Using geometric morphometrics to sex hand stencils; implications for investigating Paleolithic rock art

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Introduction

Human hand stencils appear in the archaeological record from all inhabited continents, and are abundant at Palaeolithic sites such as El Castillo, La Garma and Maltravieso (Spain), and Gargas (France). They were produced by pressing the hand against a substrate and then applying pigment around the hand to create a stencil. It has generally been assumed that many of the hands represented in European Paleolithic rock art are those of men and boys[1,2]; this assumption largely hinges upon size-based differences. However, a recent resurgence in sexing Paleolithic hand stencils implicate both sexes in the creation of rock art[3,4,5,6]; with a possible bias in favour of females[7].

Accurate determination of the sex of stencilled hands would provide a significant advance for reconstructing artistic activity in the Paleolithic and would help resolve conflicting interpretations about the role and meaning of its imagery. Here we present preliminary results of a method for predicting sex using geometric morphometrics (GMM) to quantify sexually dimorphic size and shape variation reflected in hand stencils.

Materials & Methods

Experimental replication of hand stencils comparable with Palaeolithic homologues was undertaken at the University of Liverpool on a sample of students and delegates at the HOBET Conference (2012), resulting in a sample of outlines from Caucasian 132 individuals (53 males; 79 females). Standardised digital images were captured of both left and right hands (n 264), with 19 type II and III landmarks applied to each stencil (see Fig. 1) using TPS Digit[8] following an adaptation of the protocol of Randolph-Quinney and colleagues[9]. Shape analyses were undertaken using the Shapes library and complementary R statistical routines[10], Partial Least Squares analysis in MorphoJ[11], and additional statistical analyses in SPSS 20.0.

Landmark configurations were subjected to Generalised Procrustes Analysis with assessment of measurement error applied using a 5 x 5 x 5 repeat procedure and Procrustes ANOVA on group means[12]. Post-hoc tests comprised: (1) Principal Components Analysis (PCA) to reduce dimensionality and investigate patterns of population variation; (2) classification using Fisher's linear discriminant analysis (LDA) based on the first p PC scores (where p is the tuning parameter chosen to give the best cross-validation performance in the production of the discriminant function), with leave-one-out cross validation to assess performance of the classification; (3) Partial Least Squares (PLS) analysis within a single configuration to test for structural modularity[13]; and (4) stepwise re-sampling and re-analysis of dataset following PLS to optimise shape classification criteria.

PC	Eigenvalue	% Variance	Cum. % Variance
1	0.00184350	29.75	29.75
2	0.00150459	24.28	54.03
3	0.00080262	12.95	66.98
4	0.00045589	7.36	74.34
5	0.00034764	5.61	79.95

Table 1. Significant principal component loadings showing eigenvalues and percentage of variation expressed.

Landmark Set	PC	Shape Only	Shape + Size
All (*k* 19)	1-5	73.5%	88.3%
Digits (*k* 10)	1-3	58.3%	84.8%
Palm (*k* 9)	1-4	73.5%	91.3%

Table 2. Cross-validation results based on complete and re-sampled landmark sets indicating classification based on shape only and shape plus size (PC scores and log of centroid size). Table indicates optimal re-sampling results only.

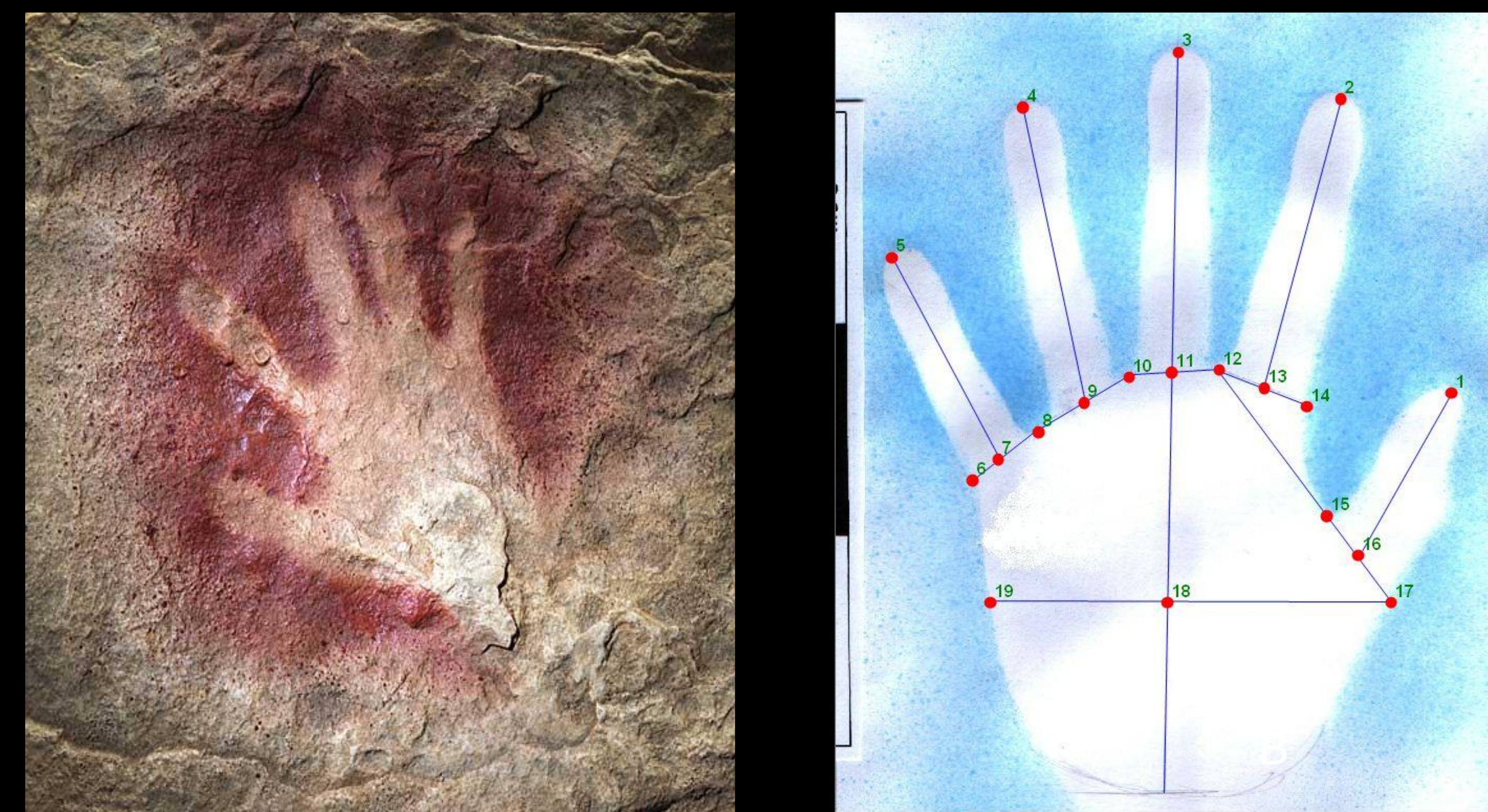
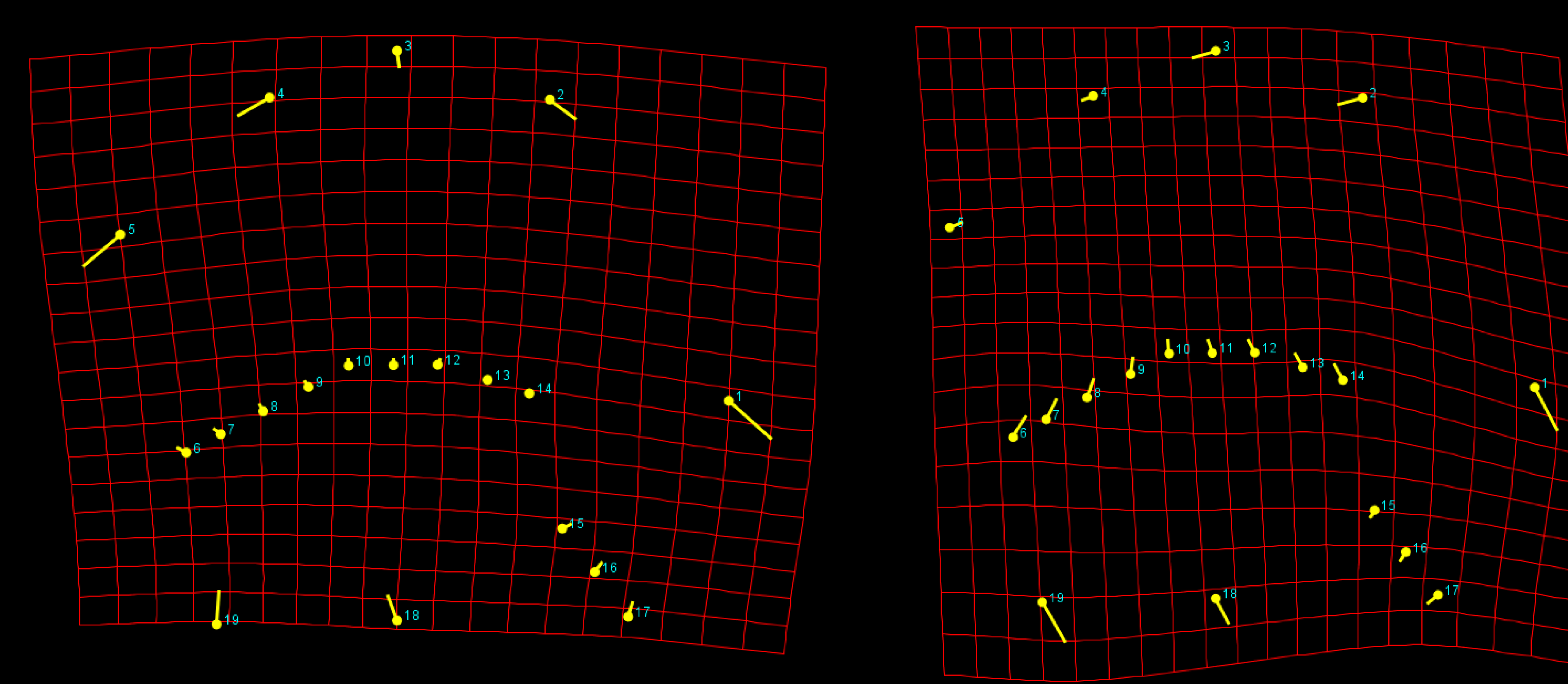


Figure 1. Palaeolithic hand stencil from Chauvet Cave in France (left) and (right) example of an experimental hand stencil with resulting applied landmark s (*k* 19) as used in this study.



PC1 PC2

Figure 2. **V**isualisation of shape variation for PC 1 and PC 2 for full landmark set (*k* 19).

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Results

34 principal components were produced following GPA, the first 5 of which account for around 80% of shape variation in the sample (Table 1). Global shape variation is expressed in Fig. 2 by the visualisation of principal components 1 and 2; vectors indicate sex-based differences. Procrustes ANOVA of shape residuals indicated significant shape difference between the sexes ($p < 0.0001$). Error testing of repeated runs indicated no significant difference ($p=0.884$) and therefore low measurement error. The utility of the resulting shape variables as an aid in assessment of sex was undertaken using stepwise linear discrimination (DFA) based on PC scores (analyses undertaken with and without size included), with reliability of classification based on leave-one-out validation with permutation test for significance. Using all 19 landmarks the resulting shape variables (size invariant) successfully classified 88.3% of individuals by sex (Table 2).

Following DFA a 2-block PLS was applied. PLS examines covariation between two or more sets of variables, and identifies features of shape that most strongly covary between blocks allowing for an assessment of modularity. Landmarks were sub-divided between digital (LM 1-5, 7, 9, 11, 13 & 16) and palmar landmarks (LM 6, 8, 10, 12, 14, 15, 17-19). PLS produced an RV coefficient (the measure of covariance) of 0.361. This indicates a poor degree of association between blocks (implying the variables are largely uncorrelated), and hence a low degree of modularity. To investigate this further, we performed a series of stepwise exclusion tests removing 10% of landmarks at each stage. Reanalysed data was based on iterations of dependent (both blocks) and independent units (single blocks). This produced an optimum classification based on k = 9 landmarks of the palm with an increased cross validation of 91.3% of cases by sex (Table 2).

Discussion and future directions

This study has presented the preliminary results of a methodology currently being developed to analyse dimorphism in hand size and shape using GMM and data extracted from hand stencils. Our results show successful classification rates of between 85% and 91% depending on which anatomical region is sampled. Stepwise permutation tests and analyses of regional covariation indicate limited functional coupling, with a low degree of modular integration between the digits and palm patterns. This suggests that functional ties between the units are uncorrelated in influencing sex-based morphological expression. Consequently such units may be studied together or in isolation, and this may allow accurate sex-assessment based on stencils of the whole hand, the digits, or isolated parts of each. Thus, this method may be applicable in assessing sex for both whole hand pictographs and fragmented artistic representations depending on the archaeological context. This will be particularly useful for panels that display images which are difficult to fully capture due to uneven substrates or incomplete hand stencils such as those with missing, or folded over digits (e.g., Gargas, France).

The classification rates quoted above are an improvement on other techniques[3,6,7]; however our results still needs to be replicated. We are currently cross-validating this method using data based on hand stencils from other ethnic groups and experimenting with hand stencils created on a simulated cave wall. Our experiments in the simulated cave are also providing new insights into the behaviour of artists creating art in low-light conditions. Our aim is to develop a robust methodology that is stable enough to cope with data collected from several populations and a variety of conditions, before we apply it to Paleolithic images.

A recent study has proposed that pigment on the cave walls of El Castillo (Spain) is more than 40,800 Kya[14]; a period in prehistory when both Neanderthals and anatomically modern humans (AMH) occupied Europe[15,16]. Although dating speleothem associated with cave art can be fraught with uncertainty and the dates for the arrival of AMH in Western Europe remain contentious, the new evidence suggests that some Paleolithic depictions could (in theory) have been created by Neanderthals. Investigating size and shape differences of hand stencils using GMM methods, such as the one

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