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Visualizing childhood in Upper Palaeolithic societies: Experimental and archaeological approach to artists' age estimation through cave art hand stencils

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ABSTRACT

This paper presents rock art as a collective action in which different strata of society took part, including children and subadults. Until recent decades archaeology of childhood has not been in the main focus of the archaeological research, much less the participation of those children in the artistic activity. The present study approaches the palaeodemography of artists in the decorated caves through the paleolithic rock art itself. The approximate age of these individuals has been calculated through the biometric analysis of hand stencils in the caves of Fuente del Salín, Castillo, La Garma, Maltravieso and Fuente del Trucho, using 3D photogrammetric models as reference. The results have been compared with a modern reference population in order to assign the Palaeolithic hands to certain age groups. It has been demonstrated the presence of hand stencil motifs belongs to infants, children and juveniles, revealing this stratum's importance in the artistic activity.

1. Introduction: archaeology of childhood in Palaeolithic societies

The Archaeology of childhood studies the role of children within past societies and their relationship with the community and material culture. The first scientific approach began in the 1970s with the research conducted by G. Lillehammer (1979, 1989, 2010, 2015). This discipline considers children as an object of study in themselves and analyses the relations they maintained within the group (Bahn, 1998; Kamp, 2001; Baxter, 2005, 2008; Konner, 2005, 2016; Montañés et al., 2013; Ember and Cunnar, 2015; Hilal, 2016; Sánchez-Romero, 2010; Nowell and White, 2010; Cordoş, 2019; Rebay-Salisbury and Pany-Kucera, 2020).

Historically, the first attempts to approach presence of children in Palaeolithic populations has been considered through the anthropological studies of osseous remains in the mortuary contexts of such sites as: Lagar Velho in Portugal (Zilhão and Trinkaus, 2002), Sungir in Russia (Trinkaus and Buzhilova, 2012; Trinkaus et al., 2014), Dolní Věstonice in Moravia (Oliva, 2001), Kostenki in Russia (Oliva, 2001), Krems in Austria (Einwögerer et al., 2006, 2008), Abri Pataud (Billy, 1975) and La Madeleine (Vanhaeren and DÉrrico, 2001) in the French Dordogne, and Grotte des Enfants in Italy (Henry-Gambier, 2001), as well as finds of remains of human infants (Wilczyński et al., 2016: Garralda et al., 2019). Along with it, ethnological studies have also had an important role to attune to the interconnections and overlap between the worlds of adults and children among hunter-gatherers and other "traditional" societies and the possible role of this children inside their communities (Ucko and Rosenfeld, 1967; David, 2002; Zeller, 1987; Hawkes et al., 1995; Owens and Hayden, 1997; Derevensky, 2000), not forgetting that caution must be used when drawing this kind of parallels.

Recent studies have gradually introduced the consideration of children as generators of the archaeological record. In the Palaeolithic case they have focused on the search for evidence of learning in lithic reduction (Pigeot, 1987; Hocsman, 2006); the interpretation of some objects as toys (Politis, 1998, Politis et al., 2005; Kamp, 2001; Shea, 2006; Crawford et al., 2018; Riede et al., 2017; Langley and Litster, 2018; Langley, 2018); and the transmission of knowledge of artistic activities, like engraving (Rivero, 2011) and parietal art (Van Gelder, 2015a, 2016; Cooney and Janik, 2018; May and Goldhahn, 2021; Fernández-Navarro and Garate Maidagan, 2021; Van Gelder and Nowell, 2021).

Other fields of study, such as ichnology (i.e. the study of fossilised evidence of human imprints), can provide reliable results in this

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approach to the childhood community in human populations. However, the main aim of the present study is to explore the role of children in Palaeolithic societies through the objective and precise analysis of stencilled hand paintings in Upper Palaeolithic decorated caves in Europe, using an experimental and biometric methodology.

It is necessary to point out the inaccuracy problematic that often accompanies the term "child" in all studies of this period of life of individuals, especially when extrapolating it to such a distant society. We must not forget that the concept of childhood we have today is an actualism and social construction and is conditioned by the actual culture (Lally and Ardren, 2008). It is a conception influenced by different factors: on one hand, biological and osteological development and, on the other, the social construction of the idea, which reflects the beliefs and needs of a society at a given moment. In addition, the terminology used in this field of study (subadult, juvenile, child, non-adult, infant …) is a dynamic concept and has varied according to author and time depending on the factors used to generate the classification. Therefore, trying to establish a clear division between childhood and adulthood in the Palaeolithic can be problematic. However, the existence of this stage of life is clear and present in all societies and a general and common pattern and characteristics can be observed (Kamp, 2001). All these ideas should therefore be considered when drawing up an approach to children's social and demographic groups.

2. Background: palaeodemographic approach to cave hand stencils

For the reconstruction to Upper Palaeolithic palaeodemography it is necessary to obtain primary and original images from which information can be extracted. Although they are not common, human ichnites are found in the archaeological record. The most abundant are footprints (i.e., imprints of the sole and toes) and hand and finger imprints (i.e., fingerprints on different kinds of surfaces and painted hands and palms).

The former, the marks of feet imprinted in clay floors, enable the identification of individuals that transited cave passages. The individuals can be characterised and the models of circulation through the cave can be reconstructed. The latter, the diverse types of marks related to hands and fingers, such as finger flutings, painted hands and fingerprints, have enabled an estimate of the age of the individuals who left them (Fernández-Navarro and Garate Maidagan, 2021). It has thus been suggested that children left some of the marks seen at several sites and caves (Obermaier, 1914; Clottes and Simonnet, 1972a, 1972b; Hahn and von Koenigswald, 1977; Bosinski, 1982; Harrington, 1999; Müller-Beck, 2001; Králík and Novotný, 2003; Bednarik, 2002; Van Gelder, 2012; Van Gelder and Sharpe, 2005, Van Gelder and Sharpe, 2009, Van Gelder, 2015b; Guthrie, 2005; Králík and Novotný, 2003; Adovasio et al., 2007; Králik and Nejman, 2017; Romano et al., 2019).

Stencilled and imprinted hands are some of the most useful archaeological evidences to be able to approach Upper Palaeolithic artists physicality and, therefore, their study from a palaeodemographic perspective is essential for understanding holistically past societies. Based on the size and shape of hand imprints in the archaeological record, different biometric methods have been proposed to estimate the age and sex (Groenen, 1988; Manhire, 1998; Ripoll et al., 1999a; Guthrie, 2005; Gunn, 2006; Bednarik, 2008; Snow, 2006, 2013; Pettitt et al., 2014; Mackie, 2015; Carden and Blanco, 2016; Rabazo-Rodriguez et al., 2017, Chazine et al., 2021).), height (Manhire, 1998) and laterality (Faurie and Raymond, 2004; Gunn, 2007; Cashmore et al., 2008; Uomini, 2009) of the corresponding individuals (Fig. 1).

For the estimation of the sex from hand stencils, a specific parameter, called the Manning Index, stands out, on which many of the previous paleodemographic studies have been based. This ratio was originally proposed already in the scientific literature of the 19th century (Ecker, 1875; Baker, 1888), however, it was generalised and adopted by Professor J.T. Manning. This parameter sustains that the relationship between index and ring fingers (2D:4D) is affected by exposure to

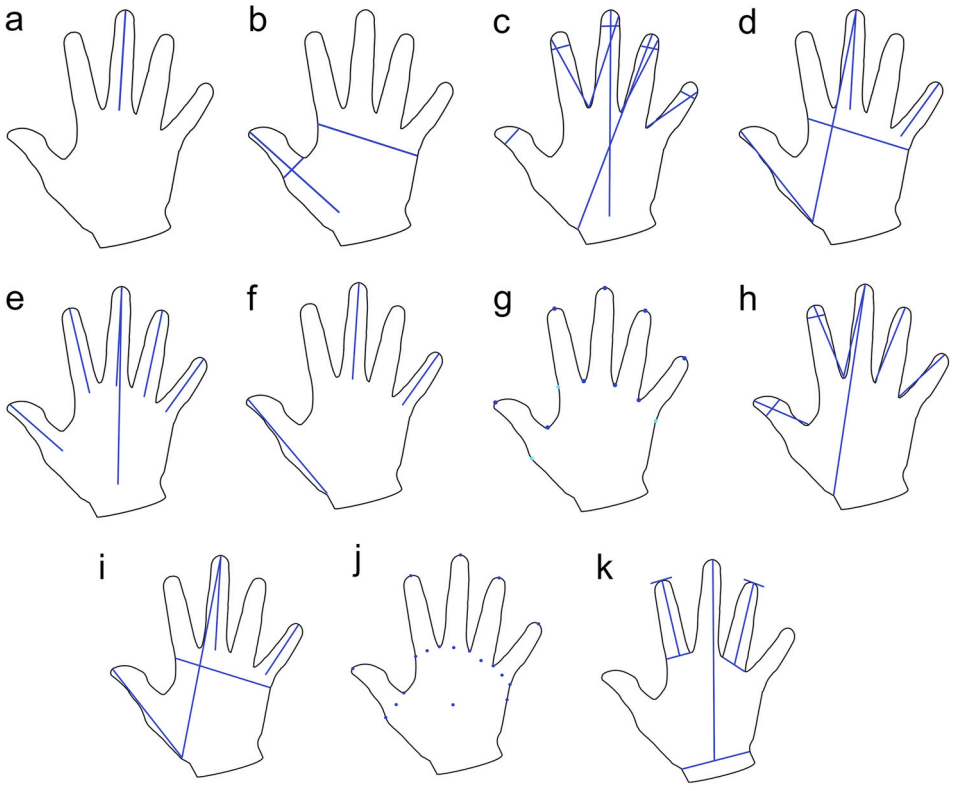

Fig. 1. Main biometric measurements developed by palaeodemography-related studies based on hand representations in the archaeological record. (A) Flood (1987). (B) Groenen (1988). (C) Guthrie (2005). (D) Gunn (2006). (E) Snow (2013). (F) David (2002). (G) Wang et al., 2010. (H) Mackie (2015). (I) Carden and Blanco (2016). (J) Nelson et al., 2017. (K) Rabazo-Rodriguez et al., 2017.

androgens, with the quotient between the lengths of these being slightly lower in men than in women. (Manning et al., 1998).

The methodology of many of these studies was conditioned by the tools of the time, and, in today's eyes, may seem imprecise. For example, the methodological basis of some of these researches were measurements taken on printed 2D photographs or even in situ in the caves. If we look at the chosen measurement system, we consider that, in some cases, very few metric parameters have been taken into account, basing all the result in a few single measures (Flood, 1987; Groenen, 1988). This data acquisition is consequently subject to a considerable degree of error, which influences the result. In recent years, new studies have emerged with more precise methodologies based on computer-aided techniques, such as software for the recognition and analysis of forms (Chazine and Noury, 2006; Wang et al., 2010).

The present research proposes an analytical system for the calculation of age from hand stencils that solves the above issues, based on a novel integrated experimental and archaeological biometric approach.

3. Materials: cave art and current reference population

The implementation of the new methodological proposal for the biometric characterisation of hand stencils has employed two different data sources that operate in conjunction. These are Palaeolithic hand paintings in caves in the Iberian Peninsula, which were selected for their state of conservation, and a modern population sample with which they can be compared.

3.1. Archaeological sample

Currently, 56 caves with human hand motifs are known in European Palaeolithic art. These contain a total of 769 hands, of which 90% are negative images or stencils, 9% are positive images or imprints and 1% are mixed representations. The caves with these motifs are concentrated in two main areas, northern Spain and southern France. To be precise, 30 of the caves are in France, 23 in Spain, 1 in Gibraltar and 2 in Italy.

The sample of motifs studied here are located in five Spanish caves (Fig. 2): El Castillo (Alcalde del Río, 1906; Alcalde del Río et al., 1911; Moure et al., 1996; Groenen, 2006), Maltravieso (Ripoll et al., 1999a; 1999b), Fuente del Salín (Bohigas et al., 1985; Moure et al., 1984; Valle and Serna, 2002), Fuente del Trucho (Ripoll et al., 2001; Utrilla et al., 2012, 2014) and La Garma (Arias et al., 1999, Arias and Ontañón, 2008, 2014; González-Sainz, 2003). These caves were chosen because of the large numbers of hand motifs in them, the availability of specific photogrammetric models and the state of conservation of the paintings. We have been lucky to be able to count on the raw 3D models which incredibly enriches the quality of the data acquisition thanks to the collaboration of H. Collado, director of "Handpas. Hand of the past" project. The models are also available on their website of the "Handpas. Hand from the Past" Project.

The hands in the archaeological sample have been classified in three categories depending on the percentage of measurements that can be taken and their state of conservation (measurement taken from total: >80%; 20–80%; <1–20%). It also has to be considered that some of the measures cannot be taken due to incomplete or missing fingers. Hands allowing measurements because of their defined edges have been selected, while faint or incomplete hands, or those invisible to the human eye, have been discarded (Table 1).

3.2. Modern population sample

With the aim of analysing the archaeological sample we have gathered data obtained from a present-day population, to compare the relevant biometric measurements defined in the present study. An experimental programme was conducted with different groups, divided by age and sex, to determine the parameters of the morphometric study of the archaeological sample. In this way, a total of 545 hands were scanned (Table 2). The current sample has been limited to Iberian population, to match as much as possible the geographical area of the archaeological sample. None of the participants had any pathologies affecting the limbs or amputations or deformities of the fingers and/or hands. Only the left hands were considered in the study, following the proportions of laterality of the hands imprinted on the caves.

To be able to carry out this demographic reconstruction we have categorize the individuals according to the classification stablished by B.

Fig. 2. Caves in the Iberian Peninsula studied here: Fuente del Salín, El Castillo, La Garma (Cantabria), Fuente del Trucho (Huesca), Maltravieso (Cáceres). Map drawn with QGIS 3.16.3. Base map from Bing Aerial.

Table 1
Hand stencils selected in each cave. Only negative hand stencils have been selected. Maximum values between the five fingers have been selected. SD, SE, max, min and mean values in Supplementary Table S2.

Site	Total neg. hand stencils (n)	Hand stencils with 3D model available	1–20% (n)	20–80% (n)	>80% (n)	Non-measurable hands	Percentage of measured hands (n/%)
Fuente Salín	21	19	0	3	8	8	11/21 52,38%
Fuente del Trucho	57	43	6	22	3	12	31/57 54,39%
Castillo	77	71	5	21	26	19	52/77.66,53%.
La Garma	36	31	2	11	8	10	21/36. 58,33%
Maltravieso	60	53	5	22	13	13	40/60. 66,66%
TOTAL	252	217	18	79	58	62	155/252 61,51%

Table 2
Current population hand scans. Classification by Bogin, 2000). SD, SE, max, min and mean values in Supplementary Table S3.

Stage	Duration	Scanned hands (n)	Sex (M/F)
Infancy	2–36 months	6	Female: 3 Male: 3
Childhood	3–7 years	76	Female: 37 Male: 39
Juvenile	7–10 years (Female) 7–12 (Male)	117	Female: 44 Male: 73
Adolescence	11–19 (Female) 13–19 (Male)	199	Female: 114 Male: 85
Adulthood	20–50 years aprox	119	Female: 63 Male: 56
Old Age	+50 years	28	Female: 14 Male: 14
TOTAL		**545**	Female: 275 Male: 270

Bogin (Bogin and Smith, 2000). This age ranges have been widely accepted in anthropology and biology studies and are, in our view, the most accurate ones, being aware, as it has been clarified before, of the problematic of the establishment of these stages.

4. Methodology: 3D imagery, experimentation and analytical statistics

As explained above, most previous studies in this field have been based on two-dimensional photographs or measurements of the motifs taken directly. These methods can lead to significant errors, mainly because of the transformation of the natural irregular surface of the cave wall into a flat representation that deforms the real measurements and results in a biometric distortion.

In contrast, our methodology approaches the sample by three-dimensional documentation which allow us to measure with high precision levels and no optical deformations. From that 3D models 2D orthoimages are created, which allows us to obtain a 2D image without conical deformations, typical of traditional 2D images, from which we can extract real orthogonal measurements. Moreover, this methodology can be applied and replicated for any kind of archaeological record, while it can also be completed and implemented with other types of analysis, such as geometric morphometry (Sanfilippo et al., 2013; Králík et al., 2014; Nelson et al., 2017).

4.1. Photogrammetric record of hand stencils

As it has been mentioned, the creation of the 3D models has been carried out within the framework of the project Handpas (Hand from the Past) with high quality base, which we have been able to count on for this study. A 3D model of high resolution has been generated for each of the representations of archaeological hands. This gives us a high level of precision when performing the measurement.

Additionally, the D-Stretch tool has been important to improve the visualisation of the more faded images and emphasise the colours. This is a freeware application developed by J. Harman in 2005, inspired by the technique of 'decorrelation stretching', which artificially and automatically enhances the colour of a photograph and produces an image with false colour (Quesada, 2008).

With the combination of both tools, a scaled 2D orthophoto has been obtained with a false colour texture, and the relevant measurements were taken using Autocad® software.

4.2. Current population hand scanning

The data for the modern sample was taken during practical workshops in Primary and Secondary Schools, College and cultural activities (Sup. 3). In total, 545 participants took part in the process, all of them from Spain. Hands of 545 individuals were scanned with an Epson Stylus SX125 contact image scanner to which was added a scale, thus acquiring real and proportional measurements. Each participant was asked for his/her biological sex and age for the subsequent classification. For underage individuals a written permit was asked by tutors or parents. No other personal data was asked or registered. Although both of the hands were scanned for each participants only the left ones were taken into account in the study.

This experiment has been approved by the Ethics Committee of Cantabria University following all the values and regulations asked and having the informed consent of all the participants and/or their legal guardians.

4.3. Experimental programme

The aim of the experimental programme was to explore the different parameters and key factors in the Palaeolithic hand paintings that might affect the results of the study. In this way, we are able to quantify the deformation between the sizes of the real hands and the stencils produced by spraying pigment on the rock wall.

Thus, 20 individuals' hands, whose measurements were known, were selected. Then a group of 10 blowed stencils of each one were made on natural rock surface, spraying the pigment from different angles, obtaining 200 different hand stencils. A scaled photogrammetric model was made of each of these stencilled hands and different measurements were taken, following the metric parameters of the study, to compare their morphometry with the real hands.

After this experiment, an average error was established from the values obtained for the deformations in each of the paintings, when they were compared with the original models of the hands (Fig. 3). This "average deformation index" was calculated for the length and width of the hand and length and width of the fingers. Finally, this correction was applied to the measurements of the archaeological motifs in order to

Fig. 3. Experimental programme and documentation. A) Photogrammetry process. B) Experimental hand stencil. C) Experimental hand stencil 3D model. D) Modern sample of scanned hands.

align the archaeological and modern samples.

4.4. Metrical analysis

The measurement system comprised a total of 12 measurements: length of the hand, width of the hand, and length and width of all the fingers. They were chosen after verifying in specific literature and research results that these were the most representative for the determination of age (Fig. 4). Before using them in the study, the efficacy of several parameters was tested by analysing the modern population and observing their degree of accuracy.

All the hands, both archaeological and modern ones, were measured with the same parameters. The indications of J.T. Manning et al., 1998) for action have been followed. The length of the finger is taken from the proximal fold of the palm of the hand at the base of the finger to the tip of the finger in the midline axis, excluding the nail and without compressing the fingertips. For the hand, we have connected the most external part of the middle finger in its central axis with the union point between the palm and the wrist on the thumb side.

AutoCAD® was chosen to measure the sample of modern hands, as it allowed each sample to be scaled with a physical scale introduced in the scanner, as well as because of the precision of its calculations. Together with it, Blender® software was the tool used to take measurements from the photogrammetric models of the archaeological sample.

The statistical study was performed with the freeware programmes JMP Pro 14® and PAST®. First, the modern sample was characterised, as it formed the reference framework into which the archaeological record would be inserted. In this way, this sample was studied by univariate and multivariate analysis and also by Principal Component Analysis (PCA). The main objective was to characterize the current

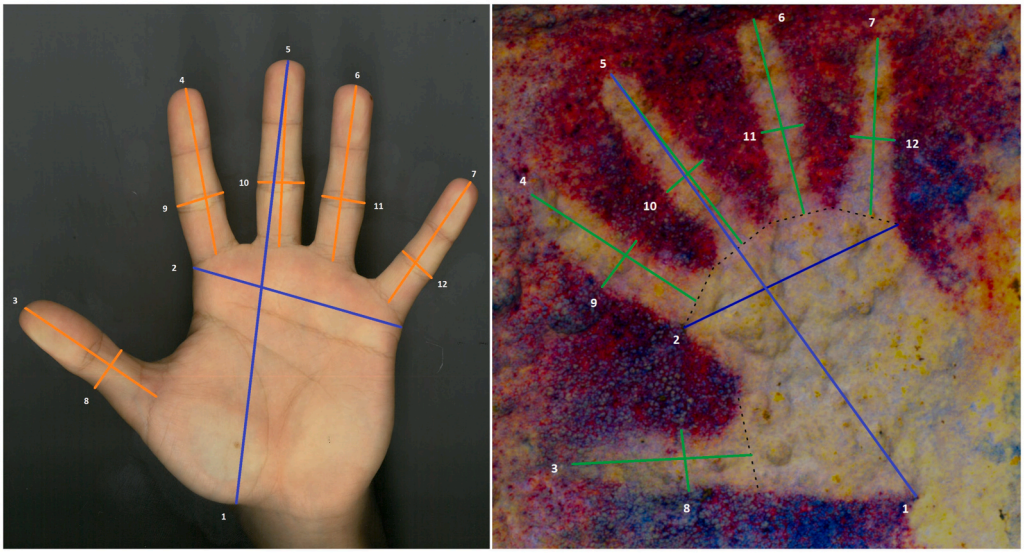

Fig. 4. Study measurement system and current sample measurement 1. Hand Length; 2. Hand Width; 3. Thumb Length; 4. Thumb Width; 5. Index finger Length; 6. Index finger Width; 7. Middle finger Length; 8. Miggle finger; 9. Ring finger Length; 10. Ring finger Width; 11. Little finger Length; 12. Little finger.

sample as detailly as possible to then included the archaeological sample to a well-known framework.

5. Results: age estimation from cave art hand stencils

The data obtained from the modern sample was compared with the archaeological data. First, the validity of the chosen biometric parameters was verified and the deformation index was calculated for the differences in size between the real scanned hands and their stencilled representations. Later, the archaeological data was analysed both in general and individually for each of the five archaeological cases used in the present study.

5.1. Accuracy of the biometric parameters in the modern population

A key step in the statistical study was to determine the efficacy of the parameters being used. This has tested the appropriateness of the potential parameters for the study: length and width of the hand and fingers in order to classify the individuals in their correct age stage.

First the featured intervals were calculated for each age group based on their hand and fingers length and width, with the values between 25 and 75 percentiles (Sup. 4). Then this modern sample was reclassified with the data obtained for the parameters and the real and suggested results were compared. These intervals will later be used to classify the archaeological data.

Traditional studies focusing on establishing the sex of an individual have focused attention on specific body parts that have been shown to confer a high degree of accuracy quantified at well over 80%. These include: the pelvis with a 60–90% reliability rate (Iscan and Steyn, 2012; Patriquin et al., 2005; Nagesh et al., 2007), the skull with up to 80–90% accuracy (Kalmey and Rathbun, 1996), teeth between 70 and 80% (Bañuls et al., 2014; Franklin et al., 2005; Schwartz and Dean, 2005; Kazzazi and Kranioti 2018) or different long bones Alunni-Perret et al., (2008); Curate et al., (2016). If we do not count these aforementioned "key bones" and thus using other parts of the body such as forearms (Holman and Bennett 1991), feet (Robling and Ubelaker 1997; Smith 1997; Atamtürk, 2010) and hands (Scheuer and Elkington, 1993, (Falsetti 1995) the overlap between the two sexes has been documented to be as high as 85% with a lower success rate, from 58% (Sierp and Henneberg 2015).

Through this analysis it was found that the indicators for the estimation of age provide results with a high level of reliability (Table 3). The morphology of the hand itself provides a percentage of accuracy between 77,29% and 82,05%, a very high percent of success considering the general rates in sex determination in the anthropological area. For the finger morphology the intervals are a bit lower but considerably elevated as well, between 78,39% and 82,05% for the length and 63,37% and 69,41% for the width. is It is concluded that hand morphometry is a reliable methodology for estimating the age of an individual with good precision.

Table 3
Accuracy of the study parameters.

Accuracy of the age parameters	
Hand length	82,05%
Hand width	77,29%
Finger length (average)	80,072%
- Thumb length	78,75%
- Index length	82,05%
- Middle Finger length	81,50%
- Ring Length	78,39%
- Little Finger length	79,67%
Finger width (average)	67,324%
- Thumb width	63,37%
- Index width	69,41%
- Middle Finger width	68,68%
- Ring Width	68,86%
- Little Finger width	66,30%

Once the main parameters of the study had been selected, it is essential to characterize the modern population sample as it will be the statistical comparison framework for the archaeological sample. Thus, it is crucial to know the behaviour and growth at each stage of human development and how it changes and evolves.

As results suggest both measures, length and width of the hand, seem to have an exponential growth as human gets older (Fig. 5). Hand development is faster and more pronounced in the early stages of the individual's life, infancy, childhood and juvenile period. This behaviour makes these age groups less overlapping with each other, making the subsequent classification in age stages more reliable. When reaching adolescence, hand growth appears to reach its maximum development, adopting the definitive adult morphology.

Qualifier intervals have been calculated for each age group, which will later be used to classify the archaeological hands into one group or another. These intervals have been calculated using the 25–75 percentiles (detailed values in Sup. 4). As can be seen, last three groups (adolescence, adulthood, old age) present a high overlapping that makes it almost impossible to distinguish between these stages, so it has been decided to join them into a single group at the time of age classification.

5.2. Calculation of the deformation of the hand stencils

When working with blown and printed hand stencils, it is visually apparent that there is a difference between the original hands and the resulted ones on the wall surface. The calculation of this error caused by deformation is essential in this type of analysis, in which archaeological motifs are compared with real hands, not having been considered in the past studies It is important to equalise the values and measurements between the two samples so that the results are statistically correct and thus ensure the accuracy of the method.

The error has been calculated separately for the length and width of the hand and the length and width of the fingers. The original scanned hands of each person that took part in the experimental programme were established as the point of reference. After a detailed archaeological experimentation, the experimental stencilled hands of each participant were measured and the average error was calculated for each of the measurements, taking the original hands as the references. The error in the length and width of the fingers has been calculated from the average of the results of the five fingers (Table 4). After, these values were applied to the archaeological handprints when carrying out the statistical analysis.

5.3. Estimation of age from the archaeological motifs

Once the error index was applied to the archaeological measurements the archaeological sample was plotted into the reference framework (current sample) In this way, the archaeological hands were characterised by comparison with the modern sample.

The general hand lengths and widths measured in the archaeological hand stencils are distributed throughout the whole population, from the start of the smallest band to the end (Fig. 6). Most points are concentrated in the area of the adult population, but the participation of children is abundant and homogeneous from four years of age and at least until nine years. This suggests that individuals of all ages took part in graphic activity.

Complementarily, when analysing the morphometry of the fingers themselves (Fig. 7) results do not differ significantly. It also highlights the wide distribution of the archaeological sample throughout all age groups. As in the previous case, the highest concentration seems to be in the area of the juvenile/adults.

The final classification of archaeological hand stencils of the age has been carried out following the characterization intervals previously obtained. Thus, each measure ascribed an individual to a specific age group. For the definitive adscription to a group, the mode, that is, the

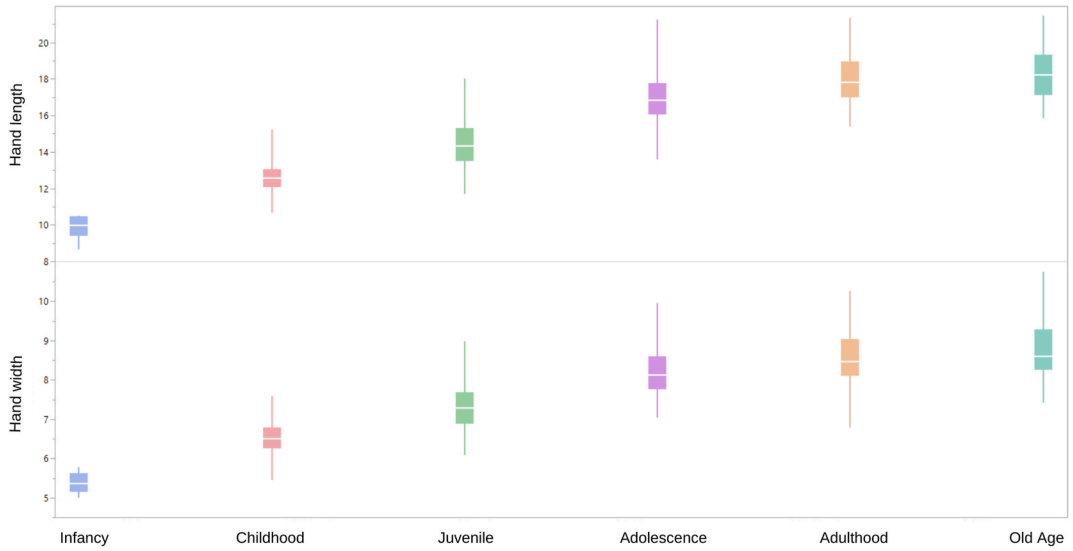

Fig. 5. Hand length and width behaviour on general human growth. Modern sample.

Table 4
Average error of deformation between the scanned hands and the hand stencils.

Average deformation error			
Hand length:	Hand width:	Finger length:	Finger width:
−0,994684815	−0,21118796	−0,24683693	−0,21640359

most repeated parameter, was considered. It should be noted that in most cases the ascription was clear since all the parameters were homogeneous towards the same group.

As few parameters have been included, it has been decided to present estimated percentage intervals for each age group and not a fixed rate or average (Table 5). In this way, we obtain a quite similar behaviour in accordance with what it was proposed. Infancy tends to be the less representative group with a maximum presence of 9,52%, followed by childhood with maximum value reach 27,27%. After that, these ages tend to homogenize.

Although all the caves follow a similar pattern, slightly differences can be observed. The adulthood group, which includes individuals up to 10/12 years is the most numerous one in all cases, being almost the exclusive one in Castillo cave (57,59–82,69%). In contrast, Fuente del Salín is the one which presents greater presence of infants and children with a maximum of 9,09% and 27,27%. In the three remaining caves the participation appears to be more homogeneous. In general, the presence of individuals of every age group is a continuous in every case with a higher participation of juvenile, adolescents and adults in all cases.

6. Discussion: children and symbolic activities in Upper Palaeolithic societies

The present study is viewed as an initial and basic approach to a more complete palaeodemographic research programme that addresses a wider range of the archaeological record and other anatomical aspects complementary to age, such as the sex or pathologies. It is necessary to follow that order, as sexual dimorphism of the hand and its size-shape relation is strongly marked by ontogeny, i.e. by the evolution of the individual over time.

Recent years have seen a noticeable increase in studies on childhood in the Upper Palaeolithic, the role of children in prehistoric societies and the archaeological evidence deriving from their activity. Much of this evidence is connected with ritual or symbolic activities and includes footprints (Harrington, 1999; Guthrie 2005; Clottes and Simonnet,

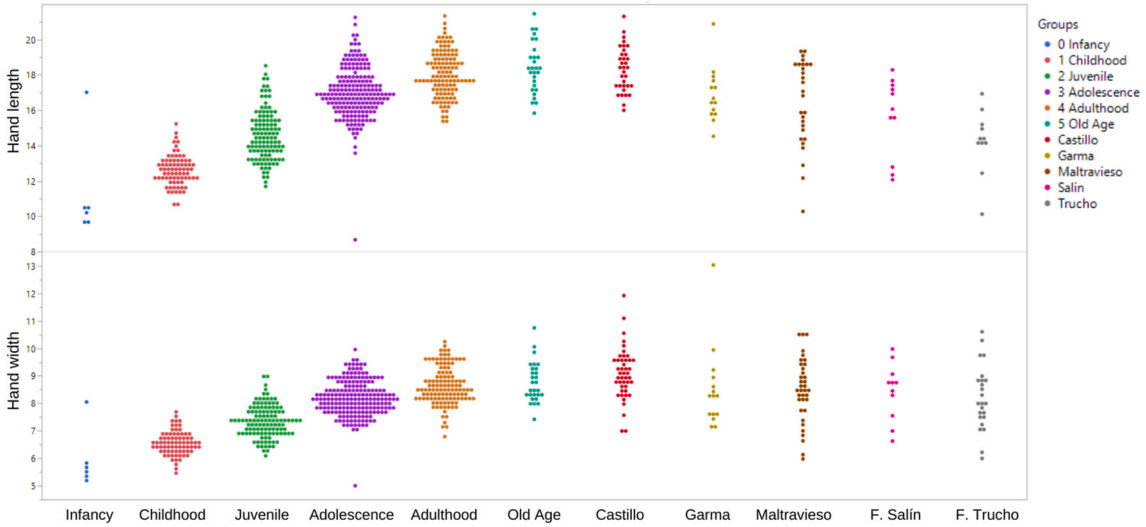

Fig. 6. Hand length and width. Analysis of the current sample and archaeological motifs.

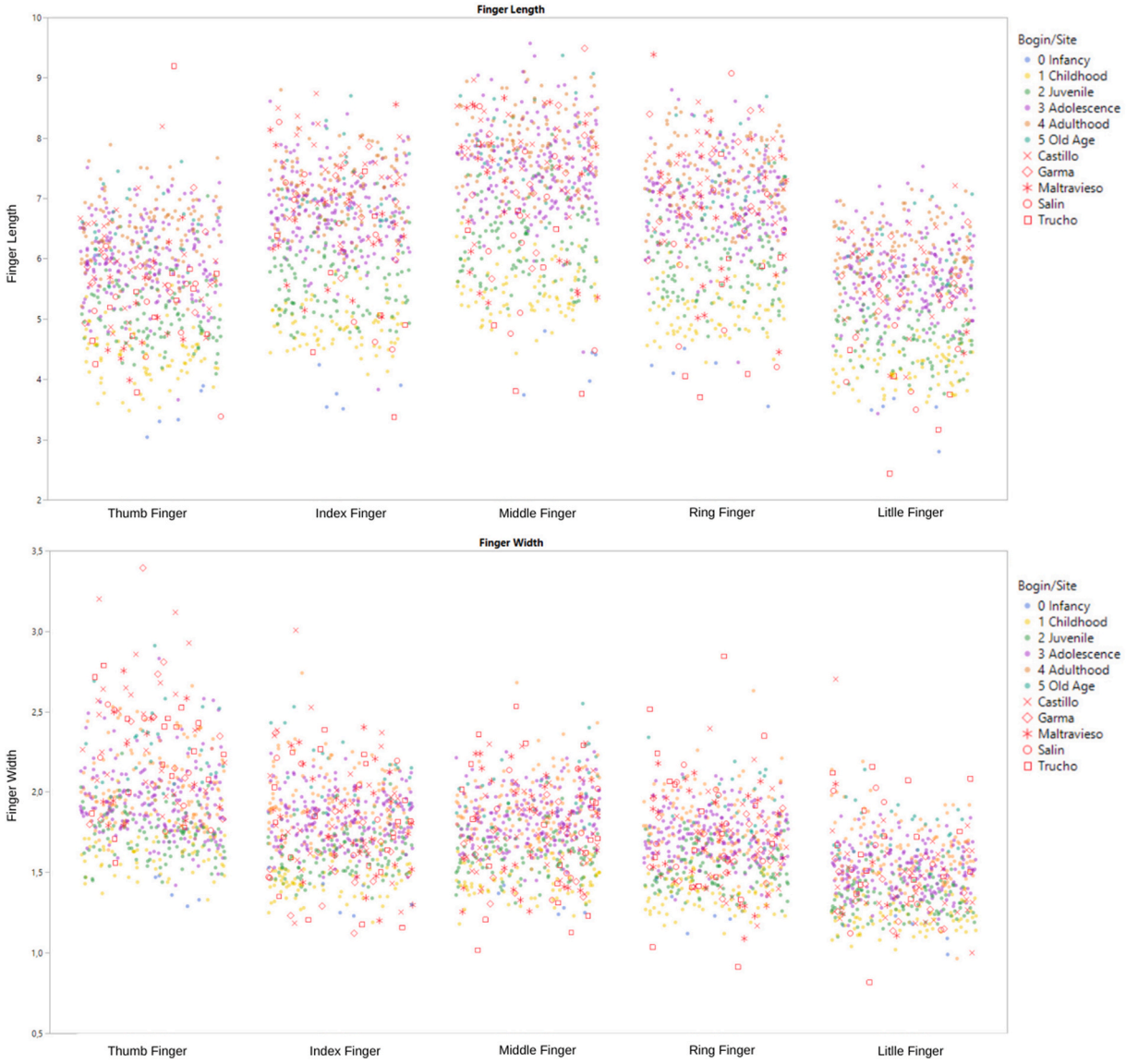

Fig. 7. Finger length and width. Analysis of the current sample and archaeological motifs.

Table 5
Results based on length and width of the hands and fingers. It should be borne in mind that not all measures could be carried out in all hand stencils. Detailed data in Sup. 5.

Age Stage/Site	F. Salín	F. Trucho	Maltravieso	Garma	Castillo
Infancy	Up to 9,09%	Up to 3,23%	2,5-5%	Up to 9,52%	Up to 1,92%
Childhood	9,09–27,27%	3,23–6,45%	5-7,5%	Up to 4,76%	1,92–5,77%
Juvenile	9,09%-36,36%	2,25–12,90%	10–20%	9,52–33,33%	3,85–11,54%
Adolescence/Adulthood/Old Age	36,36–72,73%	6,45–48,39%	32,5–70%	42,86–57,14%	57,59–82,69%

1972a, 1972b; Van Gelder, 2015a; Romano et al., 2019), finger marks (Van Gelder, 2012, 2015b; Van Gelder and Sharpe, 2005, 2009), fingerprints (Obermaier, 1914; Hahn and von Koenigswald, 1977; Bosinski 1982; Müller-Beck, 2001; Králík and Novotný, 2003, 2005; Adovasio et al., 2007; Králik and Nejman, 2017), and possible toys (Politis, 1998, 2005; Kamp, 2001; Shea, 2006; Crawford et al., 2018; Riede et al., 2017; Langley and Litster, 2018; Langley, 2018). The results of these studies as a whole seem to increasingly show that children took part in the social and cultural activities of Upper Palaeolithic groups.

This study contributes new data point in the same direction, as it indicates a significant participation of children in the graphic activity related to hand stencil paintings in caves. This also means that children may have also taken part in graphic production more generally, and this has already been suggested by other evidence, such as children's fingerprints found on portable art objects and the marks of fingers studied in the caves of Rouffignac (France) (Van Gelder, 2012; Van Gelder and Sharpe, 2009), Chimeneas (Spain) (Saura, 2017) and Gargas (France) (Nowell and Van Gelder, 2020). All this is indicative of the assiduous participation of children in the creation and development of rock art.

In this way, graphic activity appears to have been a field that was open to the whole group, in which both children and adults played a role in the production of motifs. It would not have been an activity closely

linked to men and subsistence, as has traditionally been professed, without considering that women and children might have been involved. Similarly, the participation of such young members of society, even babies, suggests that this activity was connected with an aim of the cohesion and reaffirmation of the group, through the art (Králik and Nejman, 2017).

It is important to mention that when conducting bioarchaeological and anthropological studies of prehistory, one must be aware of the possible differences between prehistoric and modern study populations, especially if there is a comparison of any kind between the two. This premise can influence many of the fields of study covered by archaeology, such as accessibility, movement, gestures, muscle structure or mass …

However, this potential comparison is based on the premise that the Palaeolithic record can be compared with a modern sample, bearing in mind the evidence provided by anthropological (Holliday, 1997; Brewster et al., 2014; Mieklejohn and Babb, 2011) and genetic studies (Caramelli et al., 2008; Fu et al., 2013). Alongside these similarities, the Homo hand is an anatomical structure that has experienced slight modification (i.e., finger and thumbs lengths) since the Last Common Ancestor with Pan, probably because of refined manipulation (Napier, 1962). Current research suggests little change in the hand-length proportion during human evolution (Almécija et al., 2015), which enables comparative approaches such as the one conducted within our experiment.

Finally, it is worth mentioning the "Ancient fingertip paradox" (Králík and Novotný, 2003). This paradox is based on the idea that these traces give us a selective and distorted vision of the population of origin, since they only allow us to study those individuals who came into contact with the object in question, not necessarily the creators of the artefact. Nevertheless, the fact that the various studies carried out on many of the graphic and artistic expressions mentioned suggest child authorship is quite enlightening. In the case of handprints there is a clear difference since they are not residual images, but images made intentionally. In this article we do not refer only to the creator of the Paleolithic hand images but to those who took part in the graphic activity itself, since the individual could have made the negative of his own hand or could have blown someone else's, but always participating in the activity.

7. Conclusion

The present research has reviewed previous methodologies related to palaeodemographic studies of painted hand motifs. In that framework, we have developed a method allowing a precise definition of the size and shape of the hand stencils. The statistical analysis has enabled visual and very clear results of the hand ensembles, resulting in a more complete interpretation than the individualised ascription made by other researchers in the past.

This new methodological systematisation was applied first to a modern population to corroborate the validity of the parameters used, and then to a sample of prehistoric hand stencils in five decorated caves. A correction index was applied to homogenize the sample and correct the error between the painted representations and the real hands. This study has determined that the proportion of infants, children and juveniles hands is significantly high, which attests the clear participation of these groups in the symbolic activities of Upper Palaeolithic groups in south-west Europe.

Declaration of competing interest

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

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Appendix A. Supplementary data

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