Journal of Paleolithic Archaeology (2020) 3:33–58
https://doi.org/10.1007/s41982-019-00033-5

Beyond a Cutting Edge: a Morpho-technological Analysis of Acheulian Handaxes and Cleavers from Gesher Benot Ya'aqov, Israel

Gadi Herzlinger[1,2] · Naama Goren-Inbar[1]

Published online: 6 July 2019

Abstract
Handaxes and cleavers are among the most iconic stone tool types of the Acheulian Technocomplex. As they share several morphological and technological traits, they are considered to belong to the wider category of "bifaces" or "large cutting tools." Concurrently, each of these types presents substantial morphological and technological variability across time and space. Thus, the criteria on which their typological classification is based are relatively vague, varying among different research approaches and schools. Furthermore, the factors governing the variability within and between these types remain controversial, resulting in several competing and non-comprehensive hypotheses. In this study, we apply a combination of 3D geometric morphometric shape analysis with standard typo-technological attribute analysis to a large sample of handaxes and cleavers from the Acheulian site of Gesher Benot Ya'aqov, Israel. The results indicate that in each of these types, priority was given to different morphological traits. In light of common hypotheses explaining variability in Acheulian bifacial tool assemblages, it appears that while in cleavers these traits are mainly related to functional-utilitarian aspects, in handaxes, they may be related to social aspects as well.

Keywords Acheulian · Handaxes · Cleavers · 3D geometric morphometrics · Symmetry · Gesher Benot Ya'aqov

✉ Gadi Herzlinger
gadi.herzlinger@mail.huji.ac.il

[1] Institute of Archaeology, The Hebrew University of Jerusalem, Mt. Scopus, 9190501 Jerusalem, Israel

[2] The Jack, Joseph and Morton Mandel School for Advanced Studies in the Humanities, The Hebrew University of Jerusalem, Jerusalem, Israel

Introduction

One of the most distinctive traits of the Lower Paleolithic Acheulian Technocomplex is the production of stone tools referred to as “bifaces” or “large cutting tools” (LCTs), of which the three main types are handaxes, cleavers, and knives (Kleindienst 1962). They are usually characterized by several common attributes: their relatively large size, the use of a bifacial technique, and the intentional imposition of a particular morphology by their knapper. These traits form a watershed separating the Acheulian assemblages from the preceding Oldowan assemblages and are usually interpreted as representing substantial developments in terms of hominin cognitive capacities and behavioral complexity (Semaw et al. 2009).

The handaxe is the most iconic type of the three, usually considered the hallmark of the Acheulian culture. It is “characterized by a cutting edge around the entire circumference of the tool... usually bilaterally symmetrical, and more-or-less biconvex in major and minor sections”, although this morphology can vary greatly between individual artifacts in their planforms, sections, symmetries, and refinement (Kleindienst 1962: 85). It is among the earliest of the types identified as Paleolithic artifacts by European scholars more than 150 years ago and is exceptional in terms of its geographical and chronological extent, appearing throughout the Old World for more than 1.5 million years (Wynn 1995; Sharon 2007; Lycett and Gowlett 2008). It is so strongly associated with the Acheulian that its presence or absence in assemblages is sometimes used to define the geographical and chronological range of the Acheulian Technocomplex (Bar-Yosef and Wang 2012; Wang et al. 2012). As such, it is one of the most intensively studied tool types, with abundant research articles and books focusing on its various attributes and their significance for ancient hominin behavior.

The cleaver is similar in most morphological aspects to the handaxe, while differing in its broad and unretouched distal working edge. It too displays substantial morphological variability (Kleindienst 1962; Sharon 2007). In the vast majority of cases, this type appears alongside and in association with handaxes. However, as it is substantially more restricted in its geographical and chronological extents and is much less common in Central and Northwestern Europe, it has received much less attention (Santonja and Villa 2006). Furthermore, the definition of the cleaver is less clear-cut than that of the handaxe, as researchers have used this term to describe various artifacts on the basis of different criteria. For example, in traditional British Paleolithic research, the cleaver has been defined by the relative width and straightness of the distal edge alone (Roe 1964; Wymer 1968), while in African Paleolithic research, other criteria such as the blank type and the configuration of the distal edge have been used (Tixier 1956; Kleindienst 1962).

Despite the widespread adoption of this typological division, the great morphological and technological variability within each of these groups seriously weakens their objective classification and therefore prevents a universal application of this terminology (see discussion in Sharon 2007). Hence, in cases such as the Azraq Basin (Rollefson 1983) or Tabun Cave (Matskevich 2006), artifacts classified as cleavers by one definition would be classified as oval handaxes by a different definition. Consequently, in assemblages containing both types, they are often considered two variants within the wider LCT category (Kleindienst 1962; Isaac 1969; Isaac and Isaac 1977; Leakey and Roe 1994; Clark 2001; Goren-Inbar et al. 2018). Some researchers have even considered them a single tool type with a high and grading morphological variability (Isaac and Isaac 1977).

Many studies have addressed the morphological variability of Acheulian bifacial tools and suggested numerous factors that may affect it. Although these explanations focus specifically on variability within the handaxe class, they could theoretically be applied to the handaxe-cleaver division as well. Perhaps the most common explanations relate to the chrono-spatial patterning of the various morphologies, considering aspects such as hominin cognitive development, cultural transmission processes, and environmental settings as the main factors behind biface variability (Roe 1969; Wynn and Tierson 1990; Norton et al. 2006; Lycett and Gowlett 2008; Lycett and von Cramon-Taubadel 2008; Beyene et al. 2013). Other studies have suggested production technology, raw material constraints, the knappers' skill level, and aspects related to the tools' life histories (such as resharpening and maintenance) as having the most significant effect on their morphology (White 1998; McPherron 1999; Shipton 2013, 2018; Sharon and Barsky 2016; Herzlinger et al. 2017a). Lastly, both utilitarian and non-utilitarian functions of these tools have been suggested as impacting their final morphology (O'Brien 1981; Mitchell 1996; Kohn and Mithen 1999; Vaughan 2001; Spikins 2012).

In recent years, various novel geometric morphometric shape analyses methods were used to study the morphological variability of prehistoric lithic artifacts and gain insights regarding the factors affecting it (e.g., Lycett 2008; Grosman et al. 2011; Iovita and McPherron 2011; Wang et al. 2012; Eren et al. 2014; Serwatka 2014; Archer et al. 2015; Lycett et al. 2016; García-Medrano et al. 2018; McNabb et al. 2018; Weiss et al. 2018; Hoggard et al. 2019; Viallet 2019). Among these methods, one of the most powerful and popular is the 3D homologous landmarks-based geometric morphometric shape analysis (3DGM) (Lycett et al. 2006; Lycett 2008; Archer and Braun 2010; Lycett et al. 2010; Archer et al. 2015; Chacón et al. 2016; Herzlinger et al. 2017a). This method was recently adapted into a comprehensive computer software for the analysis of archeological artifacts (Herzlinger and Grosman 2018) and was applied to study the morpho-technological variabilities of handaxes and cleavers at Gesher Benot Ya'aqov (GBY) (Herzlinger et al. 2017b; Herzlinger and Goren-Inbar 2019a). In the present study, we will present a comparison between these two types in order to shed light on possible factors that may underlie their morpho-technological differences. To do so, we combine two methodological approaches, 3DGM and typo-technological attribute analysis, and apply them to a sample of bifacial tools from the Acheulian site of GBY, Israel. The wealth of individual biface assemblages and the vast temporal extent of the bifacial tools at the site enable in-depth study of these aspects. First, we divide the sample into two typological classes (handaxes and cleavers) based on an explicit technological definition. Next, we perform an in-depth analysis of the morphological differences between the two types as well as analyze differences in the technological procedures used for their production and their effect on various morphological aspects. Finally, we interpret the results in the light of various functional studies and speculate on the functions that these tools were intended to fulfill and the motivations behind their production.

Materials and Methods

Materials

The material analyzed in this study originates in the Acheulian site of GBY, Israel. The site, located in the Northern Jordan Valley and dated to 780 ky BP, has a depositional sequence spanning 100 ky, all of which is assigned to the Acheulian Technocomplex. It was excavated during seven field seasons, and many of its various cultural and environmental aspects have been published in detail in four monographs and a multitude of articles (see Goren-Inbar et al. 2002; Alperson-Afil and Goren-Inbar 2010; Rabinovich et al. 2012; Goren-Inbar et al. 2018 and references therein). The lithic industry at the site displays three major modes of raw material exploitation (basalt, limestone, and flint), each consisting of several distinct reduction sequences used for tool production. The *chaîne opératoire* of basalt is dedicated almost exclusively to the production of large bifacial tools, with a minor component of percussive tools and massive scrapers manufactured from its by-products (Goren-Inbar et al. 2018). The technological tradition reflected by this *chaîne opératoire* is that of the "Large Flake Acheulian" (LFA), which consists of the modification of bifacial tools on large flake blanks struck from giant cores reduced by a number of core design methods (Madsen and Goren-Inbar 2004; Goren-Inbar 2011; Goren-Inbar et al. 2018). The bifacial assemblages analyzed in this study are mainly derived from the depositional complex of Layer II-6, which comprises eight superimposed distinct archeological horizons that yielded the vast majority of the cultural material at the site. An additional assemblage of cleavers is derived from two superimposed layers in area C (Table 1). All the archeological levels from which the assemblages were excavated were found in pristine condition and represent short-lived occupation events that were rapidly sealed and were not disturbed by postdepositional processes (Goren-Inbar et al. 2018; see detailed discussion and references in Herzlinger and Goren-Inbar 2019a).

Overall, the sample comprises of 222 handaxes and 141 cleavers. All artifacts analyzed in this study are available as 3D models in *.3dl format along with all their typo-technological observation at a public online repository (Herzlinger and Goren-Inbar

Table 1 Typological and assemblage composition of the sample arranged from youngest at the top to oldest at the bottom

	Type	
Level	Handaxes	Cleavers
Area C	0	18
II-6/L1	35	10
II-6/L2	16	10
II-6/L3	7	11
II-6/L4	96	54
II-6/Lb4	35	15
II-6/L5	5	7
II-6/L6	13	7
II-6/L7	15	9
Total	222	141

2019b). Although the total number of bifacial tools recovered from the site is higher, only complete items or those with slightly broken tips or minimal surface exfoliation were selected in order to prevent bias in the results of the morphometric analysis (Grosman et al. 2011). Furthermore, only basalt tools were included in this analysis, since more than 99% of the cleavers and 91% of the handaxes at the site were produced on this raw material. Since all the basalt bifacial tools derive from the same general *chaîne opératoire* conforming to the LFA, they were all produced on large flake blanks.

Methods

Morphological Analysis

For the analysis of the morphological aspects of the tools, a 3D homologous landmarks-based geometric morphometric shape analysis was conducted in order to provide an objective, quantitative, and reproducible description of within- and between-group shape variability. Each artifact was scanned using a structured light camera and a turntable to produce a high-resolution 3D digital model (Grosman et al. 2008; Grosman et al. 2014). Next, each of the models was automatically positioned using an explicit geometric protocol. First, each artifact was oriented to planform view so that its plane of intersection between the dorsal and ventral faces was set parallel to the XY plane, based on the distribution of its normal vectors. Next, the artifact was rotated about the Z axis so that its plane of maximal bilateral symmetry was set parallel to the Y axis. While these last two stages were preformed automatically, artifacts were then manually flipped and rotated in 90 degrees intervals so that their dorsal face would always point toward the positive end of the Z axis, and that their distal end would always point toward the positive end of the Y axis (Herzlinger and Grosman 2018). Next, a deformed grid of 50 × 50 homologous landmarks was deployed on each of its two faces following another explicit geometric protocol. This consisted of the placing of 50 equidistant parallel latitudes along the maximal length of each artifact. The length of each latitude reflects the width of the artifact at that specific length interval. Next, 50 equidistant points were placed along each latitude. In fact, each of these points is two different landmarks, one placed on each face, so that their X and Y values are identical but they differ in their Z value. The top and bottom latitudes are not parallel to the other, but they capture the exact morphologies of the proximal and distal ends of the artifacts (Herzlinger et al. 2017a; Herzlinger and Grosman 2018). This resulted in the collection of 5000 3D landmarks per item, representing in high resolution its complete volumetric configuration.

The landmark lists of all artifacts were combined into a comprehensive dataset that was subjected to standard multivariate statistical procedures and analyses consisting of generalized Procrustes analysis (GPA) and principal component analysis (PCA) (Dryden and Mardia 1998). GPA is used as a superimposition procedure to remove variability that is not shape-related (stemming from differences in scale, location, and orientation in space), enabling the separate analysis of the morphology and size of the tools. PCA is used to reduce dimensionality, identify the main shape trends that underlie the shape variability, and calculate the mean shapes and morphological variability of various subgroups in the sample. The morphological variability was calculated as the mean multidimensional Euclidean distance between each item in the group and the group centroid (corresponding to the position of the group's mean shape in shape space) (Herzlinger and Grosman 2018; Herzlinger and Goren-Inbar 2019a). This allows the description of specific shape trends as well as the spatial distribution of the variability. The distribution of variability across the three spatial dimensions (X, Y, and Z corresponding to relative width, length, and thickness respectively) is also expressed by these results. In addition, the size of each item in the sample was described using the centroid size index, corresponding to the total 3D Euclidean distance of all landmarks from the item's centroid reflecting the item's volume. Differences in morphometric indices between various subgroups were tested for statistical significance using the non-parametric Wilcoxon rank sum test. This test was selected in contrast to parametric test as it does not make any assumptions regarding the distribution of the population. Furthermore, when applying it to inter-point data in a multidimensional space, such as the shape space used in this study, it allows to reliably test differences in cases where observations dimensionality exceeds the sample size (Marozzi 2016; Herzlinger and Grosman 2018). Both data acquisition and analytical phases were performed using the AGMT3D V3.0 software package (Herzlinger and Grosman 2018; for further details of the 3DGM method see Herzlinger et al. 2017a; Herzlinger and Goren-Inbar 2019a).

Lastly, the landmarks data was used to calculate the degree of deviation from perfect bilateral and bifacial symmetries of each item in the sample. For bilateral symmetry, this was done by measuring the mean 3D Euclidean distance between a mirror reflection of the landmarks placed on one lateral half of each object and the corresponding landmarks on the other half (Fig. 1a). The same procedure was performed for bifacial symmetry, but on the two opposing faces (Fig. 1b). In a perfect bilaterally or bifacially symmetrical item, these indices will have the value of 0, with increasing values indicating less symmetrical items. Calculations of these indices were performed on the landmarks data using Matlab R2017b. Nominal logistic fit and linear regression models were conducted using SAS JMP 14.0. In all statistical analyses used in this study, significance level was set to 5%.

Typo-Technological Classification

The items in the sample were subdivided into typological and technological groups in order to analyze the morphological difference between the two types and the effect of

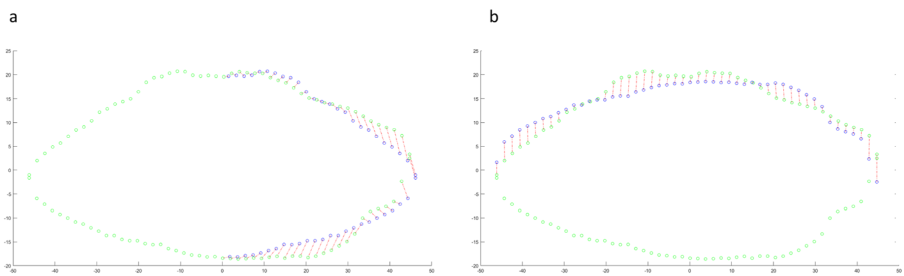

Fig. 1 Visualization of deviation from perfect bilateral and bifacial symmetry. Green points represent the landmarks placed along a single latitude (transversal section) of a handaxe. **a** Blue points represent a mirror reflection of the left side landmarks. **b** Blue points represent a mirror reflection of the lower (ventral) face landmarks. Red lines represent the degree of deviation from perfect symmetry of each individual landmark

different production procedures on their morphology. The primary division is the typological classification into handaxes and cleavers. This was based on the typological definition used for the detailed analysis of the entire lithic assemblage from GBY (Goren-Inbar et al. 2018). While the identification of handaxes is fairly clear-cut and unambiguous, the variety of analytical approaches makes the identification of cleavers more difficult. Here, the definition of cleavers is based on a combination of Roe (1964) and Tixier (1956) in which a cleaver is a bifacially shaped flake tool possessing an unretouched distal edge that is formed by an intersection between the two flat surfaces of the ventral and dorsal faces and must be wider than half of the tool's maximal width (Goren-Inbar et al. 2018).

Following this classification, each typological group was subdivided into subgroups following various technological criteria. The attributes used for these classifications are the direction of the blow used to remove the flake blank from the core and the blank's striking platform. These two attributes mainly describe technological procedures related to the production of the blank on which the tool was designed. Additional attributes analyzed are the number of flake scars on each of the tools' surfaces and the mode of modification performed after the blank was detached (Herzlinger et al. 2017b; Goren-Inbar et al. 2018). These two attributes provide information on technological procedures performed after the blank was struck from the core and selected to be modified into a finished tool. While the former attribute provides an indication of the intensity of post-detachment modification of the blank, the latter is applicable only to cleavers and describes the way in which the typical distal-dorsal configuration was designed (Herzlinger et al. 2017b). In addition, in order to reflect not only the intensity of post-detachment investment but also the intensity of reduction, the total number of scars on each artifact was adjusted in accordance with its centroid size. This was performed by dividing the total number of scars on each artifact by the centroid size multiplied by 100 in order to express the scar density. The scar density index (SDI), calculated as the number of scars divided by the artifact's surface area, was shown to be a strong indicator of the reduction intensity, and specifically of the proportion of mass remaining from the original nodule at the given stage of reduction, regardless of reduction strategy (Clarkson 2013). Despite the fact that SDI should be based on surface area and not volume, the fact that all artifacts are modified on flake blanks, having a roughly similar volume to surface area ratio, allows the use of the latter without causing substantial bias (Clarkson 2013).

The direction of blow attribute can be assigned three different values: "end-struck," describing items for which the blow was delivered parallel to the maximal length; "side-struck," items for which the blow was delivered perpendicular to the maximal length; and "special side-struck," items for which the blow was delivered at an angle of about 45° to the maximal length (Isaac and Keller 1968; Goren-Inbar et al. 2018). The striking platform attribute can be assigned five different values: "plain," describing items with a flat and unprepared striking platform; "cortical," items whose striking platform is mostly covered by cortex; "dihedral," items whose striking platform presents two facets separated by a ridge; "facetted," items whose striking platform presents more than two such facets; and "removed," items that do not retain their striking platform (Goren-Inbar et al. 2018). The number of scars attribute is a quantitative one describing for each of the tool's faces the number of flake scars whose maximal dimension is larger than 2 mm. These were manually counted by direct observation using a standard caliper. The mode of modification attribute refers only to cleavers and can be assigned three different values: "scar of core," describing items whose distal-dorsal configuration is created by an intersection between the ventral face and the negative scar of a flake removal that existed on the core prior to the removal of the blank; "unmodified Kombewa surface," items whose distal-dorsal configuration is created by the intersection of two unmodified ventral surfaces of a Kombewa flake blank; and "delineated by knapping," items whose distal-dorsal configuration is created by knapping used to delineate a flat or convex unmodified surface on the dorsal face intersecting the ventral face (Herzlinger et al. 2017b). Description of the distributions of the various attributes and calculation of linear regression and Pearson's Chi-square statistical tests were performed using SAS JMP 14.0.

Results

The first and most striking result of the morpho-typo-technological analysis is that there is a morphological overlap between individual handaxes and cleavers in the two shape trends explaining the highest proportions of variability in the sample, as reflected by the first two principal components (Fig. 2). This means that the general morphology of both handaxes and cleavers occupies similar locations in the most prominent 2D shape plane. Hence, individual specimens in the two groups can be quite similar to one another. Nevertheless, when considering the artifacts in terms of typological groups, it is clear that, despite this overlap, handaxes are more skewed toward the negative part of PC01, while cleavers are skewed toward the opposite direction. As PC01 describes a shape trend ranging from pointed to broad distal ends on the negative and positive extremities respectively, this observation is quite trivial. Such evident differences in morphology are also observed on the first four principal components, together explaining about 45% of the variability in the sample. This is reflected in the morphological difference between mean shapes of the two groups, which was tested using a Wilcoxon rank sum test and was found to be statistically significant ($n1 = 141$, $n2 = 222$, rank sum = 120,718, $p < 0.01$) (Fig. 3). Moreover, the difference in mean shape between handaxes and cleavers remains significant when inspected in the assemblages of each individual archeological horizon.

For further confirmation of the morphological difference between handaxes and cleavers, nominal logistic fit models were applied to the sample, with the typological class being the dependent variable and the first 36 principal components, together explaining 90% of the variability in the sample, being taken as independent variables. This value was selected as an optimum point, balancing between maximization of the described morphological variability and minimization of the number of redundant shape trends and hence reduces chances of overfitting. A backward stepwise selection procedure was applied, so that only variables with a probability lower than 0.05 in their likelihood ratio test were used in the models. This resulted in the selection of 18 principal components that complied with the criterion for a training set consisting of 75% of the observations in the sample. Another 25% were left out to be used as a validation set. The model was applied to three additional training and validation sets with similar proportions, randomly selected from the sample. The models provided correct classification rates in the different validation sets, ranging between 82 and 87%.

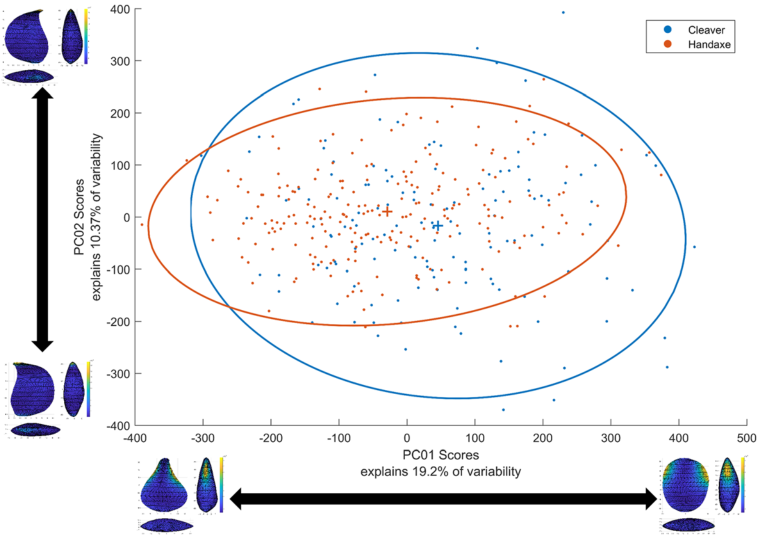

Fig. 2 Scatterplot of the first two principal components. Illustrations represent hypothetical objects situated at the extremities of each principal component, reflecting the shape trend it represents. + signs represent the mean shapes (centroids) of each group. Ellipses represent 95% confidence ellipses

These results too indicate that, despite the perceived morphological overlap in the two first principal components, handaxes and cleavers are significantly different and can in fact be distinguished based on morphological criteria.

Another important result relates to the differences in shape variability within each of the groups, as the cleavers are more morphologically variable than the handaxes. In Fig. 2, this difference is mostly observable on PC02, reflecting a morphological trend that ranges from objects whose distal ends are highly skewed to the left on the negative extremity to items whose distal ends are highly skewed to the right on the positive one.

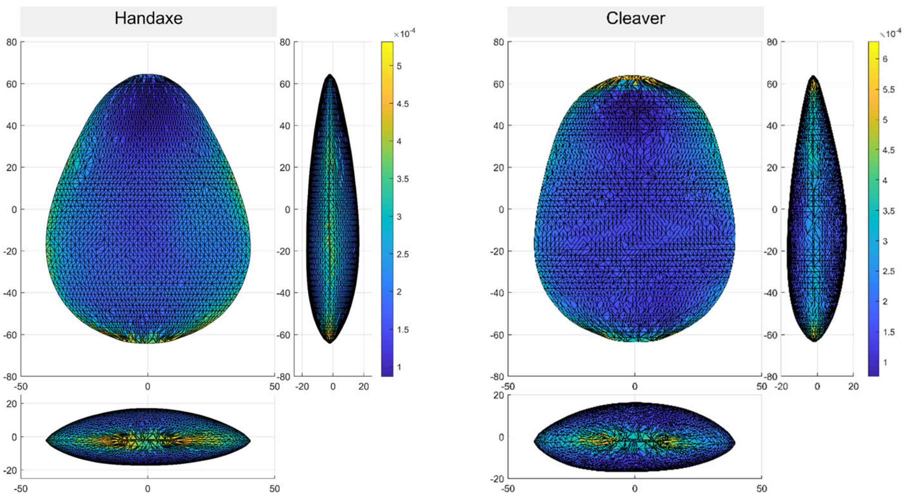

Fig. 3 The mean shapes of handaxes and cleavers. Color coding represents the relative degree of variability of each individual landmark reflecting the spatial distribution of variability across the tools

The pattern in which cleavers are more morphologically variable than handaxes occurs consistently in most shape trends, explaining more than 1% of the variability in the sample. This is indeed reflected in the general shape variability, measured as the mean multidimensional Euclidean distance of all items in the group to the group centroid, with values of 350.36 and 310.14 for cleavers and handaxes respectively. This 11% difference in total shape variability was tested using a Wilcoxon rank sum test and was found to be statistically significant (n1 = 141, n2 = 222, rank sum = 30,563, $p < 0.001$). In order to gain a better understanding of this difference, the spatial and dimensional distributions of this variability were inspected. Figure 3 shows that while in cleavers the variability is concentrated on the distal end and distal-lateral edges, in handaxes, it is more evenly distributed along the proximal and medial-lateral edges, as well as in the central parts of the tools. If the tools are divided into fifths along their maximal lengths, it can clearly be seen that most of the variability in the cleavers group stems from differences in the upper fifth of the tools (Table 2). Furthermore, the vast majority of that variability stems from differences in the X dimension corresponding to relative width. In light of the shape trend represented by PC02, which reflects differences in the direction of the distal skewness of the tools, this result can be interpreted as variability stemming from the different directions in which the distal end of the cleavers is slanted. In addition, it should be noted that in terms of the Z dimension, corresponding to relative thickness and hence to the characteristic dorsal-distal configuration of the cleavers, the upper fifth of the cleavers shows the lowest variability. Thus, if only the lower four fifths of both groups are considered, the cleavers' variability value is 252.8, which is quite similar to the 260.5 variability value of the handaxes. In addition, the spatial and dimensional distributions of the variability in these parts of the tools are remarkably similar.

Table 2 Distribution of morphological variability in handaxes and cleavers along the five fifths of the maximal length and three spatial dimensions

		Handaxes				Cleavers			
		X	Y	Z	Total	X	Y	Z	Total
Distal fifth	Variability	23.9	7.0	18.8	49.7	75.3	6.8	15.6	97.6
	%	7.7	2.3	6.1	16.0	21.5	1.9	4.5	27.9
4/5	Variability	25.9	2.2	27.9	56.0	37.8	2.5	23.1	63.4
	%	8.3	0.7	9.0	18.1	10.8	0.7	6.6	18.1
3/5	Variability	26.3	0.7	36.0	63.0	19.0	1.0	32.7	52.7
	%	8.5	0.2	11.6	20.3	5.4	0.3	9.3	15.1
2/5	Variability	18.8	2.4	38.0	59.3	16.3	2.5	35.2	54.0
	%	6.1	0.8	12.3	19.1	4.6	0.7	10.0	15.4
Proximal fifth	Variability	35.8	7.2	39.2	82.2	37.6	6.9	38.1	82.6
	%	11.5	2.3	12.6	26.5	10.7	2.0	10.9	23.6
Total	Variability	130.6	19.6	159.9	310.1	186.0	19.6	144.7	350.4
	%	42.1	6.3	51.6	100.0	53.1	5.6	41.3	100.0

A different aspect of the morphology of the tools is their degree of symmetry. Table 3 shows the summary statistics of the degree of deviation from perfect 3D bilateral and bifacial symmetry for each group. It can be seen that while in terms of bilateral symmetry cleavers are some 23% less symmetrical, in terms of bifacial symmetry, they are only about 0.9% less symmetrical (Table 3). Wilcoxon rank sum tests confirm that the former difference is statistically significant (n1 = 141, n2 = 222, rank sum = 31,962, $p < 0.001$) while the latter is not (n1 = 141, n2 = 222, rank sum = 26,455, $p = 0.41$). Lastly, analysis of the sizes of the typological groups using the centroid size index indicates that cleavers are 7.6% larger than handaxes (Table 3). This difference too was tested using a Wilcoxon rank sum test and was found to be statistically significant (n1 = 141, n2 = 222, rank sum = 29,539, $p < 0.001$). However, a standard least square regression model with the centroid size as the dependent variable and the first three principal components as the independent variables does not seem to indicate a strong correlation between the sizes and shapes of the artifacts, with an R^2 value of 0.19 and RMSE of 481.

While the results of the morphometric analysis provide the different patterns in the morphology of the tools, the technological attributes shed light on their production process and the technological procedures employed by their makers. Examination of the different direction of blow groups reveals a highly similar pattern for both types. If we ignore the relatively large indeterminate group ($n = 43$, 30.5% of cleavers; $n = 114$, 51.4% of handaxes), there is no significant difference between handaxes and cleavers in

Table 3 Summary statistics for deviation from perfect bilateral and bifacial symmetry and centroid size for handaxes and cleavers

		Cleavers	Handaxes
	N	141	222
Deviation from perfect bilateral symmetry	Max	10.7	9.53
	Median	5.36	4.15
	Min	2.59	1.89
	Mean	5.46	4.43
	Std Dev	1.6	1.46
	Std Err	0.13	0.1
Deviation from perfect bifacial symmetry	Max	7.39	8.56
	Median	4.42	4.37
	Min	3.38	3.36
	Mean	4.63	4.59
	Std Dev	0.84	0.88
	Std Err	0.07	0.06
Centroid size	Max	4304.3	4444.1
	Median	3275	3056.5
	Min	1944.8	1766.2
	Mean	3270.1	3038.5
	Std Dev	503.2	534
	Std Err	42.4	35.8

the distribution of blow directions (Pearson's $\chi^2 = 0.528$; $p = 0.77$) (Table 4). The frequencies of the different directions of blow are nearly identical between the two types, with end-struck blanks being the least common and side-struck and special side-struck being the most common in both cleavers and handaxes. In terms of shape variability, a similar pattern to that observed for the general typological groups, in which handaxes are more homogeneous than cleavers is apparent. Furthermore, the differences in shape variability observed between the different directions of blow within each type are highly similar; both handaxes and cleavers produced on end-struck blanks are significantly more variable than those produced on side-struck or special side-struck blanks. Moreover, for both types, the side-struck group is more variable than the special side-struck one, although this difference is not statistically significant in either case.

In terms of mean shape, the pattern is mostly dependent on the typological classification in accordance with the general observations for the two typological classes. Thus, irrespective of the direction of blow group, the mean shapes of cleavers and handaxes are similar within them and distinct between them (Fig. 4). For all directions of blow among the cleavers, the morphological variability mostly stems from differences in the distal end (Fig. 4). The handaxes present a more complex pattern in which for the end-struck and special side-struck groups, the variability is mostly concentrated around the proximal end and the lower lateral edges. In the side-struck group, however, the variability is more dispersed along the entire length of the lateral edges. In terms of the dimensional distribution, the patterns are again clustered following the typological classification and are generally in accordance with those observed for the general typological groups (Table 5).

Similar patterns emerge from examination of the morphological aspects of the different striking platform groups for each tool type. If we ignore the indeterminate group ($n = 14$, 10% of cleavers; $n = 83$, 37.7% of handaxes), there is a slightly significant difference in the distribution of striking platform types between the handaxes and cleavers (Pearson's $\chi^2 = 10.125$; $p = 0.038$) (Table 6). However, this mainly stems from the presence or absence of small categories such as dihedral, facetted, and cortical, which comprise six, three, and one tools respectively in both types. In both cleavers and handaxes, the two categories of plain and removed striking platforms account for over 95% of the observations, with removed striking platform being the most common and presenting slightly higher frequencies among the cleavers. In terms of shape variability of the different groups, there appears to be a stark difference between the handaxes and the cleavers. While in the former the plain striking

Table 4 Distribution and morphological variability of the different direction of blow groups in handaxes and cleavers

Direction of blow	Handaxes			Cleavers		
	N	%	Variability	*N*	%	Variability
End-struck	23	21.3	317.88	23	23.5	384.27
Side-struck	40	37	294.73	39	39.8	337.46
Special side-struck	45	41.7	289.73	36	36.7	328.61

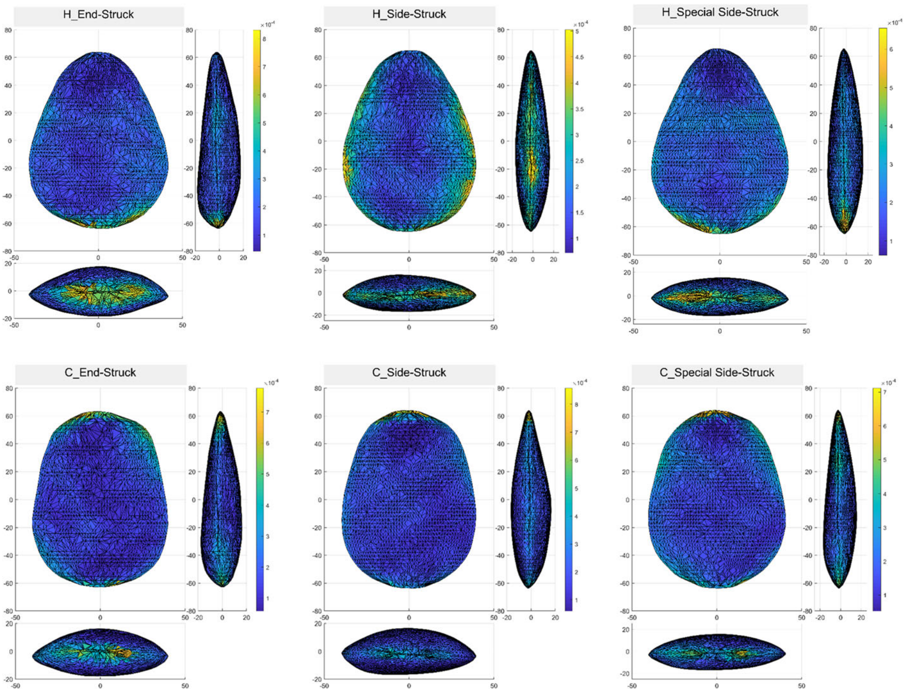

Fig. 4 Mean shapes of each direction of blow group for handaxes and cleavers. Color coding represents the relative degree of variability of each individual landmark reflecting the spatial distribution of variability across the tools

platform group is significantly more variable than the removed group (Wilcoxon's rank sum = 4111, $p < 0.01$); in the latter, there is no significant difference between the two groups. Nevertheless, similarly to the general trend, the cleaver groups are consistently more variable than the handaxe groups.

In terms of mean shape and spatial and dimensional distributions, the patterns for the different striking platform groups in each of the types are very similar to those observed

Table 5 Distribution of morphological variability in the different direction of blow groups across the three spatial dimensions

	Number	Variability	Differences in X (%)	Differences in Y (%)	Differences in Z (%)
End-struck handaxes	23	317.88	45.53	7.82	46.64
Side-struck handaxes	40	294.73	42.21	6.18	51.61
Special side-struck handaxes	45	289.73	40.76	5.29	53.95
End-struck cleavers	23	384.27	56.24	7.11	36.65
Side-struck cleavers	39	337.46	57.01	4.7	38.29
Special side-struck cleavers	36	328.61	54.92	6.3	38.78

Table 6 Distribution and morphological variability of the different striking platform groups in handaxes and cleavers

Striking platform	Handaxes			Cleavers		
	N	%	Variability	*N*	%	Variability
Removed	82	59	289.62	88	69.3	349.99
Plain	52	37.4	323.5	34	26.7	344.59
Dihedral	5	3.6	270.38	1	0.8	–
Facetted	0	0	–	3	2.4	321.15
Cortical	0	0	–	1	0.8	–

for the directions of blow and the general typological groups (Fig. 5, Table 7). In other words, the mean shapes of both cleavers and handaxes do not differ significantly between the different striking platform groups. Concurrently, however, the mean shapes of handaxes and cleavers differ significantly from one another regardless of whether their striking platform is plain or removed. In terms of spatial and dimensional distributions, the pattern seems to agree generally with that observed for the general typological groups, in which a more substantial proportion of the cleaver's morphological variability is related to the direction toward which their distal end is skewed.

The analysis of the two technological attributes provides information on the technological procedures used in the production of the blank. Additional technological attributes can shed light on procedures that were applied for the modification of the blank into a finished tool. The number of flake scars on each tool is a good indication of the intensiveness of this modification and the amount of effort invested in the design of the tool's final morphology. When examining the dorsal and ventral scar count in each typological category, it is evident that while handaxes are more intensively flaked on both faces than cleavers, this difference is more substantial on the ventral side (Table 8). A Wilcoxon rank sum test conducted on both differences confirms that only the latter is statistically significant (dorsal: n1 = 128, n2 = 204, rank sum = 20,120, $p = 0.16$; ventral: n1 = 122, n2 = 202, rank sum = 15,991, $p < 0.001$). It is important to note that the ventral scar count is more indicative of modification subsequent to blank detachment, as pre-detachment scars on the dorsal face cannot in most cases be distinguished from those produced after the blank was detached. When considering the total number of scars, the difference between the two categories is statistically significant (n1 = 120, n2 = 200, rank sum = 16,637, $p = 0.001$). A similar pattern is observed for the total scar counts adjusted for centroid size (n1 = 120, n2 = 200, rank sum = 15,070, $p < 0.001$).

Nonetheless, it is important to note that while at the level of the typological classification there are significant differences in the number of scars, their correlation with the three major shape trends in the sample is weak. The highest R^2 correlation coefficient value obtained was 0.01 (for the correlation between the total number of scars and PC02), while other correlations between the dorsal or ventral number of scars and each of the first three principal components were even lower. The scar counts adjusted to centroid size also did not show a significant correlation to either of the first three shape trends with the highest R^2 value being 0.04 for PC3. Similarly, despite the fact that there is a significant difference between the sizes of handaxes and cleavers,

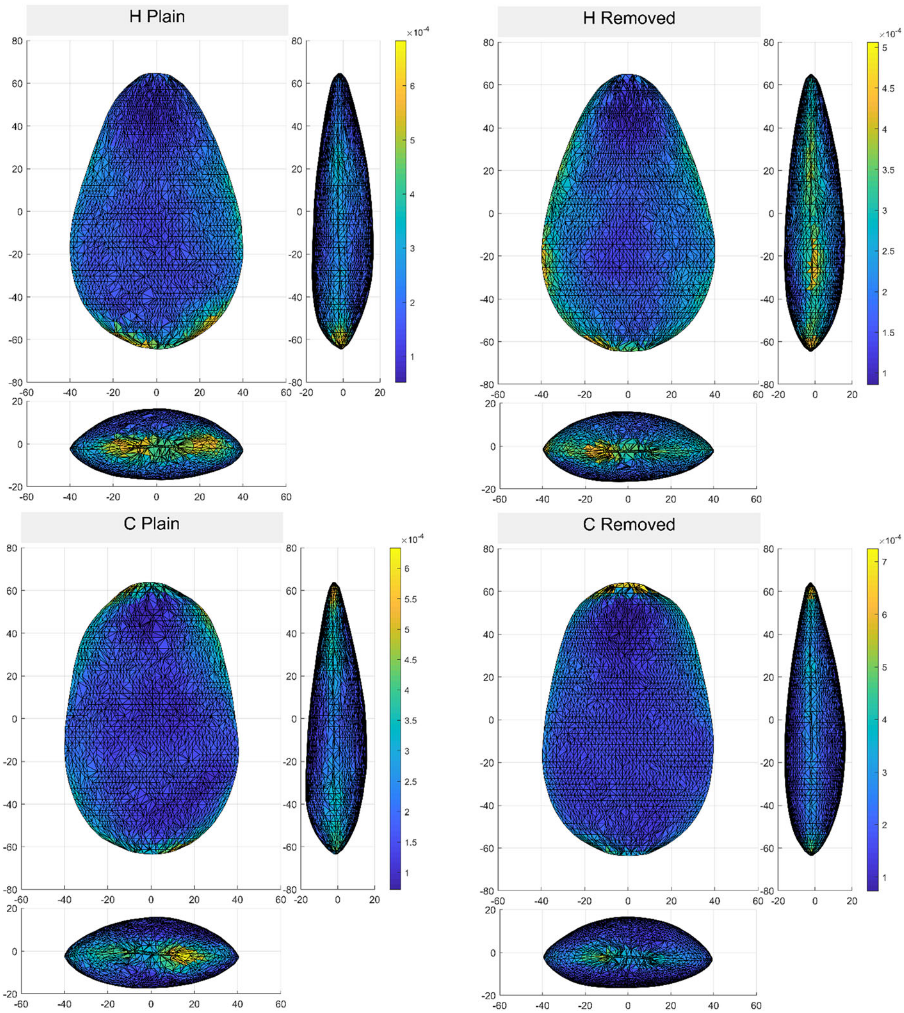

Fig. 5 Mean shapes of each striking platform group for handaxes and cleavers. Color coding represents the relative degree of variability of each individual landmark reflecting the spatial distribution of variability across the tools

only a weak correlation was found between the total number of scars and centroid size, with a correlation coefficient of $R^2 = 0.06$. The same patterns are observed when examining the correlation between number of scars and deviation from perfect bilateral and bifacial symmetry, which shows a generally weak correlation with a maximal R^2 value of 0.07. Testing the correlation between the scar counts adjusted to centroid size and deviation from symmetry value also did not yield significant correlations with a maximal R^2 value of 0.02. However, examination of the correlation between the mean number of scars and shape variability in each of the archeological levels and in each of the two types provides higher R^2 values. A negative correlation with a maximal value of $R^2 = 0.66$ was observed for the correlation between the mean number of ventral scars and assemblage shape variability in assemblages larger than ten items.

Table 7 Distribution of morphological variability in the different striking platform groups across the three spatial dimensions

	Number	Variability	Differences in X (%)	Differences in Y (%)	Differences in Z (%)
Handaxes with plain SP	52	323.5	45.22	6.45	48.33
Handaxes with removed SP	82	289.62	39.91	7.27	52.83
Handaxes with dihedral SP	5	270.38	45.03	2.28	52.69
Cleavers with plain SP	34	344.59	51.28	5.98	42.74
Cleavers with removed SP	88	349.99	54.41	5.8	39.79
Cleavers with facetted SP	3	321.15	67.1	4.32	28.58

In addition to the intensity of modification, reflected by the number of flake scars, the mode of modification can also highlight important aspects of the production process of the tools. While handaxes have a single mode of shaping the blank into a finished tool using several types of retouch, cleavers show three distinct modes in which secondary flaking is arranged (Herzlinger et al. 2017b; Goren-Inbar et al. 2018; Herzlinger and Goren-Inbar 2019a). These are used to design the distinctive dorsal-distal cleaver configuration. Excluding the indeterminate group ($n = 34$, 24%), the scar

Table 8 Summary statistics for dorsal, ventral, and total number of flake scars for handaxes and cleavers

		Cleavers	Handaxes
Dorsal N scars	*N*	128	204
	Max	32	35
	Median	13	14
	Min	4	4
	Mean	13.49	14.64
	Std Dev	5.44	6.03
	Std Err	0.48	0.42
Ventral N scars	*N*	122	202
	Max	23	36
	Median	7	10
	Min	1	3
	Mean	8	10.9
	Std Dev	4.53	5.66
	Std Err	0.41	0.4
Total N scars	*N*	120	200
	Max	47	67
	Median	21	24
	Min	6	8
	Mean	21.48	25.59
	Std Dev	8.18	10.26
	Std Err	0.75	0.73

of core and delineation by knapping are the two most frequent groups and are applied in almost equal proportions (Table 9). However, despite the somewhat lower number of the unmodified Kombewa group, there does not seem to be a very strong preference for any of these modes. In terms of overall shape variability, the cleavers whose dorsal-distal scar is delineated by knapping show the lowest value, which has only a small and insignificant difference from that of handaxes (n1 = 222, n2 = 41, rank sum = 28,830, $p = 0.28$). The slightly higher variability value of the unmodified Kombewa group as well does not significantly differ from that of handaxes (n1 = 222, n2 = 26, rank sum = 27,101, $p = 0.12$).

Examination of the mean shape and spatial and dimensional distributions in each of these groups shows similar patterns to the other technological attributes (Fig. 6, Table 10). In other words, while there are no significant differences between the mean shape of each cleaver group, each of them is significantly different from the mean shape of the handaxes. The spatial and dimensional distributions accord with the general pattern observed for the cleavers in which most of the variability can be attributed to the relative width, corresponding to the degree of skewness of the distal edge.

Discussion

Handaxes and cleavers have always been perceived as components of the same large typological family in the Acheulian repertoire, referred to as bifaces or large cutting tools (Kleindienst 1962; Isaac and Isaac 1977; Sharon 2007; Goren-Inbar et al. 2018). This is due to many similarities observed in their morphological and technological attributes, especially with regard to classical LFA industries (Sharon 2007). Despite these similarities, their division into two discrete typological categories has been widely considered as valid by most prehistorians. This typological division can be based either on morphological (Roe 1964) or on technological criteria (Tixier 1956), or on a combination of both (Goren-Inbar et al. 2018). The application of novel, objective, and quantitative morpho-technological analyses now allows to better describe and statistically test the similarities and differences within and between these groups. This can be used to test the validity of the typological division and gain a better understanding of the factors that affect their variability and underlie their production.

The results of the in-depth morpho-typo-technological analysis conducted on a large sample of bifacial tool assemblages from GBY generally describe an intricate and

Table 9 Distribution and morphological variability of the different mode of modification groups in cleavers and handaxes

Type	Mode of modification	Number	%	Variability	Differences in X (%)	Differences in Y (%)	Differences in Z (%)
Handaxes		222	100	310.14	42.11	6.32	51.57
Cleavers	Delineated by knapping	41	38.3	317.3	54.30	4.75	40.96
	Scar of core	40	37.4	370.58	57.16	6.05	36.78
	Unmodified Kombewa surface	26	24.3	335.84	50.83	5.49	43.68

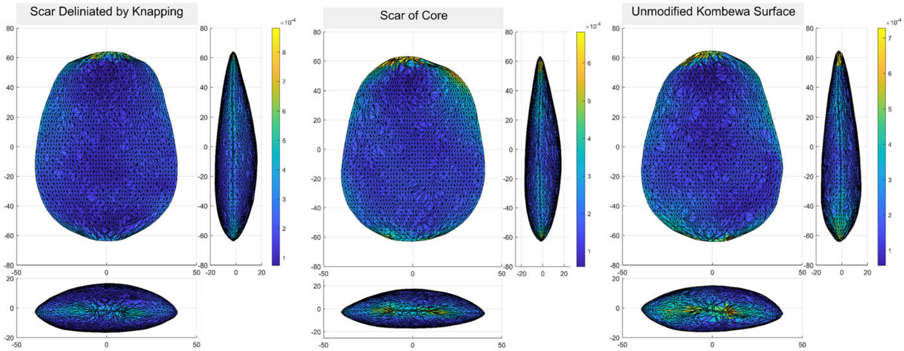

Fig. 6 Mean shapes of each mode of modification group for cleavers. Color coding represents the relative degree of variability of each individual landmark reflecting the spatial distribution of variability across the tools

complex pattern that enables some interesting insights. Firstly, regarding the morphological aspect of the tools, a clear overlap is observed in the shapes of the two types, indicating a morphological continuum which may cause an individual handaxe to be very similar to an individual cleaver. However, statistical testing confirms that the morphologies of their mean shapes differ significantly. This means that despite the apparent morphological similarity, the differences in the mean shapes are large enough to reject the hypothesis that the two types share the same morphological distribution at a probability of 5%. While in itself not necessarily indicating a behavioral difference, this observation quantitatively strengthens the notion that the typological division is valid despite the morphological similarities and allows to reject the approach suggesting it was arbitrarily imposed on the morphological continuum (Isaac and Isaac 1977). While the substantial morphological overlap may be the result of high intra-group morphological variability, the central tendencies within each group clearly differ. This insight is further corroborated by the results of nominal fit models, which on the basis of a number of morphological indices accounting for some 62% of the variability in the sample, were able to assign items to their correct type with high levels of confidence. This provides an additional indication that despite the apparent morphological overlap, the differences are large enough to allow an objective classification into types, validating the fact that the typological division is an accurate reflection of a real archeological phenomenon. Despite the apparent triviality of this insight, it is important to remember that the typological classification used in this study relates mainly to technological (i.e.,

Table 10 Distribution of morphological variability in the different mode of modification groups of cleavers across the three spatial dimensions

	Number	Variability	Differences in X (%)	Differences in Y (%)	Differences in Z (%)
Delineated by knapping	41	317.3	54.30	4.75	40.96
Scar of core	40	370.58	57.16	6.05	36.78
Unmodified Kombewa surface	26	335.84	50.83	5.49	43.68

the dorsal-distal configuration) rather than morphological aspects (Goren-Inbar et al. 2018). Thus, these results strengthen the relationship between technology and morphology expressed in the typological classification and confirms that the Acheulian hominins at GBY indeed produced two distinct morphotypes of bifacial tools.

This typological distinction seemingly contrasts with an apparently homogenous technological production procedure, as both types are products of the same *chaîne opératoire* and both were modified predominantly on large basalt flakes (Goren-Inbar et al. 2018). However, in-depth observation reveals a more complex picture. On the one hand, given the rigid tripartite division of raw material exploitation modalities at GBY, it is true that both types were produced, and probably perceived, as part of the same tool class of large basalt bifacial tools (Madsen and Goren-Inbar 2004; Goren-Inbar et al. 2018). On the other hand, the production of cleavers required blanks of specific morpho-technological characteristics, thus dictating a narrower selection of possibilities than those available for the production of handaxes. Such blanks had to be produced using a narrower variation of core methods and required that the decision to produce a cleaver be made by the knappers as early as the design of the core (Herzlinger et al. 2017b). Thus, despite being the products of a similar reduction sequence, a high-resolution analysis of the technological attributes of the blanks and core modification methods reveal that there must have been a difference in the production intentions of their makers, manifested in the decision-making process.

This complex pattern is also apparent when considering the specific production procedures and their effect on the morphology and morphological variation of the end products. When considering the direction of blow used to detach the blank from the core, a strong similarity is observed between the two types. Both types present a very similar distribution in which the three directions were used in relatively equal proportions. Furthermore, it appears that for both types, this pattern of technological selection had an almost identical effect on the tools' morphology and morphological variability. This may be an indication of the hominins' flexibility and high levels of knapping skill, which allowed them to cope with diverse core geometries and physical constraints dictated by fracture mechanics. The two tool types are also highly similar in distribution of striking platform types, with a clear preference for either plain unprepared, or striking platforms that were removed after the blank was struck off the core. However, in contrast to the direction of blow, the removal of the striking platform did not similarly affect the morphological variability of the two types. While in handaxe production this procedure resulted in a reduction of morphological variability, in cleavers, the removal of the striking platform had no such effect, and hence was probably performed for a different reason.

This last observation highlights an important insight that emerges from the analysis. It appears that in the production process of the two tool types, different degrees of priority were given to different morphological aspects. In cleavers, the emphasis was placed on the regularity of the intersection between dorsal and ventral faces at the distal end. This is reflected in the extraordinarily low variability stemming from differences in the relative thickness of the distal part of the tool. Other important morphological aspects are the deviation from perfect bifacial symmetry and centroid size, which present low values of variability. In contrast, it appears that very little emphasis was placed on the direction and degree of skewness of the distal edge, which has a strong effect on the general morphological variability in this tool type. Similarly, only little emphasis is seemed to be given to deviation from perfect bilateral symmetry. However, the fact that the distal end of cleavers cannot be modified by retouch after the detachment of the blank limits substantial modification of their general morphology. This is reflected in the spatial distribution of variability on the cleavers, where the four lower fifths show similar and even lower values of variability than those of the handaxes. Thus, the morpho-technological requirements of the dorsal-distal configuration probably consists the main reason underlying the significant differences in shape variability between the two types. This observation provides support for the notion that in the case of cleavers, the configuration of the distal edge was substantially more important than overall morphological homogeneity. These patterns are further highlighted by other technological procedures, such as the removal of the striking platform which does not seem to have had a reductive effect on the general variability of shape. In terms of modes of modification, while the delineation procedure did have such an effect, it was not predominantly preferred over the other modification methods (Herzlinger et al. 2017b).

In handaxes, the emphasis placed on the various morphological aspects appears to be very different. Firstly, in these tools, the overall morphological variability is significantly lower. Furthermore, analysis of the spatial and dimensional distributions of the morphological variability indicates that, in contrast to cleavers, it is not a specific morphological aspect but the overall tool morphology that is highly homogenous. This pattern is also evident in the removal of the striking platform, which had a reductive effect on the morphological variability only in the production of handaxes but not when it was performed in cleaver production. Furthermore, the intensity of modification after removal of the blank was shown to be strongly negatively correlated to morphological variability, and such flaking is indeed more intense in handaxes. Finally, the deviation from perfect bilateral symmetry is significantly lower and less variable in handaxes than in cleavers. On the other hand, centroid sizes of handaxes are not only lower than those of cleavers but also more variable.

It should be stressed here that similarity and difference are inherently relative concepts. While subjective, or even low-resolution quantitative observations may highlight the similarities between the two types, the high-resolution analysis conducted in this study allows discerning finer differences between them. Due to the quantitative nature of these observations, statistical testing which takes into account sample sizes and distributions can provide quantitative and objective assessments of whether an observed difference is random or significant. While statistically significant differences are not necessarily behaviorally significant, such results are the only means by which archeologists can draw an objective line between differences that may be archeologically significant and those that are probably random.

The observed morpho-technological differences between the two types can now be considered in light of the various factors that have been advanced to explain morphological variability in Acheulian bifacial tools. Firstly, these differences are clearly not related to chronological, environmental, or cognitive factors, as both types appear together at GBY in almost all the archeological horizons. In addition, they do not stem from differences in blank types or raw materials, as these attributes are identical in both types. These differences might have been explained as stemming from different intensities of resharpening or maintenance, given that, as a group, handaxes are significantly smaller and more intensively flaked than cleavers (McPherron 1999;

Iovita and McPherron 2011). However, a detailed examination reveals that only very weak correlations are found between the size and morphology of the tools, between the number of scars and the tools' morphology, and between the number of scars and the tools' size. This pattern was also observed when testing the effect of the scar counts adjusted for centroid size, a more powerful estimator of reduction intensity, on artifact morphology. These results indicate that although theoretically cleavers could have been turned into handaxes by additional modification, this was not the case at GBY, similarly to other studies addressing this issue in various Acheulian bifacial assemblages (Shipton and Clarkson 2015). Thus, the hypothesis of different life histories is not supported by our results either.

This leaves the hypothesis that differences in tool function were responsible for the observed morphological differences. Unfortunately, this necessitates a more speculative approach, as the issue of the functionalities of bifacial tools is far from being fully understood. Many utilitarian and non-utilitarian functions have been suggested over the years for Acheulian bifaces (mostly handaxes), for example, that they were used as projectiles (O'Brien 1981; Calvin 2002; Samson 2006) or stationary traps (Wayman 2010), or were products of sexual selection (Kohn and Mithen 1999; Burriss 2009), social signaling (Spikins 2012), or symbolic behavior (Carbonell and Mosquera 2006). These suggestions, however, have been largely dismissed by researchers, and today, the most widely accepted interpretation of their functions is that they were used for heavy-duty cutting and chopping tasks in the contexts of butchery and woodworking (Kleindienst and Keller 1976; Ohel 1987; McCall and Whittaker 2007; Key and Lycett 2017a and references therein). This interpretation is supported by experimental, use wear, and residue analysis results (Keeley 1980; Jones 1980; Domínguez-Rodrigo et al. 2001; Claud et al. 2015; Key and Lycett 2017c). Hence, the important morphological aspects of each of the tool types may be considered in light of these suggested functions.

In cleavers, the configuration of the distal edge, and specifically the intersection between the flat ventral and dorsal surfaces, the bifacial symmetry, and the larger size of the tools were of the greatest importance. As with a modern butcher's cleaver, these morphological aspects are the ones that account for the tool's shearing and penetration capacities and therefore accord with the morphological requirements for heavy-duty cutting and chopping tasks (Jones 1980; Mitchell 1996; Claud et al. 2015). Similarly, the fact that little emphasis was placed on the cleavers' overall morphological homogeneity conforms to such an interpretation.

In handaxes, the most important aspects appear to be morphological homogeneity and high bilateral symmetry. Morphological homogeneity is not relevant in itself to cutting or chopping tasks, as it does not address a specific morphological aspect of the tool but rather its overall morphology (Key and Lycett 2017b). In contrast, maintaining a degree of morphological homogeneity is an important requirement for cognitive categorization of objects which in itself is a prerequisite for their use for conveying social information. Moreover, the bilateral symmetry does not appear to be an important requirement for butchery-related tasks (Machin et al. 2005; Machin et al. 2007). In contrast, studies dealing with handaxe symmetry regularly emphasize its importance from non-utilitarian perspectives (Mithen 2003; Hodgson 2009; Hodgson 2015; McNabb and Cole 2015; White and Foulds 2018).

These lines of reasoning may offer a glimpse, albeit speculative, into the functions that these tools were intended to fulfill and the motivation behind their production. Accordingly, it appears that in cleavers, the emphasis was placed mainly on morpho-technological attributes which are directly associated with the utilitarian function of heavy-duty cutting. In handaxe on the other hand, most of the focus in the production process seems to have been given to attributes that do not appear to be related to this utilitarian function. It is important to stress that this does not mean that handaxes were not used and designed for utilitarian functions or that cleavers were entirely devoid of social information. As mentioned above, many experiments have confirmed that handaxes could have been efficiently used for butchery and woodworking. Similarly, the high knapping skill level and difficulty entailed in cleaver production may have constituted a strong social signal. However, the results of this study suggest that these two types differed in the proportions and importance given to the utilitarian and social functions each of them fulfilled. The capacity of material objects to fulfill multiple functions simultaneously in different realms (utilitarian, social, ideological) and different proportions has been demonstrated for both modern and traditional societies (Wiessner 1983; Stevenson 1989; Steg 2005). In traditional societies, various utilitarian material objects such as knives, arrowheads, and axes convey important social information such as group membership and social status. Thus, in their manufacture process, substantial emphasis is also given to morphological aspects which are not necessarily intended to fulfill a utilitarian propose (Vial 1940; Wiessner 1983; Paton 1994). In modern industrialized societies, countless examples can be given to material objects which are intended to concurrently fulfill varying proportions of utilitarian and social functions such as luxury cars, clothes, and watches (Han et al. 2010; Nelissen and Meijers 2011). In both cases, the proportions to which a given objects is intended to function in social and utilitarian contexts may differ substantially, affecting its morpho-technological attributes accordingly. The transmission of social information through material objects that often possess utilitarian functions as well is a universal and unique human trait, which must have developed at some time along our evolutionary path (Jeffares 2010). The hominins that occupied GBY have been shown to possess some fully developed modern cognitive mechanisms (Herzlinger et al. 2017b; Alperson-Afil et al. under review) and to be part of large, complex, and highly interconnected social groups (Herzlinger and Goren-Inbar 2019a). The results of this study demonstrate that they also produced two very similar tool types, which differ in the emphasis placed on morpho-technological attributes related to utilitarian and non-utilitarian functions. Thus, there is no reason to reject the possibility that the handaxes produced by the GBY hominins were intentionally designed and used to transmit social information between group members, while the cleavers were mainly produced to fulfill utilitarian functions.

Conclusions

Hominins at GBY produced two distinct morphotypes of bifacial tools: handaxes and cleavers. Despite some morphological overlap stemming from within-type morphological variability, they are morphologically different from one another. While generally similar technological procedures were used for their production, different morphological aspects were given priority in each. In cleavers, the distal intersection between the two faces was of the greatest importance, along with bifacial symmetry and large size. In handaxes, general morphological homogeneity and bilateral symmetry were given the greatest emphasis. While the main morphological traits of the former are probably related to the utilitarian function of heavy-duty cutting and chopping, those of the latter seem to correspond more to aspects of social signaling. This may indicate that while the motivation behind the production of cleavers was mostly utilitarian, the production of handaxes took into account additional non-utilitarian considerations as well.

Funding Information This research was made possible thanks to the generous scholarship granted to GH by the Israeli Planning and Budgeting Committee (VATAT) in memory of Nathan Rotenstreich, via the Hebrew University's PhD honors program at The Jack, Joseph and Morton Mandel School for Advanced Studies in the Humanities. This research was supported by the Ministry of Science and Technology, Israel and Ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation, France (2018). We thank Sue Gorodetsky for editing this manuscript.

Compliance with Ethical Standards

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

References

Alperson-Afil, N., & Goren-Inbar, N. (2010). *The Acheulian site of Gesher Benot Ya'aqov volume II: Ancient flames and controlled use of fire*. Dordrecht: Springer.

Archer, W., & Braun, D. R. (2010). Variability in bifacial technology at Elandsfontein, Western cape, South Africa: a geometric morphometric approach. *Journal of Archaeological Science, 37*(1), 201–209.

Archer, W., Gunz, P., van Niekerk, K. L., Henshilwood, C. S., & McPherron, S. P. (2015). Diachronic change within the still bay at Blombos Cave, South Africa. *PLoS One, 10*(7), e0132428.

Bar-Yosef, O., & Wang, Y. (2012). Paleolithic archaeology in China. *Annual Review of Anthropology, 41*, 319–335.

Beyene, Y., Katoh, S., WoldeGabriel, G., Hart, W. K., Uto, K., Sudo, M., et al. (2013). The characteristics and chronology of the earliest Acheulean at Konso, Ethiopia. *Proceedings of the National Academy of Sciences, 110*(5), 1584–1591.

Burriss, R. P. (2009). Symmetry is sexy: reply to Hodgson's 'symmetry and humans'. *Antiquity, 83*(322), 1170–1175.

Calvin, W. H. (2002). Rediscovery and the cognitive aspects of toolmaking: lessons from the handaxe. *Behavioral and Brain Sciences, 25*(3), 403–404.

Carbonell, E., & Mosquera, M. (2006). The emergence of a symbolic behaviour: the sepulchral pit of Sima de los Huesos, Sierra de Atapuerca, Burgos, Spain. *Comptes Rendus Palevol, 5*(1), 155–160.

Chacón, M. G., Détroit, F., Coudenneau, A., & Moncel, M. H. (2016). Morphometric assessment of convergent tool technology and function during the Early Middle Palaeolithic: the case of Payre, France. *PLoS One, 11*(5), e0155316.

Clark, J. (2001). *Kalambo Falls prehistoric site, the earlier cultures: middle and earlier Stone Age*. Cambridge: Cambridge University Press.

Clarkson, C. (2013). Measuring core reduction using 3D flake scar density: a test case of changing core reduction at Klasies River Mouth, South Africa. *Journal of Archaeological Science, 40*(12), 4348–4357.

Claud, É., Deschamps, M., Colonge, D., Mourre, V., & Thiébaut, C. (2015). Experimental and functional analysis of late Middle Paleolithic flake cleavers from southwestern Europe (France and Spain). *Journal of Archaeological Science, 62*, 105–127.

Domínguez-Rodrigo, M., Serrallonga, J., Juan-Tresserras, J., Alcala, L., & Luque, L. (2001). Woodworking activities by early humans: a plant residue analysis on Acheulian stone tools from Peninj (Tanzania). *Journal of Human Evolution, 40*(4), 289–299.

Dryden, I. L., & Mardia, K. V. (1998). *Statistical shape analysis*. Chichester: John Wiley & Sons.

Eren, M. I., Roos, C. I., Story, B. A., von Cramon-Taubadel, N., & Lycett, S. J. (2014). The role of raw material differences in stone tool shape variation: an experimental assessment. *Journal of Archaeological Science, 49*, 472–487.

García-Medrano, P., Ollé, A., Ashton, N., & Roberts, M. B. (2018). The mental template in handaxe manufacture: new insights into Acheulean lithic technological behavior at Boxgrove, Sussex, UK. *Journal of Archaeological Method and Theory, 26*(1), 1–27.

Goren-Inbar, N. (2011). Culture and cognition in the Acheulian industry: a case study from Gesher Benot Ya aqov. *Philosophical Transactions of the Royal Society B: Biological Sciences, 366*(1567), 1038–1049.

Goren-Inbar, N., Werker, E., & Feibel, C. S. (2002). *The Acheulian site of Gesher Benot Ya'aqov, Israel. The wood assemblage*. Oxford: Oxbow Books.

Goren-Inbar, N., Alpeson-Afil, N., Sharon, G., & Herzlinger, G. (2018). *The Acheulian site of Gesher Benot Ya'aqov volume IV: the lithic assemblages*. Doredrecht: Springer.

Grosman, L., Smikt, O., & Smilansky, U. (2008). On the application of 3-D scanning technology for the documentation and typology of lithic artifacts. *Journal of Archaeological Science, 35*(12), 3101–3110.

Grosman, L., Sharon, G., Goldman-Neuman, T., Smikt, O., & Smilansky, U. (2011). Studying post depositional damage on Acheulian bifaces using 3-D scanning. *Journal of Human Evolution, 60*(4), 398–406.

Grosman, L., Karasik, A., Harush, O., & Smilansky, U. (2014). Archaeology in three dimensions: computer-based methods in archaeological research. *Journal of Eastern Mediterranean Archaeology and Heritage Studies, 2*(1), 48–64.

Han, Y. J., Nunes, J. C., & Drèze, X. (2010). Signaling status with luxury goods: the role of brand prominence. *Journal of Marketing, 74*(4), 15–30.

Herzlinger, G., & Goren-Inbar, N. (2019a). Do a few tools necessarily mean a few people? A techno-morphological approach to the question of group size at Gesher Benot Ya'aqov, Israel. *Journal of Human Evolution, 128*, 45–58.

Herzlinger, G., & Goren-Inbar, N. (2019b). *Acheulian handaxe and cleaver assemblages from Gesher Benot Ya'aqov, Israel*. OSF. January 7. https://doi.org/10.17605/OSF.IO/U3N9K.

Herzlinger, G., & Grosman, L. (2018). AGMT3-D: a software for 3-D landmarks-based geometric morphometric shape analysis of archaeological artifacts. *PLoS One, 13*(11), e0207890.

Herzlinger, G., Goren-Inbar, N., & Grosman, L. (2017a). A new method for 3D geometric morphometric shape analysis: the case study of handaxe knapping skill. *Journal of Archaeological Science: Reports, 14*, 163–173.

Herzlinger, G., Wynn, T., & Goren-Inbar, N. (2017b). Expert cognition in the production sequence of Acheulian cleavers at Gesher Benot Ya'aqov, Israel: a lithic and cognitive analysis. *PLoS One, 12*(11), e0188337.

Hodgson, D. (2009). Symmetry and humans: reply to Mithen's 'sexy handaxe theory'. *Antiquity, 83*(319), 195–198.

Hodgson, D. (2015). The symmetry of Acheulean handaxes and cognitive evolution. *Journal of Archaeological Science: Reports, 2*, 204–208.

Hoggard, C. S., McNabb, J., & Cole, J. N. (2019). The application of elliptic Fourier analysis in understanding biface shape and symmetry through the British Acheulean. *Journal of Paleolithic Archaeology*, 1–19.

Iovita, R., & McPherron, S. P. (2011). The handaxe reloaded: a morphometric reassessment of Acheulian and Middle Paleolithic handaxes. *Journal of Human Evolution, 61*(1), 61–74.

Isaac, G. L. (1969). Studies of early culture in East Africa. *World Archaeology, 1*(1), 1–28.

Isaac, G. L., & Isaac, B. (1977). *Olorgesailie: archeological studies of a middle Pleistocene lake basin in Kenya*. Chicago: University of Chicago Press.

Isaac, G. L., & Keller, C. M. (1968). Note on the proportional frequency of side-and end-struck flakes. *The South African Archaeological Bulletin, 23*(89), 17–19.

Jeffares, B. (2010). The co-evolution of tools and minds: cognition and material culture in the hominin lineage. *Phenomenology and the Cognitive Sciences, 9*(4), 503–520.

Jones, P. R. (1980). Experimental butchery with modern stone tools and its relevance for Palaeolithic archaeology. *World Archaeology, 12*(2), 153–165.

Keeley, L. H. (1980). *Experimental determination of stone tool uses: a microwear analysis*. Chicago: University of Chicago Press.

Key, A. J., & Lycett, S. J. (2017a). Form and function in the Lower Palaeolithic: history, progress, and continued relevance. *Journal of Anthropological Sciences, 95*, 67–108.

Key, A. J., & Lycett, S. J. (2017b). Influence of handaxe size and shape on cutting efficiency: a large-scale experiment and morphometric analysis. *Journal of Archaeological Method and Theory, 24*(2), 514–541.

Key, A. J., & Lycett, S. J. (2017c). Reassessing the production of handaxes versus flakes from a functional perspective. *Archaeological and Anthropological Sciences, 9*(5), 737–753.

Kleindienst, M. R. (1962). Components of the East African Acheulian assemblage: an analytic approach. In G. Mortelmans & J. Nenquin (Eds.), *Actes du IVème Congrès Panafricain de Préhistoire et de l'Etude du Quaternaire, Leopoldville, 1959* (pp. 81–105). Tervuren: Belgie Annalen, Musée Royal de l'Afrique Centrale.
Kleindienst, M. R., & Keller, C. M. (1976). Towards a functional analysis of handaxes and cleavers: the evidence from Eastern Africa. *Man, 11*(2), 176–187.
Kohn, M., & Mithen, S. (1999). Handaxes: products of sexual selection? *Antiquity, 73*(281), 518–526.
Leakey, M., & Roe, D. (1994). *Olduvai Gorge: excavations in beds III, IV and the Masek beds, 1968–1971*. Cambridge: Cambridge University Press.
Lycett, S. J. (2008). Acheulean variation and selection: does handaxe symmetry fit neutral expectations? *Journal of Archaeological Science, 35*(9), 2640–2648.
Lycett, S. J., & Gowlett, J. A. (2008). On questions surrounding the Acheulean 'tradition'. *World Archaeology, 40*(3), 295–315.
Lycett, S. J., & von Cramon-Taubadel, N. (2008). Acheulean variability and hominin dispersals: a model-bound approach. *Journal of Archaeological Science, 35*(3), 553–562.
Lycett, S. J., von Cramon-Taubadel, N., & Foley, R. A. (2006). A crossbeam co-ordinate caliper for the morphometric analysis of lithic nuclei: a description, test and empirical examples of application. *Journal of Archaeological Science, 33*(6), 847–861.
Lycett, S. J., von Cramon-Taubadel, N., & Gowlett, J. A. (2010). A comparative 3D geometric morphometric analysis of Victoria west cores: implications for the origins of Levallois technology. *Journal of Archaeological Science, 37*(5), 1110–1117.
Lycett, S. J., Schillinger, K., Eren, M. I., von Cramon-Taubadel, N., & Mesoudi, A. (2016). Factors affecting Acheulean handaxe variation: experimental insights, microevolutionary processes, and macroevolutionary outcomes. *Quaternary International, 411*, 386–401.
Machin, A., Hosfield, R., & Mithen, S. (2005). Testing the functional utility of handaxe symmetry: fallow deer butchery with replica handaxes. *Lithics: The Journal of the Lithic Studies Society, 26*, 23–37.
Machin, A. J., Hosfield, R. T., & Mithen, S. J. (2007). Why are some handaxes symmetrical? Testing the influence of handaxe morphology on butchery effectiveness. *Journal of Archaeological Science, 34*(6), 883–893.
Madsen, B., & Goren-Inbar, N. (2004). Acheulian giant core technology and beyond: an archaeological and experimental case study. *Eurasian Prehistory, 2*(1), 3–52.
Marozzi, M. (2016). Multivariate tests based on interpoint distances with application to magnetic resonance imaging. *Statistical Methods in Medical Research, 25*(6), 2593–2610.
Matskevich, Z. (2006). Cleavers in the levantine late Acheulian the case of Tabun cave. In N. Goren-Inbar & G. Sharon (Eds.), *Axe age: Acheulian tool-making from quarry to discard* (pp. 335–346). London: Equinox.
McCall, G. S., & Whittaker, J. (2007). Handaxes still don't fly. *Lithic Technology, 32*(2), 195–202.
McNabb, J., & Cole, J. (2015). The mirror cracked: symmetry and refinement in the Acheulean handaxe. *Journal of Archaeological Science: Reports, 3*, 100–111.
McNabb, J., Cole, J., & Hoggard, C. S. (2018). From side to side: Symmetry in handaxes in the British Lower and Middle Palaeolithic. *Journal of Archaeological Science: Reports, 17*, 293–310.
McPherron, S. P. (1999). Ovate and pointed handaxe assemblages: two points make a line. *Préhistoire Européenne, 14*, 9–32.
Mitchell, J. (1996). Studying biface butchery at Boxgrove: roe deer butchery with replica handaxes. *Lithics, 16*, 64–69.
Mithen, S. (2003). Handaxes: the first aesthetic artefacts. In E. Voland & K. Grammer (Eds.), *Evolutionary aesthetics* (pp. 261–275). Berlin: Springer.
Nelissen, R. M., & Meijers, M. H. (2011). Social benefits of luxury brands as costly signals of wealth and status. *Evolution and Human Behavior, 32*(5), 343–355.
Norton, C. J., Bae, K., Harris, J. W., & Lee, H. (2006). Middle Pleistocene handaxes from the Korean peninsula. *Journal of Human Evolution, 51*(5), 527–536.
O'Brien, E. M. (1981). The projectile capabilities of an Acheulian handaxe from Olorgesailie. *Current Anthropology, 22*(1), 76–79.
Ohel, M. Y. (1987). The Acheulean handaxe: a maintainable multifunctional tool. *Lithic Technology, 16*(2–3), 54–55.
Paton, R. (1994). Speaking through stones: a study from northern Australia. *World Archaeology, 26*(2), 172–184.
Rabinovich, R., Gaudzinski-Windheuser, S., Kindler, L., & Goren-Inbar, N. (2012). *The Acheulian site of Gesher Benot Ya'aqov. Mammalian Taphonomy. The assemblages of layers V-5 and V-6*. Dordrecht: Springer.
Roe, D. A. (1964). The British Lower and Middle Palaeolithic: some problems, methods of study and preliminary results. *Proceedings of the Prehistoric Society (New Series), 30*, 245–267.
Roe, D. A. (1969). British Lower and Middle Palaeolithic handaxe groups. *Proceedings of the Prehistoric Society (New Series), 34*, 1–82.

Rollefson, G. O. (1983). Two seasons of excavations at Ain el-Assad near Azraq, eastern Jordan, 1980-1981. *Bulletin of the American Schools of Oriental Research, 252*, 25–34.
Samson, D. R. (2006). Stones of contention: the Acheulean handaxe lethal projectile controversy. *Lithic Technology, 31*(2), 127–135.
Santonja, M., & Villa, P. (2006). The Acheulian of Western Europe. In N. Goren-Inbar & G. Sharon (Eds.), *Axe age: Acheulian tool-making from quarry to discard* (pp. 429–478). London: Equinox.
Semaw, S., Rogers, M., & Stout, D. (2009). The Oldowan-Acheulian transition: is there a "developed Oldowan" artifact tradition? In M. Camps & P. Chauhan (Eds.), *Sourcebook of paleolithic transitions: methods, theories, and interpretations* (pp. 173–193). New York: Springer New York.
Serwatka, K. (2014). Shape variation of Middle Palaeolithic bifacial tools from southern Poland: a geometric morphometric approach to Keilmessergruppen handaxes and backed knives. *Lithics–The Journal of the Lithic Studies Society, 35*, 18–32.
Sharon, G. (2007). *Acheulian large flake industries: technology, chronology, and significance*. Oxford: British Archaeological Reports.
Sharon, G., & Barsky, D. (2016). The emergence of the Acheulian in Europe–a look from the east. *Quaternary International, 411*, 25–33.
Shipton, C. (2013). *A million years of hominin sociality and cognition: Acheulean bifaces in the Hunsgi-Baichbal Valley, India (BAR International Series)*. Oxford: Archaeopress.
Shipton, C. (2018). Biface knapping skill in the East African Acheulean: progressive trends and random walks. *African Archaeological Review, 35*(1), 107–131.
Shipton, C., & Clarkson, C. (2015). Flake scar density and handaxe reduction intensity. *Journal of Archaeological Science: Reports, 2*, 169–175.
Spikins, P. (2012). Goodwill hunting? Debates over the 'meaning'of lower Palaeolithic handaxe form revisited. *World Archaeology, 44*(3), 378–392.
Steg, L. (2005). Car use: lust and must. Instrumental, symbolic and affective motives for car use. *Transportation Research Part A: Policy and Practice, 39*(2–3), 147–162.
Stevenson, M. G. (1989). Sourdoughs and cheechakos: the formation of identity-signaling social groups. *Journal of Anthropological Archaeology, 8*(3), 270–312.
Tixier, J. (1956). *Le Hachereau dans l'Acheuléen Nord-Africain – Notes Typologiques. Congrès préhistorique de France – Compte-rendu de la XVème session – Poitiers-Angoulême, Société préhistorique française* (pp. 914–923). Paris.
Vaughan, C. D. (2001). A million years of style and function: regional and temporal variation in Acheulean handaxes. *Style and function: conceptual issues in evolutionary archaeology* (pp. 141–163).
Vial, L. G. (1940). Stone axes of Mount Hagen, New Guinea. *Oceania, 11*(2), 158–163.
Viallet, C. (2019). A new method of three-dimensional morphometry for analyzing the functional potentialities of bifaces. Contribution to the study of artefacts from AU P3 from the "Caune de l'Arago"(France). *Comptes Rendus Palevol, 18*(2), 236–250.
Wang, W., Lycett, S. J., von Cramon-Taubadel, N., Jin, J. J., & Bae, C. J. (2012). Comparison of handaxes from Bose Basin (China) and the western Acheulean indicates convergence of form, not cognitive differences. *PLoS One, 7*(4), e35804.
Wayman, J. L. (2010). Foot cutters: a new hypothesis for the function of Acheulian bifaces and related lithics. *Lithic Technology, 35*(2), 171–194.
Weiss, M., Lauer, T., Wimmer, R., & Pop, C. M. (2018). The variability of the Keilmesser-concept: a case study from Central Germany. *Journal of Paleolithic Archaeology, 1*(3), 202–246.
White, M. (1998). On the significance of Acheulean biface variability in southern Britain. *Proceedings of the Prehistoric Society, 64*, 15–44.
White, M., & Foulds, F. (2018). Symmetry is its own reward: on the character and significance of Acheulean handaxe symmetry in the Middle Pleistocene. *antiquity, 92*(362), 304–319.
Wiessner, P. (1983). Style and social information in Kalahari san projectile points. *American Antiquity, 48*(2), 253–276.
Wymer, J. (1968). *Lower Palaeolithic archaeology in Britain as represented by the Thames Valley*. London: John Baker.
Wynn, T. (1995). Handaxe enigmas. *World Archaeology, 27*(1), 10–24.
Wynn, T., & Tierson, F. (1990). Regional comparison of the shapes of later Acheulean handaxes. *American Anthropologist, 92*(1), 73–84.