauvet. Thirty-seven attributes were retained, which are the variables established to analyse the actions (Table 2). Thus, we have retained the technical quality index of the representations, the burin movements per minute, the changes in the point of contact of the burin per minute, the changes on the position of burin in the hand per minute, and the changes in the positions of the wrist and arm per minute. Other qualitative variables are the position of the burin in the hand, the point of contact of the burin on the object, the inclination of the burin, and the place in which the burin is gripped. Finally, the three engraver categories have been included: novice,

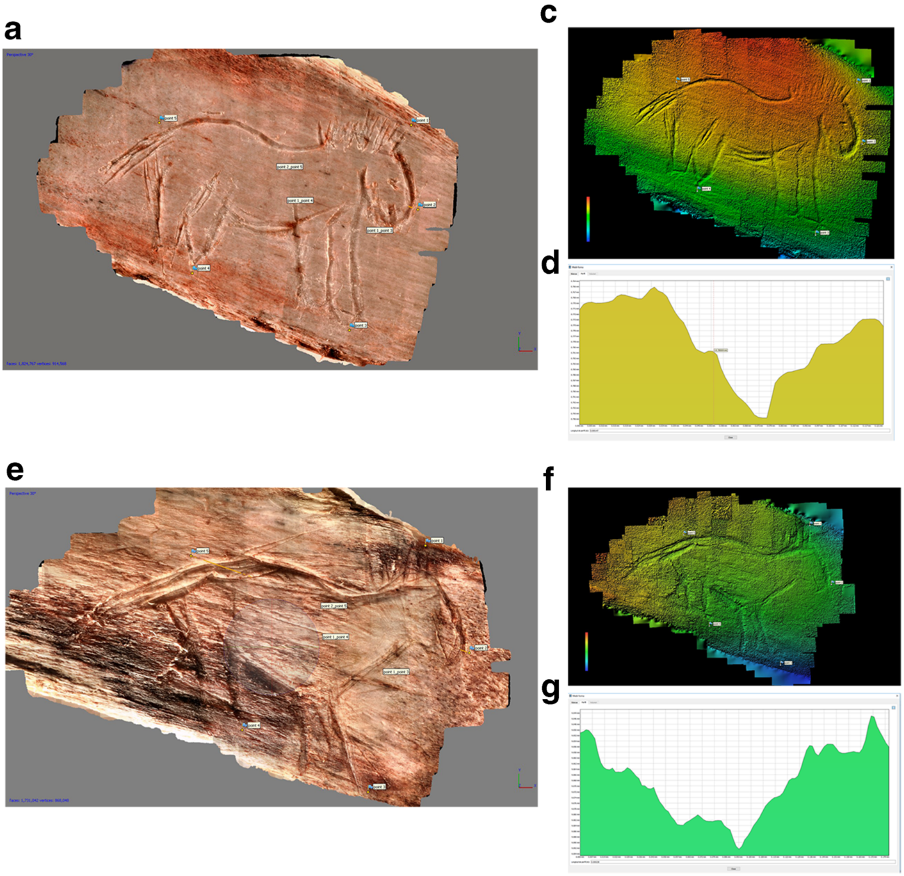

Fig. 9 Microphotogrammetry models obtained from micrographs at 30× magnification for two examples of engravings on ribs (**a**, **e**); digital elevation models (DEM) (**c**, **f**); and profiles of the incisions, used to calculate the depth of the groove (**d**, **g**)

intermediate, and expert (Table 4). Because of the needs of the analysis, all quantitative variables referring to changes in the dynamics of engraving per minute, the quality index, and the incision depth have been discretised into three modalities: low, medium, and high. This division is based on the existence of three clusters marked by inflexions in the accumulative diagram, taken from the data referring to the technical index (Fig. 10). The same inflexions have been taken for the other criteria between the 8th and 19th values.

In the case of the quality index, the correlation between the discretization and the preestablished categories 'novice,' 'intermediate,' and 'expert' shows that 18 novice engravers among the 23 (almost 80%) have a quality index of low and medium. Intermediate engravers have a medium and high quality index, and the expert engravers also have productions of high quality index. Similar correlations can be made with the other discretized values.

This demonstrates that the preestablished categories are valid, although there is a small group of novice engravers (5) who are in the eigenvalues of intermediate and expert categories.

Table 4 Codification of the criteria used in the statistical analysis

Code	Categories
Low	Quality index between − 8 and − 6
Med	Quality index between − 5 and − 4
Hig	Quality index between − 3 and 0
Mol	Burin movement/min low
Mom	Burin movement/min med
Moh	Burin movement/min high
Pcm	Change point contact/min med
Pcl	Change point contact/min low
Pch	Change point contact/min high
Hal	Change burin in hand/min low
Ham	Change burin in hand/min med
Hah	Change burin in hand/min high
Arl	Change position arm/min low
Arm	Change position arm/min med
Arh	Change position arm/min high
Bu1	Burin position in hand 1
Bu2	Burin position in hand 2
Bu3	Burin position in hand 3
Bu4	Burin position in hand 4
Po1	Burin point of contact 1
Po2	Burin point of contact 2
Po3	Burin point of contact 3
Po4	Burin point of contact 4
Po5	Burin point of contact 5
Po6	Burin point of contact 6
Me	Mesial grip point
Pro	Proximal grip point
Tir	Tilt to the right
Til	Tilt to the left
Tin	Negative rake angle
Tip	Positive rake angle
Deh	High incision depth
Dem	Medium incision depth
Del	Low incision depth
Exp	Expert
Int	Intermediate
Nov	Novice

The complete presence/absence disjunctive table (26 objects × 37 modalities) was transformed into a generalized contingency table or Burt's table, a symmetric table (37 × 37) which crosses 2-by-2 all the modalities in the complete disjunctive table. The

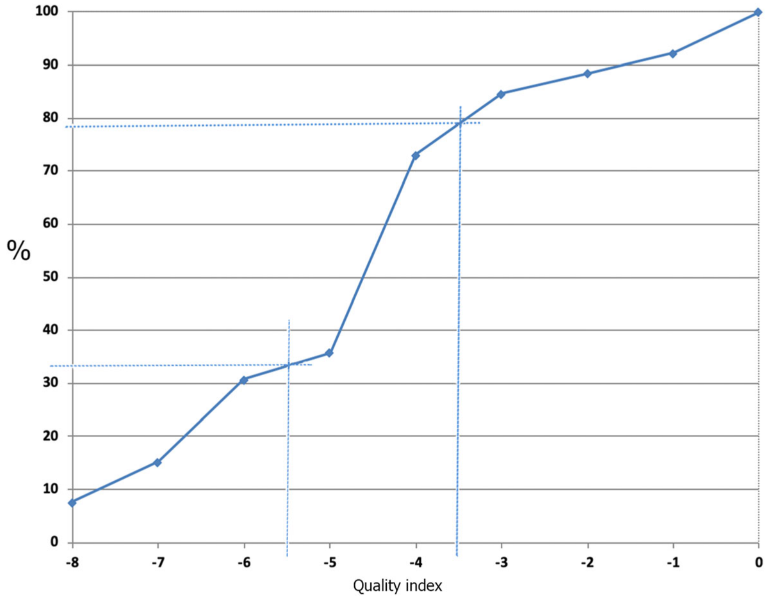

Fig. 10 Discretization of the quantitative data regarding the quality index. The values on the abscissa axis (*X*) correspond to the analysed criterion. The values on the ordinate axis (*Y*) are the cumulative percentage of engravers reaching this value in the analysed sample

crossing of line I with column J shows the number of times in which criterion I is associated with criterion J. The diagonal I × I shows the number of occurrences of criterion I. This type of table is particularly appropriate to reveal correlations between criteria although the information about the objects themselves (in this case the participants) is lost.

The FCA consists of treating the *n* properties of each object as point coordinates in a space of *n* dimensions. The method determines the inertia axes of this point cloud and later projects the points on the planes formed by the main inertia axes (Buisson *et al.* Chenorkian 1996, p. 330).

This method is complemented with ascending hierarchical classification (AHC) which is based on the principle of the successive clustering of elements in classes using a measurement of 'affinity' or proximity. The elements with similar profiles are grouped very quickly and then organized in classes, thus forming a branching ranked classification or dendrogram.

Results

The discretisation of the 'average quality index' of the 26 objects reveals that they are clustered in three groups, in accordance with the predominance of the indices (Fig. 10). One group is characterized by the predominance of very low indices (*Low*), formed by 8 objects. The intermediate level (*Med*), with indices between − 5 and − 4, is represented by eleven objects, and the highest level (*Hig*) is represented by seven objects, including the productions of 'expert' engravers (indices between − 3 and 0).

The quantitative variables describing the engraving dynamics and the depth can also be discretised into three groups (low, medium, and high), based on the same inflexions, as explained above.

To determine the extent that these criteria are associated with qualitative criteria, such as the orientation of the burin or the point of contact of the burin on the object, factorial correspondence analysis has been performed on a generalized contingency table with 37×37 criteria. The preestablished categories (*i.e.* the classification of the engravers as expert, intermediate, and novice) have been situated as supplementary elements (SE) so that they do not intervene in the distribution in the factorial plane. Additionally, the categories represented by a single engraver, such as the burin positions 5 to 11, have been eliminated to avoid distorting the analysis.

The result of the FCA reveals two groups differentiated on the two sides of the factorial axis 2 (Fig. 11). On the one side, one group is formed by the criteria *Exp* and *Hig* (*i.e.* the expert engravers together with the motifs with a high quality index of between −3 and 0) and the criterion *Deh* (high incision depth). The intermediate engravers (*Int*) and the criteria *Hal*, *Arl*, *Pcl*, and *Mol* (*i.e.* few changes in the burin position in the hand per minute; few changes in the wrist and arm position; few changes in the point of contact of the burin per minute; and few changes in burin movement per minute) are also associated with this group. Finally, the positive orientation of the rake angle (*Tip*) is also in this group, as well as the burin position in hand 4 (gripped between thumb, index finger, and middle finger).

On the other side, a second group is characterized to 95% by the criteria *Low* and *Med* (quality index between −8 and −4), and almost all the values are medium and high relating to the movements of hand, arm, burin in hand, and burin in relation with media: *Pcm*, *Pch*, *Ham*, *Arh*, *Mom*, and *Moh*. We find also the qualitative values *Tir* (burin tilted towards the right) and *Tin* (negative rake angle), along with *Me* (mesial grip point) associated with novice engravers (*Nov*), as well as *Bu1* burin between thumb and index finger supported on middle finger. The engraving dynamics appearing in this group are frequent changes in the burin position in the hand per minute, frequent changes in the wrist and arm position per minute, and some positions of the burin with negative rake angle. The values *Del* and *Dem* (depth of the incision medium and low) are also associated in a 95% of probability to this group.

We must mention the presence of the six positions of the burin point of contact in relation to media in this group. The more commonly employed by the engravers, including experts, is Po4, using the ventral arris of the tool. Thus, this criterion is in the centre of the factorial plane (24 among the 26 engravers use this position). Inexperienced engravers tend to use all parts of the tool, in order to make deeper grooves. This is the reason why all the positions of the burin appear linked in the red group.

Discussion

Just as has been demonstrated in the case of lithic reduction, engraving motifs on hard objects involves a technical learning process that is independent of innate skill in drawing. Experimentation with a large number of participants has gathered data about the production process in itself as relates the gestural dynamics of the engraver.

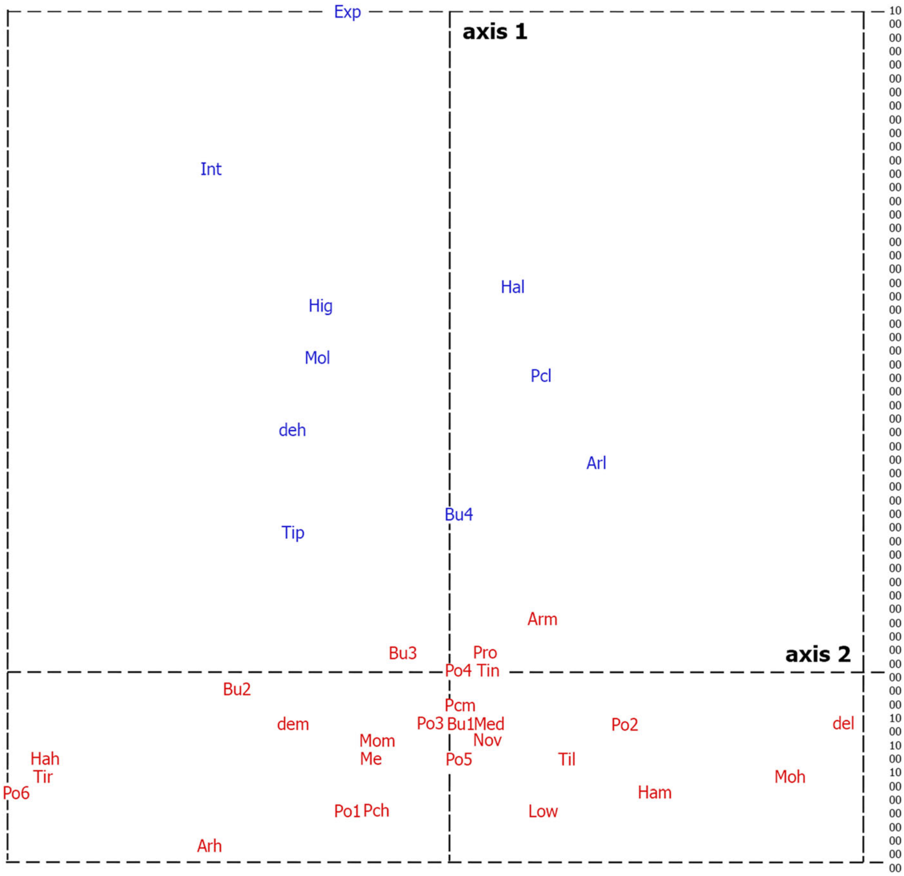

Fig. 11 FCA multivariate plot of the studied corpus of 37 × 37 criteria in the main factorial plane [1, 2]. The two coloured groups are generated by ascending hierarchical clustering. The preestablished criteria corresponding to the degree of expertise of the engravers, *Exp*, *Int*, and *Nov*, have been placed as supplementary elements (SE) and they do not intervene in the distribution in the factorial plane

The main problem we encountered was the difficulty in finding ‘effective’ modern expert engravers. Unlike the case of lithic reduction, the reproduction of Palaeolithic engravings does not enjoy a long tradition of archaeological research; this hinders obtaining a representative sample of engravers with a high level of expertise. Consequently, the analysis is conditioned by the low number of expert and intermediate engravers, and the results should be taken with caution from the statistical point of view.

Despite this, we can observe some interesting trends in actions differentiating groups of engravers.

Engraver Behaviour

As regards engraver behaviour, it has been observed that engravers with a high level of skill perform a smaller number of movements, in which the point of contact of the burin on the object is fundamental, as it remains stable throughout the duration of the task. In the same way, the burin does not change position in the hand. Similarly, the number of changes in arm and wrist position per minute is smaller—this means that expert engravers turn and rotate the wrist and arm less often. Good engravers also hold the burin between the thumb, index, and middle fingers, tilting the burin inwards (positive rake angle). This tool position allows them to balance the directional force and the downward force, which guarantees greater precision and pressure in the line of the incision, using the point with the greatest incidence of the tool (the ventral arris).

In contrast, inexpert engravers move the arm, wrist, and burin position in the hand much more often and frequently change the point of contact of the burin on the bone. Similarly, among these engravers, the burin is oriented with a negative rake angle, which results in greater difficulty in directing the force correctly, as the downward force is greater than the directional force. Added to this is the fact that inexpert engravers (20 out of 22) hold the burin incorrectly, as the tool is gripped between the index finger and the thumb, while supporting it on the middle finger, which results in a lesser effectiveness in the grip and the force exercised.

Engraving Produced

For expert engravers, the principal fact that can be stressed about their work is that they are able to obtain deeper lines with a much smaller number of mistakes, such as going outside the line or slips, and demonstrate fewer difficulties in deepening a single groove.

In contrast, in the case of inexpert engravers, multiple juxtaposed lines are visible, rather than a single deep groove, and there is great diversity seen in the profiles, along with numerous slips. These engravers find it difficult to deepen the grooves and, in an attempt to overcome the constraints imposed by the hardness of the bone, they increase their movements without following a plan of action that would enable them to complete the task successfully. They, therefore, experience difficulty with the motor control of their actions. The large number of movements is the cause of the mistakes seen in their engravings, which are visible both macroscopically and microscopically.

This tendency of novices to repeat certain actions is also observed in lithic reduction (Geribàs et al. 2010). Similarly, the excessive use of kinetic energy has been noted in experimentation involving knappers (Bril et al. 2010; Nonaka et al. 2010).

Conclusions

The present study has analysed the actions involved in the production of an engraving on a bone with a lithic implement (burin). As noted above, the results demonstrate that the greatest difficulty lies in the production of incisions that are deep enough to be visible. This problem also implies the need to repeat the actions in order to obtain a deep groove by carrying out multiple incisions. This repetition constitutes a second problem, as considerable precision is needed to go over the same line in successive incisions. Finally, a third difficulty pertains to the need to engrave curved lines as well as straight lines. This can result in considerable potential for errors, as the direction of the implement has to overcome the resistance of the osseous fibres.

This first novel approach to the gestural dynamics necessary to produce a graphical symbol by engraving on a hard substance has shown that, as observed in the case of lithic reduction, a series of technical skills are essential to be able to engrave a motif correctly, as described above. These skills refer to the position of the burin in the hand, as an incorrect position leads to the loss of part of the force that is exercised; the point of contact of the burin on the surface, as it is necessary to orient the burin in the same way in successive incisions to guarantee the homogeneity of the groove and the effectiveness of the action; and the inclination of the burin, as a negative angle makes it more difficult to control the direction of the movement, resulting in an imbalance between the forces that are exercised.

This evidence supports the hypothesis of technical learning by Palaeolithic artists; this hypothesis was based on the presence of motifs with errors attributed to the lack of motor control over the movements (Rivero 2016).

The results of experimentation show that, from the point of view of the analysis of the motifs, the same errors are present in the representations produced by modern inexpert engravers, and these mistakes are connected to the hardness of the bone surface and the lack of control over the position of the burin. Thus, inexpert artists, in order to achieve a deep groove, multiply the number of incisions, alter the contact point of the burin and place where the burin is gripped, and frequently turn and rotate the wrist. This large number of movements leads to a loss in pressure and force, as well as difficulties in maintaining direction, and this is visible in the resulting engravings. Likewise, the depth obtained is also significantly less with novice than with expert artists who are able to obtain the minimum quality of engraving required with a considerably smaller number of actions.

These results allow us to precisely define the elementary sequence of actions needed to engrave on bone with a lithic implement. They also corroborate the resemblance between the artistic productions of modern inexpert engravers and some evidence observed in Palaeolithic portable art (Rivero 2015). This supports the hypothesis of the existence of technical learning by artists in the Upper Palaeolithic, as proposed through the study of the archaeological record (Rivero 2018). Determining the existence of learning processes, identifying them in Palaeolithic sites, and characterizing the representations according to their level of expertise will undoubtedly enable a better understanding of how human societies functioned during the Upper Palaeolithic.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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