SEXUAL DIMORPHISM IN EUROPEAN UPPER PALEOLITHIC CAVE ART

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Preliminary research on hand stencils found in the Upper Paleolithic cave sites of France and Spain showed that sexual dimorphism in human hands is expressed strongly enough to allow empirical determination of the sexes of the individuals who made some of them. Further research increased the sample of measurable cases from 6 to 32, a large enough sample to show that persons who made hand stencils in the caves were predominantly females. This finding rebuts the traditional assumption that human hand stencils in European parietal art were made by male artists, either adults or subadults. Findings further suggest that the sexual dimorphism of hands was more pronounced during the Upper Paleolithic than it is in modern Europeans. Attempts to apply the same algorithms to a sample of North American Indian handprints confirms the view that different populations require separate analyses.

La investigación preliminar sobre los estarcidos de mano que se encuentran en los sitios rupestres del Paleolítico Superior de Francia y España demostró que el dimorfismo sexual en las manos de los hombres y las mujeres se expresa con fuerza suficiente como para permitir la determinación empírica de los sexos de los individuos que hicieron algunos de ellos. La investigación adicional incrementó la muestra apreciable de casos a partir de seis a 32, una muestra suficientemente grande como para mostrar que las personas que hicieron los estarcidos a mano en las cuevas eran en su mayoría mujeres. Este hallazgo refuta la suposición tradicional de que las plantillas de la mano humana en el arte parietal Europeo fueron hechas por artistas masculinos, adultos o jóvenes. Los hallazgos sugieren además que el dimorfismo sexual de las manos fue más fuerte durante del Paleolítico Superior que en los Europeos modernos. Los intentos de aplicar los mismos algoritmos a una muestra de las manos de Indios Norte Americanos confirma la opinión que las diferentes poblaciones requieren analiza por separado.

Human hands are sexually dimorphic. Male hands tend to be larger than female hands, but there are also consistent differences in the ratios of certain finger lengths. This is of archaeological interest because human handprints and hand stencils occur in parietal art at sites scattered nearly worldwide. While parietal art is widespread, what we think we know about it is often conditioned by our own biases and the easy but often silent assumptions that derive from them (Gifford-Gonzalez 1993:37). In this sense, parietal art is a special case of the implicit biases that have colored archaeological interpretation for decades (Wright 1996).

Most relevant to this article are the traditional assumptions that the Upper Paleolithic parietal art of southwestern Europe was related to hunting and produced by adult or subadult males. As comfortable as these assumptions may have been to modern readers, they are nevertheless untested assumptions. They have long been untested inferences that have not been established through rigorous hypothesis testing.

There is much current interest in getting past facile and potentially fallacious inferences in archaeological research. Solometo and Moss (2013) have documented the effects of biased inference in the history of illustration in National Geographic. They and their sources consistently use the term "gender" to refer to biological sexes, a practice that has become commonplace in archaeological literature in recent decades. While "gender" was before the 1950s a linguistic term that could imply more than two noun classes, and while "gender" was adopted by social sciences in part to allow for the definition of multiple genders, current

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archaeological literature generally uses the term as a simple dichotomy: women and men. Thus in current usage, gender categories typically correspond to the categories used by biological anthropologists to discuss sexual dimorphism. Biological sex and the terms "male" and "female" are used here for clarity.

Our research has shown that at least one common assumption about Upper Paleolithic parietal art can be disproven, namely the assumption that it was produced mainly, if not exclusively, by males. It is possible to infer the sexes of the individuals who made well-preserved examples of hand stencils in parietal art if relevant hand-scan data from appropriate reference populations are available. However, an important constraint is that human populations vary in this regard, and procedures developed from a reference population in one region of the world do not necessarily produce valid results for parietal art in another region of the world.

Population Differences

John Manning has explored the medical implications of human hand sexual dimorphism in populations studied around Liverpool and elsewhere in the United Kingdom (Manning et al. 1998; Manning et al. 2000). This work led to his publication of a more general work on digit ratios in human populations (Manning 2002). Manning's work in clinical medicine allowed him to gather relevant data from several populations, subsets of larger populations of European, South Asian, African, and other origins. Those data demonstrated that there were population differences sufficient to invalidate any attempt to develop a general set of algorithms to describe sexual dimorphism in human hands. Research by Manning and others has shown that each population has to be treated separately (Manning 2002:19–20; Napier 1993:25; Ramesh and Murty 1977; Semino et al. 2000). While Manning's efforts to extend the significance of digit ratio differences between males and females to address things such as specific disease susceptibility and sexual orientation are open to criticism, his basic finding has not been disproven. Human hands are sexually dimorphic, and one can use relevant data to argue from the general to the specific in assessing the probable sex of a handprint or hand stencil.

Although other measures are also useful, Manning focused on the ratio of index to ring finger lengths (D2/D4). In a Liverpool sample, the ratio was 1.00 for females (the fingers being of equal length on average), but .98 for males (whose ring fingers on average tend to be relatively longer than their index fingers). Manning did not focus on the little finger (D5), which on average is relatively short in females. Notice that in Figure 1 the male D5 extends above the last crease of D4, whereas in the female case it does not. This is very common.

The findings of the research reported here are significant for archaeology because they provide us with a means to infer the sex of handprints or hand stencils in parietal art. While infallible accuracy of individual identifications cannot be anticipated or claimed, sufficiently large samples offer enough overall accuracy to allow archaeologists to draw general conclusions about the sexes and ages of those individuals responsible for at least some kinds of parietal art.

Archaeological Cases

Human handprints (positive images) and human hand stencils (negative images) occur in parietal art on every inhabited continent. Incidence varies; there are regions where they are frequent and regions where they appear to be absent. Jean-Michel Chazine and his collaborators (Chazine and Noury 2006) have described hand stencils concentrated in Borneo. La Cueva de las Manos in Argentina, a World Heritage site, holds another well-known concentration of stencils. Many other relevant sites or clusters of sites occur in Africa, Australia, and elsewhere, but they tend to be few and individually indistinct compared to the better-known cases.

The largest and best-known regional set of cases is found associated with the Upper Paleolithic cave art that is concentrated in southern France and northern Spain. These sites generally fall into the 40,000–12,500 B.P. range. Many images of the hand stencils found in the caves of southwestern Europe have been published. Unfortunately the published images are almost never provided with scales. While much of the observed sexual dimorphism is found in digit ratios and is consequently independent of scale, absolute size is also important. Unfortunately, this cannot be determined from most published images. Despite this deficiency in

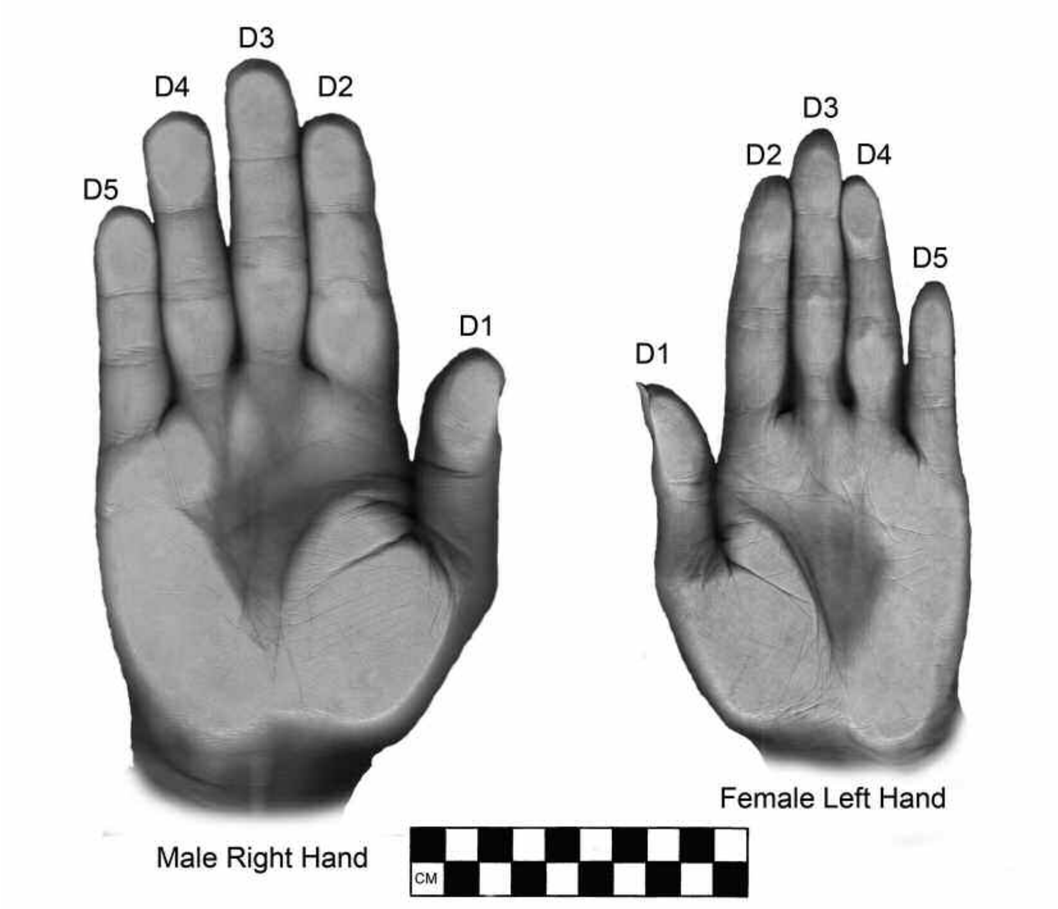

Figure 1. Male and female hands, showing dimorphism discussed in the text.

the published sources, the cluster of Upper Paleolithic cave sites in southwestern Europe are a good choice for the archaeological study of human hand sexual dimorphism. Not only are the sites known and easy to access, it is relatively easy to obtain a reference database of selected hand measures from a large population of living individuals having European ancestry.

There is some risk that evolutionary change over the last three dozen millennia has rendered the modern European population no longer sufficiently representative of the Upper Paleolithic population for our purposes. Indeed, a finding reported below indicates that there have been some significant stature changes over time. However, genetic research shows that over 95 percent of all modern European Y-chromosomes belong to a set of ten lineages that have been present there since the Upper Paleolithic (Semino et al. 2000). Thus, apart from some Neolithic inputs, Roma, Hungarians, and a few other more recent arrivals, the European gene pool until very recently has been largely of Upper Paleolithic origin. A reference population of modern European hands is appropriate for the study of European Upper Paleolithic hand stencils.

Popular publications on Upper Paleolithic cave art have typically assumed that it was largely, if not entirely, the work of adult males, and to some, of shamans. In this they have tended to follow the lead of older scholarly archaeological publications (Breuil and Lantier 1980; Canby 1961; Gifford-Gonzalez 1993; Prideaux 1973). However, as Guthrie (2005:127) has pointed out, various professional archaeologists have remarked on the small sizes of many hand stencils. Sollas (1914) tried to explain them away as the products of a race of Aurignacian pygmies. Sahly (1969) thought that they were probably made by adolescents, presumably males. Others have made similar observations, but they do not always offer possible explanations (Groenen 1987; Pradel 1975). A reading of Manning's book and a glance at the image of one of six hand stencils around the Spotted Horses mural at Pech-Merle are sufficient to prompt closer investigation (Leroi-Gourhan 1967; Manning 2002). Three of the six stencils are clear, and all three appear to have feminine characteristics.

R. Dale Guthrie (2005) made a serious effort to move beyond the basic observation that many Upper Paleolithic hand stencils appear to have been made by people other than adult males. His book was published in 2005, just after the preliminary report on the project discussed here had gone to press (Snow 2006). Circumstances also led Guthrie to publish his book before he could profit from Manning's (2002) book, in which the most useful dimensions for sexing hands are identified.

Guthrie (2005:461–470) undertook an investigation of hand dimensions in a large reference sample drawn from the Euro-American population of Fairbanks, Alaska, trying many combinations in a long and complex statistical analysis. Unfortunately, he did not choose ring finger (D4) length as one of his measures, and the protocol he (Guthrie 2005:121) used to measure index finger (D2) length was not equivalent to that used by Manning (Nelson et al. 2006). As a result, while one of Guthrie's principal conclusions has been supported by our research, another has been at least partially disconfirmed. Specifically, our research indicates that Guthrie is correct in arguing that Upper Paleolithic adult males were a small minority among those who made hand stencils, probably around 10 percent. However, his conclusion that most of those making hand stencils were subadult males has not been confirmed using the more robust approach described below. Subadult males probably account for only about 15 percent of the hand stencils studied thus far.

Developing Predictive Algorithms

The research of Manning and others has shown that digit ratios differ across human populations. Consequently, to obtain reliable results in the study of any particular set of archaeological handprints or stencils, one must have basic data from a living population that is derived as much as possible from the population responsible for the archaeological cases of interest. Suitable raw data on living populations have not been previously published, so we sampled an adult population of The Pennsylvania State University to acquire data needed to develop algorithms that could then be applied to the analysis of archaeological cases. Volunteers, mostly students, randomly self-selected, each provided two scans of each hand—one with the fingers splayed and the other with them closed and parallel. Each individual indicated their ethnicity in response to an open-ended question. Those that indicated other than European ancestry were set aside.

It might be argued that the Basques are a surviving enclave of a European population that predated the arrival of Indo-European languages, and that their hands are more likely to resemble Upper Paleolithic hands, thus making the Basques the most appropriate reference population. However, Basque is a surviving language, and Indo-European languages appear to have spread across Europe without much genetic replacement (Mallory 1989, 1992). Thus, despite arguments to the contrary by Renfrew (1987), there is currently no compelling reason to regard the Basques as more representative than most other modern Europeans for the purposes of this study.

In the initial sample, scans of both splayed and closed hands were measured and compared. No significant differences were observed. Digit and hand lengths were taken from a subsample of scans by up to three different observers. One observer took measurements to the nearest millimeter from the same subsample multiple times. While there was some minor variation observed in the results, it was consistently less than the degree of dimorphism observed in the sample of scans for which the sex of the individual was known. As a result of these trials, we had confidence in the measurement protocol as applied to modern hand scans.

Figure 2 shows how key measurements were taken on hand scans such as the scan of the left hand shown on the left. Hand length was taken from the midpoint of the crease at the base of the palm to the tip of D3. The lengths of digits D2-D5 were taken from the midpoints of the creases at the bases of the fingers to their tips.

Additional steps were required to modify the measurement protocol for extracting key measurements from images of hand stencils, such as

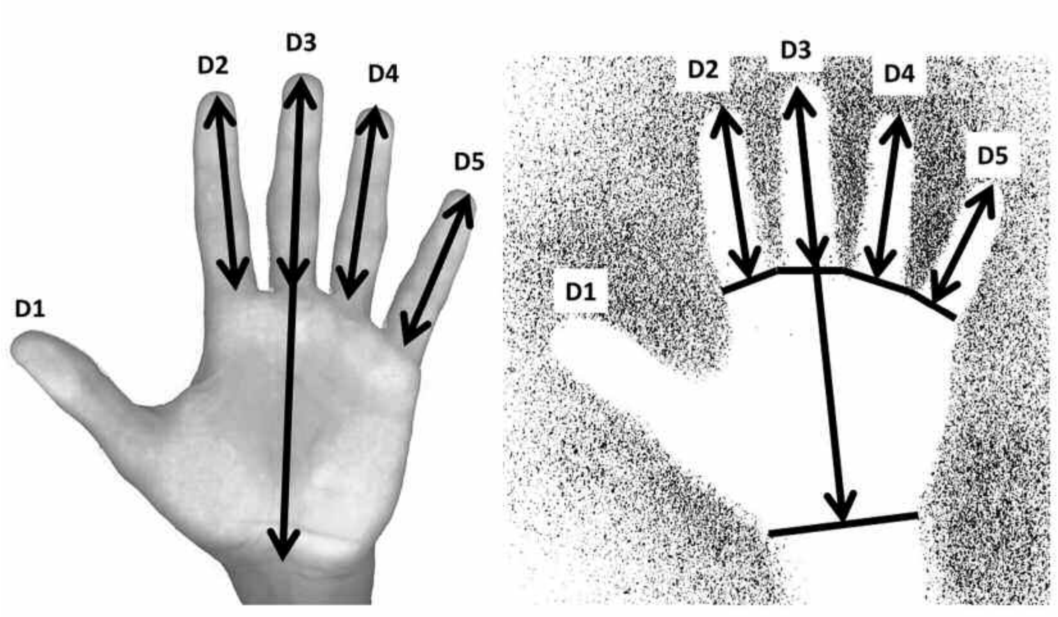

Figure 2. Measurement protocols for hand scans (left) and hand stencils (right).

that of a modern right hand shown on the right in Figure 2. The creases used as markers on scans are not visible on stencils. For stencils, a proxy for the crease at the base of the palm was drawn from the bottoms of the marginal concavities apparent on both sides of a stencil where the palm joins the wrist. Similar proxies for digit creases were created by drawing lines between the bottoms of the slots separating digits and the slight marginal concavities that mark the points where D2 and D5 articulate with the palm.

The initial sample produced an average D2/D4 ratio of .95 for males and .97 for females from a population of 113 female hands and 108 male hands. The null hypothesis is that there should be no such difference. On average, measurements from our living sample population could be described as slightly more masculine overall than was the case for Manning's Liverpool sample, but our findings were generally consistent with his.

Like Manning, we have also found that the characteristic differences in digit ratios are present on the hands of infant girls and boys, a much smaller sample. These are not characteristics that appear in adolescence but rather develop *in utero* and are present at birth (Manning et al. 1998). Thus sexual dimorphism should be apparent even in the small number of very small hand stencils found in a few Upper Paleolithic caves. While these were not incorporated into the present study, we should expect that the sexes of even these cases could be inferred if the stencils prove to be sufficiently complete and well preserved.

We used the predictive discriminant analysis function of the Statistical Package for the Social Sciences, deriving predictive equations from the data set provided by living subjects using Fisher's linear discriminant functions. Thomas (1978) used the same approach to address an analogous problem. We used an initial sample of 222 hand scans from 111 individuals of European descent, 57 females and 54 males. The results were later verified through replication using a separate sample of scans drawn from another 50 females and 50 males of European descent.

Over 20 runs using ratios in various combinations were conducted experimentally on the data, with varying results. Measures that were additional to those shown in Figure 2 were examined and then later discarded when they failed to help distinguish female and male hands. The single most successful approach proved to be one that used five measures, the lengths of digits D2, D3, D4, and D5 and overall hand length. However, division of the analysis into two steps or stages produced the best results. Step 1 involves using all five measures. But because absolute size dominates the predictive discriminant functions, this step serves mainly to distinguish between adult males and all others. The equations that follow can be used to analyze any unknown case; the higher of the two products indicates the more probable sex of the individual. But conclusions drawn from the Step 1 analysis must include the caveat that adolescent males are likely to be identified as females because of the dominance of absolute hand size in the analysis. Nevertheless, Step 1 analysis yielded a 79 percent success rate on individuals whose sex was known in the sample of 200 hands measured in the separate verification procedure.

$$\text{Male} = 2.176 \text{ Length} - 1.062 \text{ D2} - 2.192 \text{ D3} + 2{,}632 \text{ D4} + .364 \text{ D5} - 195.626$$

$$\text{Female} = 1.934 \text{ Length} - .806 \text{ D2} - 1.853 \text{ D3} + 2.426 \text{ D4} + .13 \text{ D5} - 166.24$$

Step 2 of the analysis substitutes ratios for absolute measures. This second predictive discriminant analysis examined both the ratio of the index finger to the ring finger (D2/D4) and the index finger to the little finger (D2/D5). Simple inspection suggests that both ratios should be high for females. Discriminant analysis produced the following equations:

$$\text{Male} = (1071.558 \text{ D2/D4}) + (1042.846 \text{ D2/D5}) - 99.746$$

$$\text{Female} = (106.57 \text{ D2/D4}) + (1026.336 \text{ D2/D5}) - 965.801$$

This analysis produced results that were accurate for only 60 percent of known cases. While the results were statistically significant, the approach is not robust enough to allow an archaeologist to use these measures alone to infer the sex of any particular handprint or stencil with much confidence. The best approach to hand stencils is to carry out the Step 1 analysis described above and then use the Step 2 analysis to (potentially) clear up ambiguous cases involving confusion between females and subadult males (subadult females will be identified as female at both steps). A preliminary report contains a more complete summary of these initial procedures and justifications (Snow 2006:396–400).

One advantage to this approach is that the two measures produced for any specific case can be converted into a simple ratio (female probability/male probability) that indicates the likelihood that the hand in question belonged to a male (< 1.0) or to a female (> 1.0). We used an initial sample of 111 individuals of European descent, 57 females and 54 males. When both hands were used, the Step 2 analysis produced 221 hand scans (one was unusable) that yielded the same number of ratios. Table 1 shows the results.

Table 1. Digit Ratios for a Sample of 222 Modern Hands.

	Average Digit Ratio	Standard Deviation
Females	1.000316	.001322
Males	.999577	.001208

Table 2. Predicted Sex of 221 Hands Based on 2D/4D Ratio Cross-Tabulated with Known Sex.

		Predicted Sex		
		Females	Males	Sums
Known	Females	63	38	101
Sex	Males	50	70	120
	Sums	113	108	221

There is considerable overlap between the ranges measured for females and for males in any modern European population. Consequently, it is not possible to say in a deterministic way that female hands consistently show a ratio of > 1.00 while males consistently have digit ratios of < 1.00. Table 2 shows that this approach succeeds for only 60 percent of 221 hands in the sampled population of modern adults of European descent. Adjusting the threshold to some other value near the midpoint of the .89 to 1.06 range of D2/D4 ratios does not improve this result. While individual ratios near the low end of the range are almost always male and those near the upper end are almost always female, the ranges of females and males overlap considerably around the midpoint.

The overlap found in the modern sample leads to ambiguous results more often than one would prefer. We found that we could correctly identify the sex of hand scans through simple inspection at a better than 90 percent rate, so we had to conclude that we were missing one or (probably) several important measures in the more objective analysis. To improve the success rate, we have recruited assistance from colleagues in the College of Information Science and Technology at Penn State. They are de-

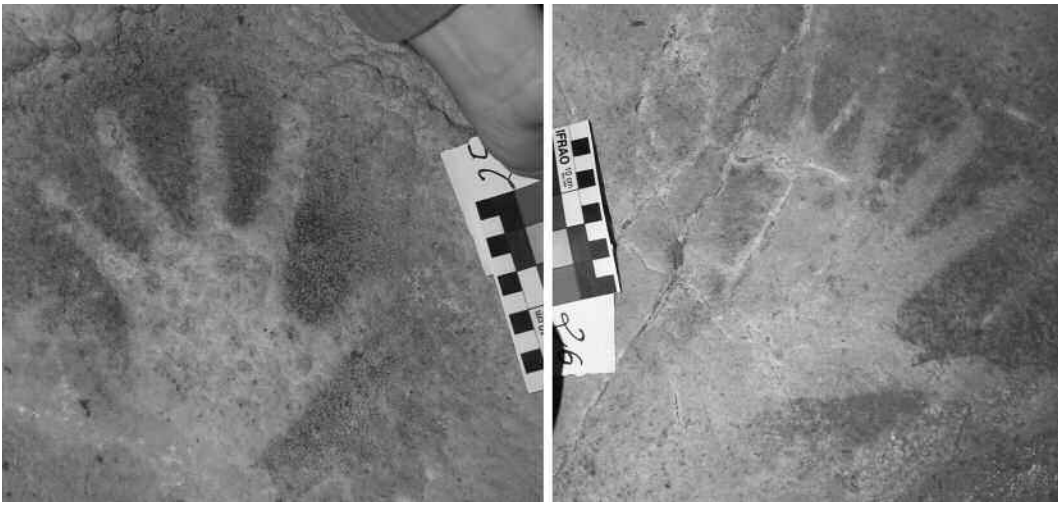

Figure 3. Hands 25 and 26 from El Castillo (photo courtesy of Roberto Ontañon Peredo).

veloping a prototype automatic scanning procedure, an analytical process that can handle many hundreds of measures simultaneously. Preliminary results show that this automated approach can yield correct identifications of the sexes of hand scans at the 72 percent rate (Wang et al. 2010). In more recent trials this has been raised to 79 percent. Research and development are continuing. Meanwhile, an unexpected finding in the archaeological sample of hand stencils from southwestern Europe has allowed the research based on the initial analysis to be reported despite the overlapping ranges found in the modern sample. The Upper Paleolithic cases fall at or near the extremes of the modern continuum. This is discussed further below.

Sampling Upper Paleolithic Caves

A preliminary study was based on three hand stencils from the caves of Les Combarelles, Font-de-Gaume, and Abri du Poisson, and proxies of three more in the museum at Pech-Merle in 2004. That study suggested that four of the six hand stencils were female (Snow 2006:401). Although there are dozens of caves containing hundreds of hand stencils in the aggregate, funding limited the expanded research to a minority of them containing relatively large numbers of hand stencils. Many caves have only one or two known examples, and many of these were likely to prove too faint or incomplete to measure. Some caves, such as Cosquer and Chauvet, were eliminated from consideration because of danger, cost, and/or rigorous entry permit restrictions. Others were eliminated because the anticipated benefits did not justify costs. However, in all of these cases, we are hopeful that the directors of current and future research projects will use the research tools this project has developed to reveal more about the origins of parietal art in the caves.

We revisited Pech-Merle and visited for the first time Bernifal, Gargas, Rocamadour, Grotte du Bison in France, El Castillo and Maltravieso in Spain. These caves, particularly Gargas, contain a large fraction of the 200–300 hand stencils that are referenced in a wide range of publications. But only a much smaller number are complete enough or preserved well enough to be potentially measurable. For example, while Gargas alone has traces of over 200 stencils, all but a few of them are either missing portions of digits or too faint to measure, and they are consequently not usable. There is an ongoing debate over why most of the stencils in Gargas have truncated digits, but that debate is beyond the scope of this paper (Leroi-Gourhan 1986; Sahly 1966).

Figure 3 shows two well-preserved hand stencils from El Castillo. Researchers familiar with sexual dimorphism in European hands will probably be able to infer from simple inspection that the person who made El Castillo hand stencil 25 on the left was probably male while specimen 26 on the

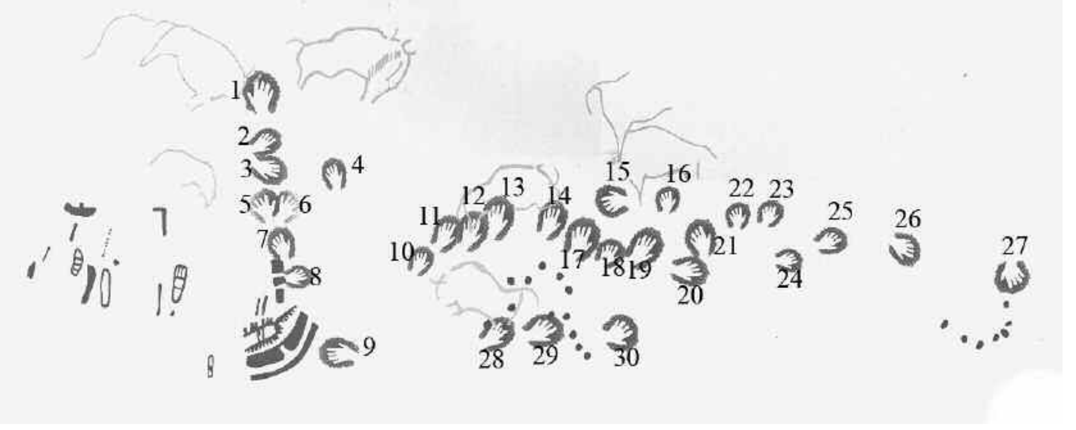

Figure 4. Friso de las Manos, El Castillo.

right was probably made by a female. The challenge is to define a set of objective measurements and procedures that can be used to produce a more reliable and compelling determination of the sexes of the individuals who made these and other hand stencils.

Guthrie (2005:118) reports that he acquired 201 usable hand images, but he does not provide images or provenience for any but a few of them. In many cases he derived scales indirectly, for he too had problems obtaining access and permissions to photograph. His analysis also suggests that he used many cases for which only some of the key dimensions could be measured. His sample is thus larger, but probably less reliable than the one reported here. His results are not reproducible based on what he has published to date.

We photographed many hand stencils that were subsequently set aside because one or more key measurements could not be made. In the end we had 32 images of sufficiently complete hands with scales and clarity sufficient to allow accurate measurement of all key dimensions. The sample is smaller than any researcher would prefer, but it is the largest possible given scientific caution, travel costs, and access restrictions. Finally, both the images and the data derived from them are available so that other researchers may reproduce the results.

The Cave Sites

Each cave is discussed separately here in order to allow future researchers to relocate each of the hand stencils discussed here if that should be necessary. Approximate locations of the caves are indicated by department (France) or province (Spain). All are open to the public and sufficiently well-known to be easily found (Berenguer 1994; Delluc and Delluc 1991; Sieveking and Sieveking 1962).

Abri du Poisson, *Dordogne, France*. There is only one hand stencil on the ceiling of this small rock shelter.

Grotte de Bernifal, *Dordogne, France*. A panel of hands includes three possible hand stencils, one of which is sufficiently legible to measure.

El Castillo, *Santander, Spain*. Figure 4 shows the panel known as "Friso de las Manos" with numbers 1–30 that were assigned for this project. Hand stencil 31 is an isolate in Galeria de los Discos. Five additional hand stencils on the panel known as "Bisontes Policromos" were numbered 32–36 for this study (Figure 5). Stencil 37 is located to the left of the Bisontes Policromos, and stencil 38 is in the passage between the Friso de las Manos and a chamber containing a sculpted bison.

Font-de-Gaume, *Dordogne, France*. There are four hand stencils, two black and two red, known for the cave, but only one is sufficiently distinct to be photographed and measured.

Gargas, *Hautes-Pyrénées, France*. There are more than 200 hand stencils, most of which have one or more incomplete digits. Only six are sufficiently complete and legible to allow measurements. The six hand stencils listed in Table 3 are identified by chambers, panel names, and hand numbers previously assigned by Barrière (1976).

Grotte du Bison, *Dordogne, France*. Because

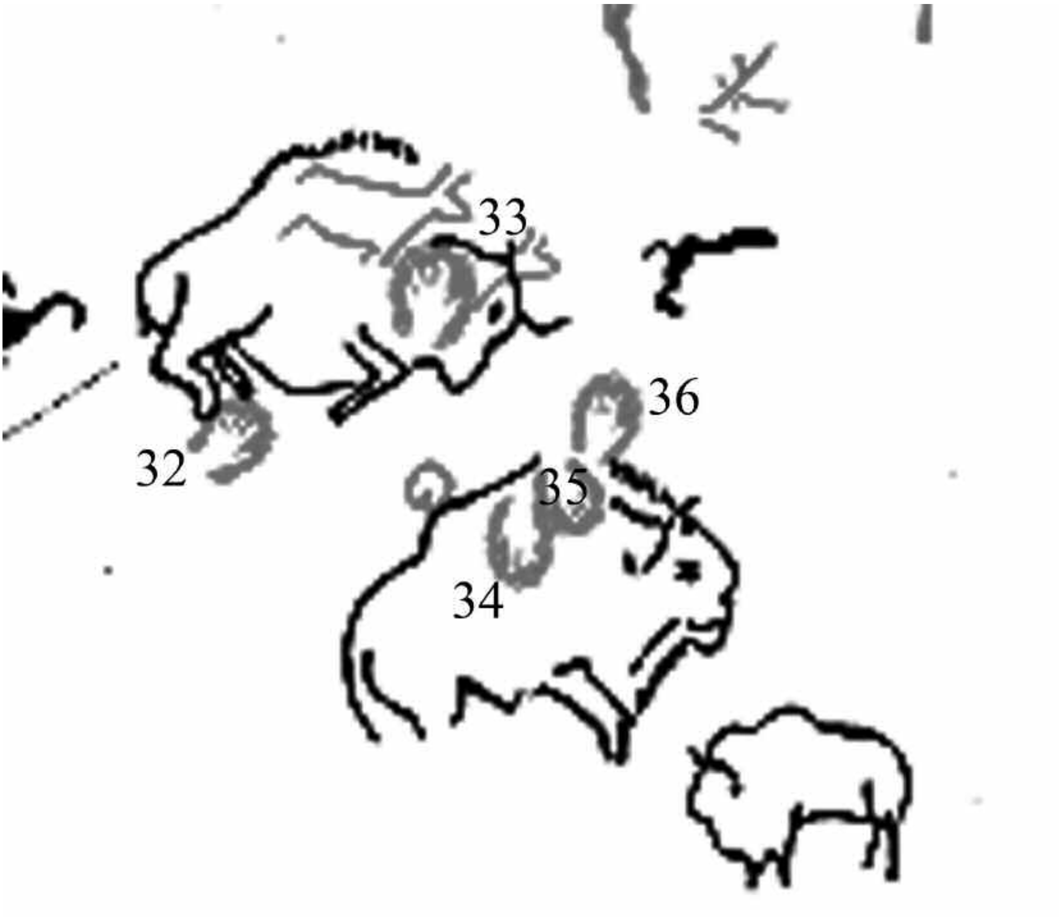

Figure 5. Bisontes Policromos, El Castillo.

the overall length of the first hand could not be measured, it is not included in Table 4. However, an inference is possible, as discussed below.

Les Combarelles, *Dordogne, France*. There is only one legible hand stencil, located deep in the part of the cave that is open to the public.

Maltravieso, *Cáceres, Spain*. New photographs are not possible, but photographs of hand stencils with scales are available in published form (Ripoll López et al. 1999). Many of the hand stencils in Maltravieso are missing digits, and it was not possible to find any cases sufficiently clear and complete enough to include in Table 4.

Pech-Merle, *Lot, France*. Black hand stencils A–F surround the Spotted Horses mural as shown in the preliminary report (Snow 2006:397). Of these, two were too faint to measure. However, the six stencils are remarkably similar and were possibly all made by the same individual (Lorblanchet 1991:29). Stencil G is a red hand stencil located in another part of the cave (Snow 2006:398).

Rocamadour, *Lot, France*. The main panel in this private cave has a hand stencil that is too indistinct to study. There is a distinct hand stencil at the far right of the main panel.

We digitally photographed hand stencils multiple times in the caves both in color with flash and in monochrome using the infrared night vision option allowed by a Sony 5.0 megapixel Cybershot camera. A 10-cm scale was held next to each hand stencil for most shots. Many hand stencils were photographed, but only a minority could be adequately measured even after the application of various digital enhancement techniques. Thirty-two images proved to be clear enough to include in the final sample. This sample might be increased with the inclusion of additional images from caves like Chauvet, but it is sufficient to allow generalization

Table 3. Locations of Gargas Hand Stencils Used in This Study.

Image	Chamber	Panel	Hand
P5M8	1	5	8
P6BM6	1	6	6
P6BM7	1	6	7
SdMFIM17	Sanctuary of Hands	Interior Façade	17
SdMFIM18	Sanctuary of Hands	Interior Façade	18
SdMFIM27	Sanctuary of Hands	Interior Façade	27

about the ages and sexes of the Upper Paleolithic individuals who made and left hand stencils behind on cave walls.

Analytical Results

In all cases, digit length measurements were recorded in millimeters using protocols that have become standard for this kind of research, as outlined above (Nelson et al. 2006). In each case, the four equations reported above were applied to the data, resulting in male and female probabilities for each case at both Step 1 and Step 2 of the analysis.

Table 4. Indices of Female Probability/Male Probability in Steps 1 and 2. Ratios in Bold Lie at or beyond the Range of Ratios Computed for Modern Europeans.

Hand Stencil	Step 1 Ratio	Step 2 Ratio
Abri du Poisson	**1.055**	1.003
Bernifal	**1.217**	1.004
El Castillo 1	1.042	**1.005**
El Castillo 2	1.020	**1.006**
El Castillo 3	1.006	**1.005**
El Castillo 6	1.039	.998
El Castillo 12	1.018	.999
El Castillo 13	.997	.998
El Castillo 15	1.018	1.002
El Castillo 17	.992	1.001
El Castillo 18	1.030	**1.007**
El Castillo 25	.986	.999
El Castillo 26	1.017	1.003
El Castillo 28	1.003	1.000
El Castillo 30	**1.064**	1.002
El Castillo 31	**1.095**	1.000
El Castillo 37	**1.110**	**1.006**
El Castillo 38	**1.088**	1.001
Font-de-Gaume	1.014	1.001
Gargas P5M8	1.017	1.000
Gargas P6BM6	1.006	1.000
Gargas P6BM7	.989	**.995**
Gargas SdMFIM17	**1.094**	**1.005**
Gargas SdMFIM18	**1.080**	**1.010**
Gargas SdMFIM27	**1.447**	**1.005**
Les Combarelles	**1.228**	.998
Pech-Merle A	1.048	**1.005**
Pech-Merle B	**1.053**	**1.009**
Pech-Merle C	1.046	1.004
Pech-Merle E	1.009	**1.005**
Pech-Merle G	1.045	**1.009**
Rocamadour	1.017	1.004

Step 1 showed that only about 10 percent of the sample cave hand stencils were left by adult males. This confirms Guthrie's finding, and it also explains observations by several earlier researchers that Upper Paleolithic hand stencils were often small compared to those of modern adult Europeans. The stature of at least early Upper Paleolithic people was similar to that of modern Europeans, so there is no basis for arguing that adult male hands might have been smaller than than they are today (Formicola and Giannecchini 1999).

Step 2 sorted all cases into those probably made by five subadult males and those probably made by 24 females. While hand size and digit lengths are probably controlled entirely or almost entirely by genetic factors, hand robustness as measured by digit widths is and probably was determined largely by physical conditioning and lifestyle. A modern individual whose work is largely outside, physical labor involving the hands is likely to have much more robust hands than one who does not engage in much such labor. European Upper Paleolithic people were hunter-gatherers that lived and worked in a physically demanding cold environment, and we should expect the hands of both sexes to have wider digit widths than those of a modern reference population. Consequently, we conclude that the dependence of Guthrie's argument on digit (especially thumb) width has led to conclusions that are much less probable than those indicated by D2/D4 ratios. Judging from the latter, only a quarter of all cases were made by males, 10 percent adult males and 15 percent subadult males. The rest (75 percent) were made by females.

For ease of communication, indices in Table 5 have been converted to statements of strong to weak maleness or femaleness. Inferences drawn from those observations are displayed in the sixth column. Notice that hands that appeared to be female in Step 1, but male in Step 2, are inferred to have been those of subadult males. There is currently no good inferential technique for separating adult females from subadult females.

Inferences drawn in the 2006 preliminary report are shown in the seventh column of Table 5. These

Table 5. Conclusions for 32 Hand Stencils in 8 Upper Paleolithic Caves. Revised Conclusion Shown in Bold Face.

Hand Stencil	Hand	Color	Step 1 Result	Step 2 Result	Current Inference	2006 Inference
Abri du Poisson	Left	Black	Strongly Female	Strongly Female	Adult Female	Female
Bernifal	Left	Black	Strongly Female	Strongly Female	Adult Female	
El Castillo 1	Right	Red	Strongly Female	Strongly Female	Adult Female	
El Castillo 2	Right	Red	Strongly Female	Strongly Female	Adult Female	
El Castillo 3	Right	Red	Weakly Female	Strongly Female	Adult Female	
El Castillo 6	Left	Red	Strongly Female	Strongly Male	Subadult Male	
El Castillo 12	Left	Red	Strongly Female	Male	Subadult Male	
El Castillo 13	Left	Red	Weakly Male	Strongly Male	Adult Male	
El Castillo 15	Right	Red	Strongly Female	Female	Adult Female	
El Castillo 17	Left	Red	Male	Female	Adult Female	
El Castillo 18	Left	Red	Strongly Female	Strongly Female	Adult Female	
El Castillo 25	Left	Red	Strongly Male	Male	Adult Male	
El Castillo 26	Left	Red	Strongly Female	Strongly Female	Adult Female	
El Castillo 28	Left	Red	Weakly Female	Weakly Male	Subadult Male	
El Castillo 30	Left	Red	Strongly Female	Female	Adult Female	
El Castillo 31	Left	Red	Strongly Female	Weakly Male	Subadult Male	
El Castillo 37	Left	Red	Strongly Female	Strongly Female	Adult Female	
El Castillo 38	Left	Red	Strongly Female	Female	Adult Female	
Font-de-Gaume	Left	Red	Strongly Female	Female	Adult Female	Female
Gargas P5M8	Left	Ochre	Strongly Female	Weakly Female	Adult Female	
Gargas P6BM6	Left	Red	Weakly Female	Weakly Female	Adult Female	
Gargas P6BM7	Left	Red	Strongly Male	Strongly Male	Adult Male	
Gargas SdMFIM17	Left	Black	Strongly Female	Strongly Female	Adult Female	
Gargas SdMFIM18	Left	Red	Strongly Female	Strongly Female	Adult Female	
Gargas SdMFIM27	Left	Black	Strongly Female	Strongly Female	Adult Female	
Les Combarelles	Left	Black	Strongly Female	Strongly Male	Subadult Male	Male
Pech-Merle A	Right	Black	Strongly Female	Strongly Female	Adult Female	Female
Pech-Merle B	Left	Black	Strongly Female	Strongly Female	Adult Female	
Pech-Merle C	Right	Black	Strongly Female	Strongly Female	Adult Female	Female
Pech-Merle E	Right	Black	Female	Strongly Female	Adult Female	
Pech-Merle G	**Left**	**Red**	**Strongly Female**	**Strongly Female**	**Adult Female**	**Male**
Rocamadour	Left	Black	Strongly Female	Strongly Female	Adult Female	

remained the same as initially reported except for one case from Pech-Merle, which is shown in bold face. Initial measurements were taken in 2004 from museum copies of three Pech-Merle stencils. Close-up photography in 2007 allowed for more precise measurements. These revealed that the museum copy of hand stencil G, a well-known red case, was not sufficiently accurate. It is now clear that hand stencil G was almost certainly made by a female. Close-up photography also allowed for sex determinations of Pech-Merle hand stencils B and E for the first time. These are very similar to the others around the Spotted Horses mural (A, C, D, and F) and they might all have been made by the same female.

An important caveat is that we do not have another independent means to infer the sex of archaeological hand stencils or handprints. We can check our inferences about any modern sample against the known sexes of the individuals in that sample, but independent confirmation of inferences regarding archaeological cases is not possible. This is a common constraint in archaeology. To the extent that a sample can be sorted into two subsets based on the computations discussed above, their identification as probably female and probably male remains inferential.

Unexpected Results

Although preliminary findings showed that females were agents in the production of Upper Paleolithic parietal art, and that they might even have dominated it, that impression was based on only six hand stencils. It was reasonable to expect that the ratio of male to female artists would shift to some-

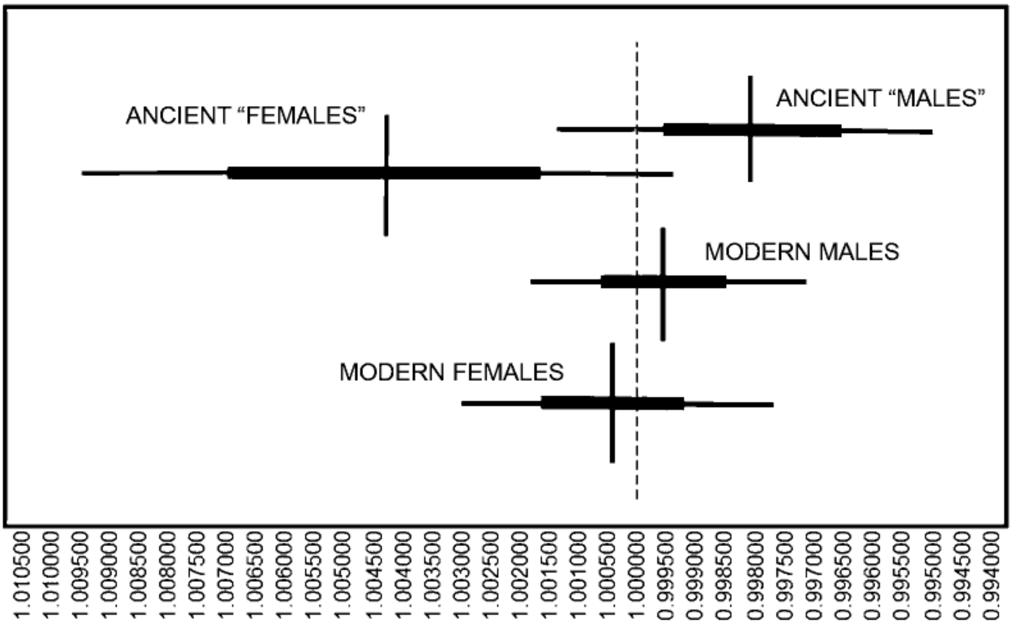

Figure 6. Means, 1α (broad line), and 2α (narrow line) ranges for Step 1 indices for ancient (Upper Paleolithic) females and males as compared to modern females and males.

thing closer to parity when a larger sample was acquired. However, the ratio for 32 cases shown in Table 3 is 8/24, 75 percent female. Thus the preliminary impression has been unexpectedly sustained by further research.

A second finding is that the average Step 2 digit ratios for inferred female and male hand stencils in the Upper Paleolithic sample are much farther apart than expected. By the measures used, sexual dimorphism in Upper Paleolithic hands was much greater than is the case for hands in the modern descendant population. The female/male probability ratios shown in Table 4 tend to fall at or beyond the ends of the range of ratios computed for the sample of 221 modern European cases reported in Tables 1 and 2. Indeed, 24 of the 64 values shown in Table 4 lie *beyond* the most feminine or most masculine values measured for *any* individual in the modern sample. Most of the remaining Upper Paleolithic ratios fell very close to the ends of the modern range. Thus the cases do not just cluster clearly; they do so in a way that suggests that sexual dimorphism was more pronounced in the Upper Paleolithic than is true today, at least as measured by hand proportions.

We cannot expect a set of ancient cases to sort neatly into two subsets, particularly given the degree of overlap observed in the modern reference population. Yet that is what occurred in this study. Only those described as "weakly female" ($n = 2$) or "weakly male" ($n = 2$) in Table 5 were even mildly ambiguous. The data in the Step 2 Ratio column of Table 4 sort into two distinct clusters near the extremes of the modern range. From this it can be argued that the inference that the clusters probably represent females and males respectively is a strong one.

Figure 6 shows the differences graphically. The ancient cases are in quotes because they are only inferentially female or male. While the one-sigma ranges for modern females and males overlap, those of the two clusters of ancient "females" and "males" do not. Moreover, while some fraction of the modern male cases in the one-sigma range fall on the female side of the 1.00 divide, and some fraction of the female cases fall on the male side of it, that is clearly not the case for the ancient cases. Thus, as measured by digit ratios, the evidence might indicate that evolutionary forces that maintained a marked degree of sexual dimorphism in hands during the Upper Paleolithic relaxed over the course of more recent millennia. Alternatively, there has been some positive force selecting against hand dimorphism in more recent millennia. Either inference appears to be consistent with osteological analysis that has revealed marked sexual dimorphism in Upper Paleolithic skeletal populations (Formicola and Giannecchini 1999:326).

Early Upper Paleolithic people appear to have been as tall as modern Europeans. Late Upper Paleolithic people were comparatively shorter in stature and less robust. There is at this time insufficient skeletal evidence to reveal a parallel shift over time in sexual dimorphism through the course of the Upper Paleolithic period (Holt and Formicola 2008:85). It is also the case that the hand stencil evidence is also insufficient to address that question. However, current evidence from both lines of inquiry supports the view that sexual dimorphism was greater at least early in the Upper Paleolithic than it is today.

Expanding Applications

Because the degree of sexual dimorphism is so great in Upper Paleolithic hand stencils, the reliability of the assignment of sex to any particular case from a European cave is greater than would be the case of an unknown example from a modern European population. Any sufficiently intact and well-preserved example can be sexed using the measurements and procedures outlined here. Given the size of the sample used here, it will be surprising if the predominance of females does not hold up as hand stencils and handprints are examined in additional caves located in southwestern Europe.

Even some hand stencils that are missing digits or are poorly preserved can be assessed with reasonable confidence given the robust nature of the findings of this research project. For example, the incomplete hand stencil from Grotte du Bison shown in Figure 7 could not be used in the Step 1 and 2 analyses, but it appears from the long index finger on this incomplete stencil of a left hand (clearer in color) that the person who made it was probably female.

Similarly, Leslie van Gelder and Kevin Sharpe have had some success in sexing finger smears on the walls of Rouffignac. The smears are typically vertical lines made by D2, D3, and D4 digits (Sharpe and Van Gelder 2006; Van Gelder and Sharpe 2009). A trace smear of the thumb often allows one to distinguish left from right hand smears. If the D2 smear starts at a point as high or higher than the D4 smear, then a female maker is suggested. If the D4 smear is higher a male maker is suggested.

Panels of palm prints, some of them with digits, have been reported for Chauvet (Clottes 2003). The heights of the panels and the sizes of the palms have been used to draw reasonably convincing inferences regarding the sexes of their makers. A panel of relatively small palm prints is set lower than a similar panel of relatively large palm prints. One can infer that the first panel was made by a female or females, and that the second panel was made by a male or males of taller stature. Assessment of D2/D4 ratios could be used to test those inferences.

We more recently tested the Step 1 and 2 equations against a population of American Indian hands of known ages and sexes. These are handprints made by living individuals when they pressed their hands into wet plaster on a wall in the Sam Noble Oklahoma Museum of Natural History in Norman, Oklahoma. All of the prints were made by adults and children of both sexes, and all of them are individually identified. We extracted measurements from 120 prints, which were as clear and measureable as hand scans. When we attempted to make inferences about the Oklahoma handprints using the algorithms developed based on European hand scans the results were disappointing. The results indicated that this population is sufficiently different from the European population to require its own predictive discriminant analysis and the development of a separate set of equations. Indeed, our observations suggest that there is less sexual dimorphism expressed in American Indian hands than is the case for European hands, certainly much less than is the case for Upper Paleolithic European hands. However, the automatic data extraction mentioned above might increase discriminatory power sufficiently to overcome a low degree of dimorphism and allow inferences about archaeological examples for which sex is currently unknown.

Prior expectation of the failure to discriminate females from males in the Oklahoma data set came after I initially attempted to infer the sexes of the American Indian handprints by inspection alone,

Figure 7. Hand stencil 2 from Grotte du Bison. Courtesy of Norbert Aujoulat.

something that is usually easy for an experienced observer in the case of scans of European hands. My attempts to assign sex by inspection of the American Indian cases failed so frequently that I would have done almost as well simply tossing a coin. This adds weight to the caution that one should use an appropriate living reference population in any study of archaeological hand stencils or handprints. The 120 handprints in the Oklahoma data set are probably too few to establish reliable algorithms.

As another example, any effort to infer the sex of hand stencils in a site such as Cueva de las Manos Pintadas in Argentina should be preceded by the development of equations based on a living reference population of native South Americans. The relatively low genetic diversity of native America as compared to the rest of the world suggests that such research could be productive in the Americas (Black 1992).

Nevertheless, Chazine and Noury (2006) have had some success sexing hand stencils on the walls of a Borneo rock shelter. While they have been criticized for apparently using a European reference population, their results seem unexpectedly promising (Nelson et al. 2006:4).

Conclusions

Inferences regarding sex are not easy to make in archaeology. Indeed, it is rare that one can draw the kinds of inferences that have been possible with regard to Upper Paleolithic hand stencils. There is reason to conclude that the techniques described here can be extended to other parts of the world where handprints and hand stencils are preserved in the archaeological record. It is also clear that one size does not fit all, and that the best results will be achieved if algorithms are developed based on relevant reference populations. This may be facilitated by the continued development of automatic data extraction procedures that will allow machine learning and more complete and comprehensive assessments of sex differences in living reference populations.

The assumption that Upper Paleolithic artists were invariably males was sufficiently well established in twentieth-century minds to prompt the publication of a cartoon in the January 21, 1980 issue of the *New Yorker* showing four cave women producing parietal art. One of them is saying, "Does it strike anyone else as weird that none of the great painters have been men?" The humorous irony in 1980 was, of course, based on the generally accepted view that cave artists must have been males. Now, more than three decades later, the cartoon still seems funny, but the focus of the irony has been shifted. The humor now has to do with the disconnect between the explicit results of objective inquiry about the identities of Upper Paleolithic artists and the facile implicit assumptions that colored archaeological inference in the recent past.

There is always a temptation to speculate beyond the limits of valid inference. Questions from audiences that have followed presentations of our findings regarding sexual dimorphism in European Upper Paleolithic hand stencils suggest that there is broad interest in finding ways to continue the research and to find ways to extend archaeological inference in this topical area. Why did females or anyone else create parietal art in the first place? Was parietal art restricted to caves, or are caves simply the only places it has survived well? We hope that theory, techniques, and data will be developed to allow such questions to be addressed in the future. For now we should not go beyond the conclusions reported here.

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