

Chapter 2

A Geometric Morphometric Assessment of Plan Shape in Bone and Stone Acheulean Bifaces from the Middle Pleistocene Site of Castel di Guido, Latium, Italy

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Abstract Flaked bone artifacts are a noteworthy component of some Early and Middle Paleolithic tool kits. Several Paleolithic sites with lithic assemblages attributable to the Acheulean Industrial Complex (Mode 2) have yielded bifacial bone artifacts. Many of these bone implements are similar to classic handaxes in plan shape. The arbitrary imposition of form represented by these bone bifaces suggests the deliberate application of certain operational concepts that originate from particular Acheulean technological behaviors, namely, stone handaxe manufacture. In addition, the presence of these bone tools suggests an application of specific reductive techniques that originated in both Mode 1 (i.e., Oldowan) and Mode 2 (i.e., Acheulean) lithic technologies. How does the Acheulean model for stone biface shape compare to that observed for bone biface shape? In order to understand the degree to which Acheulean stone bifaces may have served as a model of form in flaked bone technology, an objective method for evaluating form is necessary. The dimensionless approach of geometric morphometrics was applied to the study of 2D bone and stone biface plan shape. The similarity of bone and stone bifaces from the Middle Pleistocene (~300 kya) Acheulean site Castel di Guido, Latium, Italy was evaluated by a geometric morphometric analysis of 2D outlines. The null hypothesis that there is no difference in the 2D shape of each artifact material class was tested by principal component analysis (PCA) and MANOVA/CVA of eigenshape scores. Results of the analysis show no significant difference between the plan morphology of bone and stone bifaces. These results may indicate that Acheulean concepts of preferred 2D shape were applied in the production of some bifacial bone tools and that a great disparity in raw materials did not significantly influence 2D biface morphology. Furthermore, these results lend support to the idea that Mode 2 stone flaking techniques and tool types were directly applied to bone materials in some instances.

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Introduction

Archaeological evidence shows that bone was, at least occasionally, a component of Paleolithic tool kits throughout the Quaternary (Backwell and d'Errico 2005; Patou-Mathis 1999; Villa and d'Errico 2001; Vincent 1993). Bone is a strong and flexible material that can be broken, ground, and shaped readily into various useful forms. The zooarchaeological record shows that animal remains were common among early meat-eating hominins (e.g., Blumenshine and Pobiner 2006; Domínguez-Rodrigo and Egeland 2007; Heinzelin et al. 1999), thus the technological exploitation of bone materials could have been an optimal behavior directly associated with subsistence. Consequently, the acquisition of bone materials may have been less energetically and cognitively demanding for hominins than locating and remembering the locations of lithic raw material sources. Although evidence of bone utilization is generally sparse in the Early and Middle Paleolithic, it is probable that the relatively poor preservation potential of bone artifacts is partially responsible. Overall, the Paleolithic evidence for bone tool use indicates that hominins frequently recognized bone as a useful substance and exploited it in several ways (Backwell and d'Errico 2005; Villa and d'Errico 2001).

The archaeological evidence for Paleolithic bone utilization (excluding percussors) may be organized into three groups. These groups can be ordered in a relative chronology and include: (1) bone tools unintentionally modified through use, (2) flaked bone tools, and (3) ground-bone tools. The first group is exemplified by the 1.8–1.1 million year old (mya) bone “digging-tools” from Swartkrans (Members 1–3) and Drimolen South Africa (Backwell and d'Errico 2004, 2005, 2008; Brain and Shipman 1993). The second group is best illustrated by flaked bone bifaces known from the Middle Pleistocene of Italy (Bidditu and Celletti 2001; Radmilli and Boschian 1996; Segre and Ascenzi 1984). Finally, the third group is well characterized by Late Pleistocene bone tools from the Middle Stone Age of Africa and the Upper Paleolithic of Western Europe (Henshilwood and Sealy 1997; Singer and Wymer 1982; Straus 1995; Yellen et al. 1995).

Paleolithic implements belonging to the flaked bone tool group are particularly interesting because they may represent the co-option of reductive techniques used in Mode 1 (core-flake) and Mode 2 (bifacial) lithic technologies (Villa and d'Errico 2001). The distribution of flaked bone technology is broad in time and space; however, most of the evidence associated with the Early Paleolithic is confined to the later Middle Pleistocene (0.5–0.2 mya) (Table 2.1). Although flaked bone tools are found throughout the Paleolithic, Early and Middle Pleistocene bone artifacts were rarely fashioned into consistent or systematic forms (Villa and d'Errico 2001). In a few rare cases, however, large bones were apparently shaped like the large bifacial cutting tools (specifically handaxes), characteristic of the Acheulean Industrial Complex (Backwell and d'Errico 2005; Bidditu and Celletti 2001; Bidditu and Segre 1982; Mallegni et al. 1983; Patou-Mathis 1999; Radmilli and Boschian 1996; Shipman 1989; Villa et al. 1999; Villa and d'Errico 2001).

The arbitrary imposition of shape evident in Acheulean bifaces such as the handaxe suggests the deliberate application of certain operational concepts (i.e., “mental

Table 2.1 A list of Early Paleolithic sites where flaked bone tools have been reported

Site	Age	No. of confirmed bifaces	References
<i>Africa</i>			
Olduvai Gorge FC Bed 2 (Tanzania)	1.7–1.2 mya	1	Leakey (1971)
Ternifine (Algeria)	~700 kya	0	Geraads et al. (1986)
Grotte des Ours (Morocco)	>400 kya	0	Biberson (1961) and Clark (1977)
<i>Near East</i>			
Gesher Benot Ya'aqov, Israel	780 kya	0	Clark (1977) and Stekelis (1967)
<i>Europe</i>			
Bilzingsleben (Germany)	400–280 kya	1	Mania (1987)
Westfalen (Germany)	?	1	Günther (1988)
Verteszollos, (Hungary)	400–160 kya?	1	Dobosi (2001)
La Cotte de San Brelade (Jersey Island UK)	200–45 kya	0	Scott (1980, 1986a, b, 1989)
<i>Italy</i>			
Fontana Ranucchio	458 kya	~4	Bidditu et al. (1979), Bidditu and Celletti (2001) and Segre and Ascenzi (1984)
Castel di Guido	~300 kya	99	Mallegni et al. (1983), Mallegni and Radmilli (1988) and Radmilli and Boschian (1996)
Malagrotta	~300 kya	1	Cassoli et al. (1982)
La Polledrara di Cecanibbio	360–300 kya	0	Anzidei (2001) and Lemorini (2001)
Rebibbia-Casal de'Pazzi	240–180 kya	0	Anzidei (2001)
Cava Pompei	400 kya	0	Bidditu and Segre (1982)
Ceprano (Region)	>300 kya	0	Bidditu and Segre (1982)
Pontecorvo	300 kya?	0	Bidditu and Cassoli (1969)

Note that only a few sites have confirmed bone bifaces and many sites correspond to the temporal range of the Acheulean

templates,” “rules,” or “imperatives”) toward target artifact forms (Clark 1994; Gowlett 2006; Toth and Schick 1993; Wynn 1995). In the case of stone Acheulean bifaces, it has even been suggested that traditions of manufacture may have created distinct regional patterns at broad levels (e.g., Wynn and Tierson 1990; Lycett and Gowlett 2008). The documentation of forms similar to those seen in stone examples among Early and Middle Paleolithic flaked bone tools raises the question of whether homologous concepts of target shape were applied in their manufacture. Although many bone bifaces are morphologically similar to stone bifaces, they have so far only been compared on a subjective basis. In order to test inferences about the co-option of Mode 2 flaking techniques and the target forms that bone bifaces may indicate, the similarities in form between these two artifact classes must be quantitatively demonstrated.

During the 1960s and 1970s, subjective evaluations of biface shape were supplanted by morphometric techniques that used linear measurements and derived ratios to quantify shape attributes (Callow 1976; Isaac 1977; Roe 1964, 1968). Even so, quantifying biface morphology has been a difficult task and traditional analytical methods reduce the complexity of overall biface shape (McPherron and Dibble 1999). For instance, 3D geometric morphometric analyses of Acheulean bifaces and other Early Paleolithic cores show that traditional analyses fail to capture significant shape variables that have real utility for lithic studies, beyond just classification (Lycett 2007; Lycett et al. 2006). Geometric morphometrics represents a promising new approach to the study of biface shape variability. Geometric morphometric methods are an effective way of illustrating variability in stone tool morphology and allow shape differences to be assessed independently of size (Brande and Saragusti 1999; Buchanan 2006; Lycett et al. 2006). Furthermore, geometric morphometric analyses may use digital data, such as images, which require less time and effort to collect than traditional metric data (McPherron and Dibble 1999). In sum, a geometric morphometric approach to the question of biface shape variability accounts for more idiosyncrasies in tool form while removing the influence of size and facilitating remote lithic studies with digital datasets.

The following study applies the objective approach of geometric morphometrics to the study of 2D bone and stone biface outline shape. In order to understand how the Acheulean target form of stone bifaces compares to that of bone bifaces, 2D plan outlines of these artifacts are used as a proxy for conceptual similarity. Synchronous stone and bone biface samples are compared from the Acheulean site of Castel di Guido, Italy to test the null hypothesis that there is no difference in the 2D shape of each artifact class. The null hypothesis may be falsified if a significant difference in the 2D shape of bone and stone bifaces is found. One might predict the latter to be the case because the influence of fracture mechanics in disparate raw material types may result in different 2D shapes. Alternatively, one would also expect the null hypothesis to be rejected if different shape plans (i.e., mental templates) or manufacturing strategies were applied to bone and stone bifaces. However, if the null hypothesis cannot be rejected and there is no difference in 2D biface shape, this similarity may be attributed to shared target forms (i.e., “mental templates,” “rules,” or “imperatives”) or manufacturing strategies between the biface material classes.

Materials, Methods, and Predictions

Scanning

Outline data were obtained from the scans of 20 bone and 17 stone biface illustrations published in Radmilli and Boschian’s 1996 monograph on Castel di Guido. The stone biface sample includes several different lithologies (e.g., chert, quartzite, and limestone), but these subgroups could not be differentiated with the published information. The bone materials are assumed to be essentially homologous, although it is likely that they

came from several different large mammalian taxa such as *Elephas antiquus* or *Bos primigenius* (Radmilli and Boschian 1996). In sum, this analysis makes the assumption that intraclass differences in raw material type (i.e., chert vs. flint and elephant vs. cow bone) and their potential influence on biface shape are minor relative to interclass differences (i.e., bone vs. stone).

Bone and stone biface illustrations from Radmilli and Boschian (1996) were scanned at 300 dpi with an Epson Stylus CX46000 flatbed scanner and processed in Adobe Photoshop CS. The bone biface sample was selected from illustrations depicting the external cortical bone surface only, as opposed to the internal medullary surface. Each biface was first outlined with Photoshop's magic wand tool and the background of each scan was then deleted to reduce noise. The latter step also insured that all biface outlines were without gaps. Any gaps in biface outline detected by the magic wand tool were closed with the Photoshop pencil tool utilizing a set thickness of 1 pixel to reduce artificial distortion. Finally, all bifaces were orientated in Photoshop so their tips pointed right and each modified scan was saved as a jpeg file.

Orientation Protocol

In any comparative morphometric analysis, it is essential that artifacts be orientated in a standardized manner so that comparisons between forms are (morphologically) homologous (Lycett et al. 2006). Several methods of orientating bifaces for comparative morphometric analyses have been discussed in the literature (McPherron and Dibble 1999). This study followed Callow's (1976) method of biface orientation (also described in McPherron and Dibble 1999). Following this procedure, all bifaces were oriented around their long axis of symmetry, so that the longest orthogonal lines drawn from a central line were equal in length (Fig. 2.1b). The biface tip was thus used as a landmark to anchor the central line. McPherron and Dibble (1999) found that this orientation method provided comparable results to other methods of orientating biface outlines so that overall bilateral symmetry was maximized.

Digitization and Formatting

Two thin-plate spline (tps) geometric morphometric data files were constructed for the bone and stone jpeg images using the program tpsUtility (Rohlf 2006a). Two-dimensional outlines of the bifaces were then digitized from the bone and stone tps files using the outline tool in the program tpsDig (Rohlf 2004). Outlines were automatically traced with the outline tool from the tip on the right side of each biface image (Fig. 2.1c). Defining the biface tip as a homologous landmark in all specimens facilitated subsequent geometric alignment of shape data (MacLeod 1999). Seventy-five equidistant points were recorded by each outline in tpsDig. This number of points reproduced

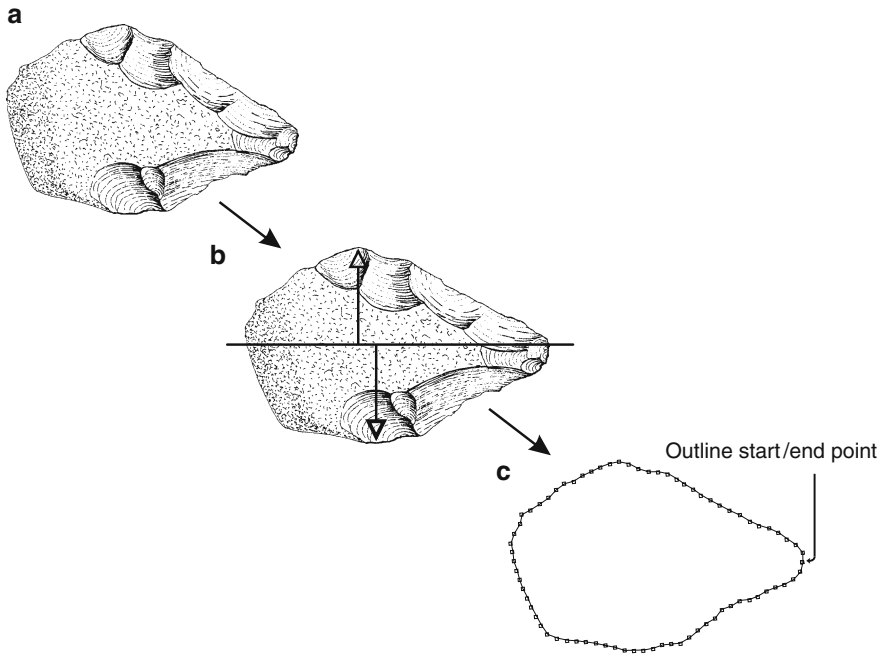


Fig. 2.1 Adjustment and acquisition of biface shape data. (a) Bitmap data from scans of biface illustrations were rotated 90° clockwise then (b) reoriented according to the technique described by Callow (1976). (c) Bitmap data were then transformed into Cartesian *XY* coordinate data in the form of a 2D biface outline with 75 equidistant points

biface shape with high fidelity. Following the digitization of all biface outlines in *tpsDig*, the bone and stone shape data were combined in *tpsUtility*. The shape data were then converted from outline to Cartesian *XY* landmark coordinates in *tpsUtility*.

Procrustes Fitting/Superimposition

The *XY* outline data file was opened in PAST (PAleontological STatistics), a program that may be used for the analysis of geometric morphometric data (Hammer et al. 2001). A 2D Procrustes superimposition of the *XY* outline coordinate data was performed and the consensus shape (i.e., sample mean) subtracted from all coordinates. This step effectively scales, rotates, and translates the *XY* coordinate data bringing all biface outlines to a standardized size, orientation, and position before subsequent analysis (Fig. 2.2) (Hammer and Harper 2006). Essentially, the shape coordinates are fitted around the centroid or group mean, which centers the specimen outlines on the origin (i.e., coordinate 0, 0). Subtracting the consensus shape or sample mean from the dataset ensures that principal component axes are centered at (0, 0) for subsequent PCA (Hammer and Harper 2006). Following the method described by

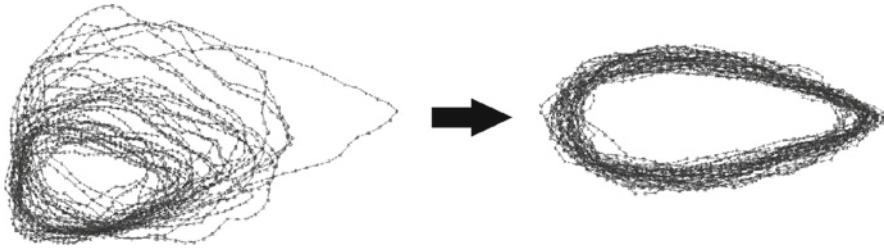


Fig. 2.2 The Procrustes superimposition process removes size, translation, and rotation (i.e., orientation) from the original shape data. Original outline data (*left*) vs. Procrustes aligned data (*right*)

Bailey and Byrnes (1990), intraobserver measurement error of this data acquisition methodology was 6.7%. Moreover, a test for significance of differences between replicate groups (five groups of five specimens each) yielded highly significant results ($p < 0.0001$), suggesting that shape differences were successfully measured by this method despite potential measurement error.

PCA of the Procrustes-adjusted XY outline data was implemented in PAST. This technique allowed the multivariate outline data to be projected into two dimensions so that the underlying shape variables could be examined and compared at a qualitative level (Hammer and Harper 2006). The principal component scores derived from the PCA also permitted a quantitative test of multivariate equality of means (MANOVA) between the two groups. One unshaped experimental bone specimen, illustrated by Backwell and d’Errico (2005, p.261), was included in the PCA for control purposes. This specimen was derived from an elephant limb bone and exhibits a biface-like plan shape, yet it reflects an initial blank form which has not been shaped through subsequent flaking in any way (Backwell and d’Errico 2005). If the Castel di Guido bone bifaces have been intentionally fashioned according to some target form, their 2D morphology should be different from this unmodified blank. Moreover, due to the fundamental differences in raw material type, one may further predict that the bone and stone bifaces will be well separated by lower-order principal components (PC 1–3) that explain a majority of the shape variance. However, if raw material differences have not significantly influenced 2D shape, one could predict that there might be overlap in principal component scatter plots.

Thin-Plate Spline Deformations

In order to interpret the meaning of the PCA results from a morphological perspective, Procrustes superimposed shape data were examined using tpsRelw, a geometric morphometric program designed for relative warps analysis (Rohlf 2006b). This program uses thin-plate splines to facilitate visualization of shape changes from the group mean along relative warp (i.e., principal component) axes (Hammer and

Harper 2006). In other words, this process allows estimated shape to be displayed at any point within a plot of any two principal components. This facilitated the translation of shape variation represented by the principal component axes into causative factors that may have affected artifact morphology.

Eigenshape Analysis

In order to ensure the reliability of morphometric results, raw outline data were subjected to an eigenshape analysis to test for MANOVA. This procedure served to replicate the MANOVA test on principal component scores utilizing a method that processes shape data differently. Eigenshape analysis is a technique used for the reduction of digitized outline shapes into a few parameters for multivariate analysis and visualization of shape variation (Hammer and Harper 2006). Eigenshape transforms XY outline coordinate data into shape functions by calculating the net deviance of tangent angles of adjacent points along the course of a digitized outline (Fig. 2.3) (MacLeod 1999). The sum of tangent angles in an outline constitute a vector describing the shape, which in this analysis is expressed as a circle-normalized net angular deviation (Φ^*)

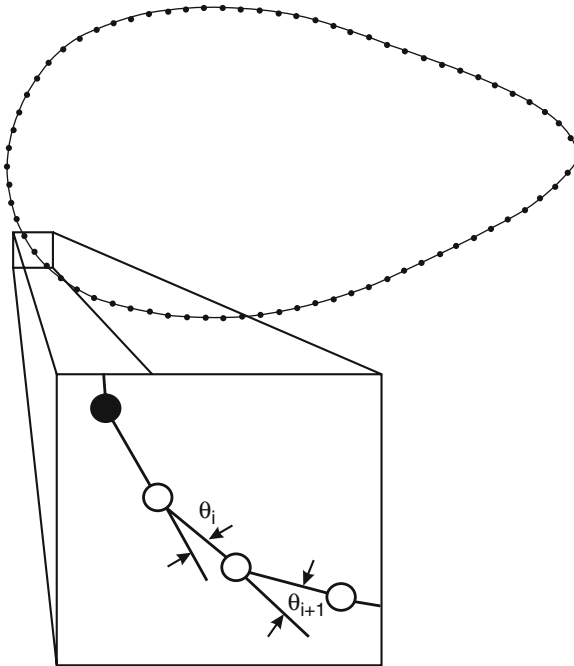


Fig. 2.3 The net angular deviation between adjacent XY coordinates in a biface outline that is transformed into a shape function during eigenshape analysis (after MacLeod 1999)

(Hammer and Harper 2006; MacLeod 1999). This normalization procedure has essentially the same effect as the Procrustes superimposition carried out in PAST for PCA allowing for dimensionless comparisons of shape to be made and evaluated with statistics. In the final step of eigenshape analysis, the variance–covariance matrix of the shape vectors is subjected to an eigenanalysis giving a number of principal components that are referred to as eigenshapes. This reduced shape data may then be exported to statistical software for further analysis (e.g., MANOVA).

Raw XY outline data were formatted in Microsoft Excel for Standard Eigenshape; a DOS program authored by Norman Macleod, which performs the eigenshape analytical procedure described above. The Standard Eigenshape program was used to convert raw XY outline data to eigenshapes that were subsequently imported into PAST for tests of MANOVA and canonical variate analysis (CVA). In PAST, MANOVA was used to test for the equality of multivariate means between the two groups while CVA is a discriminant option that produces a scatter plot of specimens along the first two canonical axes (i.e., those producing maximal and second to maximal separation between all groups) (Hammer and Harper 2006). As with the PCA, it was expected that the raw material differences would translate into significant 2D shape differences between the bone and stone biface groups. Therefore, in this analysis, it was predicted that the MANOVA test of group means (i.e., 2D shape centroids) would indicate a significant difference and CVA discriminating scatter plots would separate the two groups into distinct clusters, as assumed would occur in PCA.

Results

A qualitative examination of superimposed 2D outlines of both samples after Procrustes superimposition (i.e., with size removed) can give some indication of whether the shape model for these bifaces was similar or not (Fig. 2.4). Shape similarities and dissimilarities between the two samples are illustrated well by this simple comparison of the mean shape and specimen outlines of each group. On these grounds, the two biface groups do contrast slightly. The bone group appears more elongated and pointed relative to the stone sample, which is collectively broader and more ovate in form.

Principal Component Analysis

Contrary to expectations, results from the PCA of Procrustes superimposed data suggest that the two samples in this study are similar. Most of the variance in the shape of the PCA samples is accounted for by the first ten principal components (~95%) (Table 2.2). Scatter plots of the first three principal components with convex hulls show that there is general overlap between the two samples (Fig. 2.5). However, the observed overlap in PCA scatter plots may be a result of a small number of specimens that represent shape outliers.

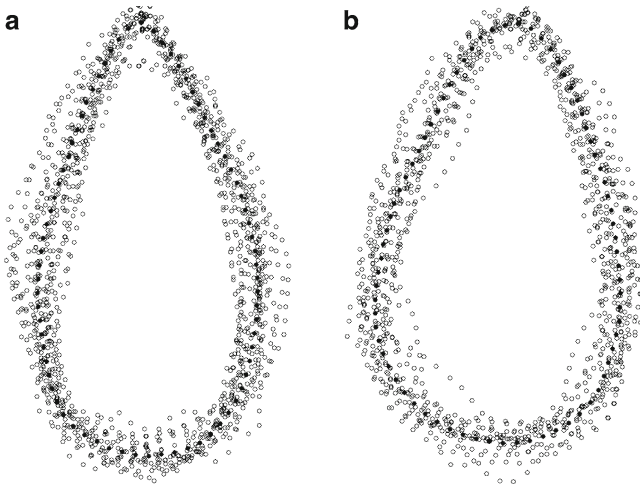


Fig. 2.4 Side-by-side Procrustes dimensionless juxtaposition of (a) bone and (b) stone bifaces from Castle di Guido. Mean biface shapes in *bold*, empty points are individual specimens

Table 2.2 Percentage shape variance explained by each principal component from the analysis

PC	Eigenvalue	% Variance	Cumulative % variance
1	0.130594	44.445	44.445
2	0.0487438	16.589	61.034
3	0.027677	9.4192	70.4532
4	0.0237399	8.0793	78.5325
5	0.0153975	5.2402	83.7727
6	0.0133478	4.5426	88.3153
7	0.00767623	2.6124	90.9277
8	0.0041865	1.4248	92.3525
9	0.0035769	1.2173	93.5698
10	0.00337478	1.1485	94.7183
11	0.00287224	0.9775	95.6958
12	0.00227543	0.77439	96.47019
13	0.00155896	0.53056	97.00075
14	0.00141924	0.48301	97.48376
15	0.00124356	0.42322	97.90698
16	0.000889937	0.30287	98.20985
17	0.000737633	0.25104	98.46089
18	0.000588693	0.20035	98.66124
19	0.00054509	0.18551	98.84675
20	0.000477487	0.1625	99.00925

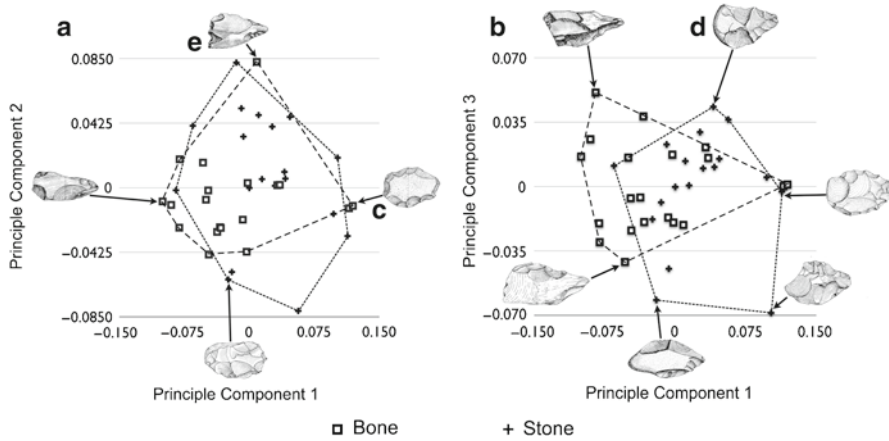


Fig. 2.5 (a) Scatter plot of principal components one and two with convex hulls, (b) scatter plot of principal components one and three with convex hulls, (c) a very ovate bone biface at the far right of principal component one, (d) intermediate stone ovate biface with a cortical butt and moderate reduction shows how incidental factors may have influenced shape, (e) the shape of this triangular bone biface may have also been influenced by incidental factors such as skeletal element morphology

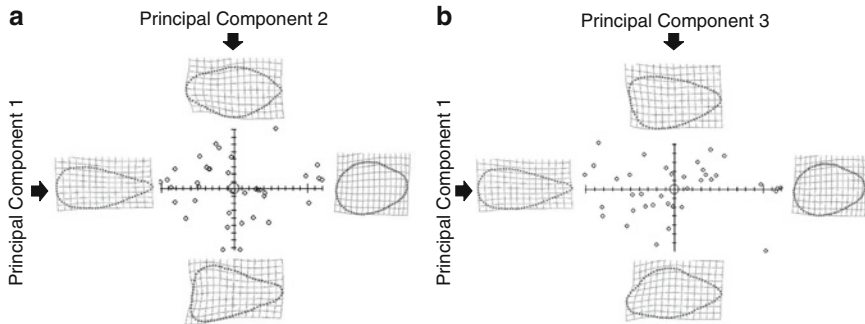


Fig. 2.6 Principal component scatter plots and deformed grids (thin-plate splines) illustrating shape deformation or changes along each principal component axis relative to the mean shape. (a) Principal component one and two. (b) Principal component one and three

By examining the thin-plate spline deformations along the relative warp axes (i.e., principal components axes) in the program tpsRelw and XY plots of specimens from the PCA scatters, it was possible to interpret the shape variation which each principal component encompassed (Fig. 2.6). Principal component one, illustrated by the horizontal axis of both illustrations in Figs. 2.5 and 2.6, represents elongation or “pointedness” vs. “ovateness” of the bifaces. Principal component two is the position of maximum breadth along the longitudinal length of the bifaces. Principal component three is more ambiguous; however, it appears to be related to the

position of maximum breadth relative to the base (i.e., base “pointedness”) and perhaps to asymmetry as well.

Looking at principal component one in the plots illustrated in Fig. 2.5, we see that the bone sample is generally more pointed than the stone sample (i.e., most points are to the left of the plot). Yet, two of the bone bifaces represent some of the most ovate-shaped tools in the study (Fig. 2.5c). Many of the ovate stone specimens, which plotted on the far right axis of principal component one, had unflaked cortical butts and were generally only moderately worked (Fig. 2.5d). The latter stone shapes contrast with the more ovate bone specimens in that the bone group is more intensively worked and nearly discoidal in plan form (see Fig. 2.5c). Considering the apparent degree of reduction, the highly ovate shape of the bone biface group along principal component one can be attributed to anthropogenic agents. In comparison, the form of the stone biface group along principal component one may be constrained by natural factors (i.e., core morphology) and/or other human-mediated causes such as a limited degree of reduction. On the opposite end of principal component one’s axis (i.e., the left side of Fig. 2.5a, b), the most pointed bone specimens are generally only partially flaked (~75% circumference), whereas the few pointed stone specimens have heavily reduced (biconcave) tips.

Looking at principal component two (Fig. 2.5a), one finds that the position of maximum breadth overlaps in both groups. This result is consistent with prior observations that biface morphology often exhibits less variability in width relative to length (McPherron 2006). The bone group, however, has a much more consistent distribution in the placement of maximum breadth, with one exception (see Fig. 2.5e); this bone specimen is triangular in shape and its shape may reflect the fact that it appears to have been fashioned from the naturally triangular morphology of the anterior crest of a tibia (additional knowledge of the third dimension would throw light on this). Finally, scatter plots of principal component three (see Fig. 2.5b) show that the stone group has some pointed bases, whereas the bone group is intermediate in base morphology.

MANOVA/CVA

Two tests for MANOVA and CVA of the first 20 principal component scores and eigenscores of bone and stone samples indicated no significant difference between the two biface groups [PCscores $F=0.8635$, $p=0.6268$ /Eigenscores $F=0.8483$, $p=0.6409$] (Fig. 2.7). These results were contrary to expectations, but in accordance with that observed from the high degree of overlap observed in PCA scatter plots and a qualitative evaluation of mean Procrustes superimposed shapes for each sample. Note that although the bone and stone samples examined here are not significantly different, they do separate slightly in the CVA scatter plot shown in Fig. 2.7. This disparity is interpreted as reflecting the elongation or “pointedness” relative to width differences represented by principal component one which explains up to 45% of the overall shape variance (see Table 2.2).

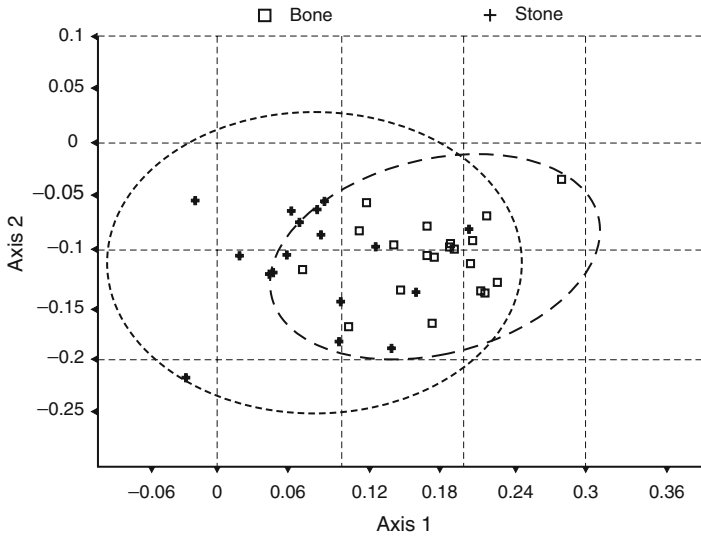


Fig. 2.7 Canonical variate analysis scatter plot of eigenscores with 95% confidence ellipses

Discussion

Evaluation of Methods

Some of the main differences in shape between the stone and bone bifaces detected in this study were variables that are captured by the length ratios and other measurements used in traditional biface shape analysis (i.e., elongation, location of maximum breadth) (e.g., Roe 1968). Therefore, if the material was available, a traditional metric analysis of these stone and bone tools would likely provide comparable 2D shape results as well as information on the omitted variable of thickness and shape of the third dimension in general. Nevertheless, the methodology applied here accounts for more idiosyncrasies in tool form and removes the influence of isometric size from the analysis, allowing allometric differences in biface form to be controlled (Crompton and Gowlett 1993; Gowlett and Crompton 1994; Lycett et al. 2006). However, this analysis was based on digitized biface images that have some important analytical limitations. An ideal morphometric analysis involves direct laboratory study of the artifacts. Accordingly, while the 2D results of this work are in some ways more instructive than a traditional metric analysis of biface shape, this study does not account for 3D variation in biface thickness and other idiosyncratic attributes that may constitute some difference not presently observed between the two groups.

Evaluation of Materials

It is possible that sample bias may have influenced the results of this study. The analyzed materials were not ideal in all respects. The Castel di Guido bifaces were selected for this study because they are assumed to be relatively synchronous and are much more closely associated relative to any other available data of this type. The biface shape data were limited to only those specimens illustrated in the Castel di Guido monograph (Radmilli and Boschian 1996). Ninety-nine flaked bone bifaces have been reported from Castel di Guido, but only 20 of these could be studied (Radmilli and Boschian 1996). Furthermore, it is probably safe to assume that those bone bifaces judged as best (i.e., specimens most convincingly modified by hominins and those which fit the typological models that archaeologists have for stone bifaces) were preferentially selected for illustration. This sampling bias could have influenced the results of this study.

The integrity of the stone sample was most likely affected in a similar way to the bone sample. The lithic assemblage from Castel di Guido was relatively deficient in stone bifaces ($n=74$) and thus the stone sample for this study was slightly smaller than the bone sample. In addition to a dissimilar relative abundance of specimens, the stone biface sample from Castel di Guido was somewhat irregular (i.e., less well-made), so it is possible that the stone biface sample used in this study is not representative of the true population of shape variation for Acheulean bifaces 300,000 years BP. Under these circumstances, collecting additional outline data from bifaces of definite temporal similarity and from within the immediate area (i.e., Latium Province) to ensure a more representative stone sample seems plausible. However, that step was beyond the present study and again it would be preferable to collect further data firsthand rather than through photographs of illustrations. Nevertheless, the results of this study indicate that, at least in some cases, knapping procedures more routinely seen in stone bifaces were applied in the manufacture of bone bifaces with sufficient fidelity that differences between samples are statistically nonsignificant.

General Considerations: Natural Vs. Artificial Forces in Biface Plan Shape

This analysis made the assumption that intraclass differences in raw material type (e.g., *Elephas antiquus* vs. *Bos primigenius*, bone/chert vs. quartzite) and their potential influence on biface shape are minor relative to interclass differences (e.g., bone vs. stone). However, bone is a complex material and analogies to stone technology can be useful, but also perilous. Unlike most isotropic crypto-crystalline lithic materials utilized by Paleolithic knappers, bone is anisotropic, breaking preferentially in a longitudinal direction in long bones (Johnson 1985). Additional variables unique to using bone as a flaking material, such as cortical bone thickness, time of acquisition

and environment (i.e., bone weathering), percussor type used, bone element morphology, mineralogical content, animal nutrition, will all influence the final shape of an artifact. Likewise stone has its own unique variables that influence tool morphology (Ashton and White 2003; Clark 1980; Jones 1979). The high degree of roundness observed on principal component one for several bifaces made on river cobbles that had unmodified butts illustrates this problem (see Fig. 2.5d). Yet the influence of natural core shape may also be related to the intensity of reduction.

McPherron (1994, 1999, 2003, 2006) has observed that size and reduction intensity are crucial factors affecting biface shape. In this study, a contrast in shape (“pointedness” vs. “ovateness”) between the two biface groups can be observed on principal component one, which may be related to reduction intensity (see Fig. 2.5). Each raw material type appears to converge in shape from an unmodified blank/core state along with the degree of reduction. At present, this relationship cannot be fully evaluated because size was removed from the analysis and no independent measure of reduction intensity was made. Nonetheless, if McPherron is correct, it may be that most of the shape variation found among the Castel di Guido bifaces can be attributed to reduction intensity (PC1=45%). A firsthand study of the Castel di Guido bifaces considering size and reduction intensity is needed to verify this observation.

It is difficult to judge for certain whether the Castel di Guido bifaces represent finished artifacts. Accounting for the degree of reduction and the possibility of recycling or resharpening is an important challenge for any analysis concerned with flaked artifact morphology and typology (Dibble 1988; McPherron 1994, 2006). However, it seems unlikely that the toolmakers of Castel di Guido could have inadvertently caused the statistical convergence of shape in the two materials accidentally through use or resharpening activities.

Many archaeologists have recognized the need to identify and exclude natural controls in order to make valid inferences on the anthropogenic controls governing Acheulean biface form (Ambrose 2001; Isaac 1986; Jones 1979; McPherron 2000). This study assessed whether natural or artificial forces were more important in determining the 2D shape of Acheulean bifaces. Two samples of extremely different materials were compared and in spite of expectations, the null hypothesis that the shapes of these artifacts were the same could not be rejected. These results may be interpreted as support for the argument that in some cases the plan shape of Acheulean bifaces is influenced more by anthropogenic (i.e., cultural) forces than natural ones (e.g., Wynn and Tierson 1990; Lycett and Gowlett 2008). Furthermore, it may be inferred from these results that the Acheulean toolmakers at Castel di Guido applied similar techniques in the production of both stone and bone bifaces (Villa and d’Errico 2001). This is not unexpected given that most Early Paleolithic evidence for flaked bone is found at Acheulean sites or in temporal contexts coeval with the latter (see Table 2.1).

Despite the results of this analysis, additional work is necessary to verify these observations and their interpretations. More robust comparative studies of flaked bone and stone artifacts are needed which specifically apply 3D approaches (e.g., Lycett et al. 2006) to larger more representative samples. These objectives

could be accomplished with an ideal sampling situation where the artifact raw materials are homogenous and well known. Experimental replicative studies of bone biface manufacture can illuminate natural variables that might affect artifact morphology (Backwell and d'Errico 2005; Stanford et al. 1981). Although the unflaked experimental bone specimen included in the study appears somewhat biface-like in shape (see Backwell and d'Errico 2005: 261), the results of the PCA shows that it can be distinguished in plan form from the true bone and stone bifaces from Castel di Guido (see Fig. 2.5). Even so, additional experiments and morphological analyses of flaked large mammalian bone are necessary to further support this observation.

Conclusions

A geometric morphometric analysis of plan shape from digitized images of stone and bone biface artifacts was undertaken to quantitatively evaluate 2D morphological similarity. The results indicate that the null hypothesis that there is no difference in the 2D shape of each artifact material class cannot be rejected. This result may be interpreted as evidence that 2D shape concepts of Acheulean stone bifaces were directly applied in the production of bone bifaces.

Therefore, this work quantitatively validates what is apparent from illustrations of these bone bifaces, namely, that they are congruent in plan shape to Acheulean stone bifaces. Additional studies concerning bone technology and geometric morphometric analyses, particularly those incorporating the third dimension will offer more insight and perhaps alternative explanations for the 2D morphological correspondence seen in the Castle di Guido bifaces. Ultimately, further analyses with this methodology may test the strength of these conclusions by examining the controls in 2D biface form using distinct lithic raw materials from the same archaeological context.

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