Journal of Archaeological Science 37 (2010) 1841–1850

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Taphonomic identification of cut marks made with lithic handaxes: an experimental study

S. de Juana, A.B. Galán, M. Domínguez-Rodrigo*

Department of Prehistory, Complutense University, 28040 Madrid, Spain

ARTICLE INFO

Article history:
Received 8 December 2009
Received in revised form
30 January 2010
Accepted 1 February 2010

Keywords:
Cut marks
Bone surface modifications
Stone tools
Handaxes
Butchery

ABSTRACT

Recent experimental studies have developed new diagnostic criteria to differentiate between trampling and cut marks. Within cut marks, these diagnostic criteria have been useful to differentiate between marks made with simple and retouched flakes. The present study expands the application of these criteria using a multivariate analysis to discriminate marks created with handaxes from those made with stone tool flakes. A discriminant analysis resulted in a selection of specific variables, which can successfully differentiate cut marks made with handaxes from those created with retouched flakes in more than 80% of occasions. The utility of this analogical taphonomic signature created by handaxes is discussed in the light of their potential value as butchering tools.

1. Introduction

During the past century, archaeologists have been intrigued by the functionality of handaxes, one of the most common tools in the early Paleolithic archaeological record. They appeared at the dawn of the Acheulian stone tool industry about 1.6 Ma and, although the Acheulian transitioned into the MSA in Africa and into the Mousterian in Europe between 300 Ka and 100 Ka, handaxes still survived marginally in some Mousterian traditions well into the Upper Pleistocene. The question still remains of why handaxes were so successful in time.

Handaxes have frequently been conceptualised as multi-task tools, although this has not been empirically supported (Isaac, 1977). The duration of the handaxe tradition has led some researchers to even think that handaxe manufacture may have been more related to sexual selection than functionality (Kohn and Mithen, 1999; for a critical view see Machin, 2008). The functional meaning of handaxes has remained elusive for so long that some researchers even argued that handaxes may have served as blanks for flake extraction (Potts, 1989; Davidson and Noble, 1993). Others interpreted them as having been projectile weapons for hunting (O'Brien, 1981). Microscopic phytolith residues found on handaxe edges from Peninj showed that at least some handaxes were used for woodworking activities (Domínguez-Rodrigo et al., 2001). However, the oldest and most frequent interpretation of handaxe functionality has been to link it to butchery (e.g., Leakey, 1936; Clark, 1959; Cole, 1963; Howell, 1966). Studies on the morphology and manufacture of handaxes, as well as experiments carried out to test their performance in butchery (Roe, 1994; Jones, 1980, 1994; Mitchell, 1995) suggest that these artefacts could have been used for improving the efficiency of the butchery process, especially when dealing with large carcasses (Cole, 1963; Howell, 1966; Clark and Haynes, 1970; Shipman et al., 1981; Jones, 1980, 1994). Researchers have analysed handaxe functionality also through the study of use wear on their edges and as a result, butchery with handaxes has been argued to have existed in certain European Middle Pleistocene contexts (Keeley, 1980; Mitchell, 1997). A more direct signature of handaxe use during butchery than the interpretation of microscopic use wear would be the occurrence of cut marks caused by these artefacts on bones. Bello et al. (2009) have experimentally determined some of the microscopic characteristics of cut marks created with handaxes and have compared them to cut marks found on bones from the 500 Ka site of Boxgrove (U.K.). This expanded previous work on microscopic signature of cut marks (e.g., Bunn, 1981; Potts and Shipman, 1981; Bromage and Boyde, 1984; Walker and Long, 1977; Walker, 1978; see review in Fisher, 1995; Bello and Soligo, 2008). However, not a clear link between the fossil cut marks from Boxgrove and those replicated with handaxes could be established, beyond showing that fossil cut marks were produced by greater force than those observed on modern experimental material (Bello et al., 2009).

* Corresponding author. Tel./fax: +34 91 394 6008.
E-mail addresses: m.dominguez.rodrigo@gmail.com, manueldr@ghis.ucm.es (M. Domínguez-Rodrigo).

0305-4403/$ – see front matter
doi:10.1016/j.jas.2010.02.002

Recent studies suggest that cut marks can only be properly interpreted from a multivariate approach, as their variability is linked to taphonomic processes related to the intensity of bone fragmentation, carnivore ravaging, carcass size and tool type (Domínguez-Rodrigo and Yravedra, 2008). More specifically, regarding mark morphology, a selection of variables that define cut marks have been comparatively used to discriminate between cut marks and trampling marks, and within the former, cut marks imparted with simple flakes from those created by retouched flakes (Domínguez-Rodrigo et al., 2009).

Given the success in differentiating between cut marks made with simple and retouched flakes, there existed a possibility of further expanding the array of tool types whose cut marks could also be discriminated. Since handaxes have been linked to butchery, the resulting cut marks created with these tools could potentially be also differentiated from cut marks created by the use of different artefacts (e.g., small flakes). This work presents the results of an experimental study on cut marks made with handaxes. It is shown how these marks resemble marks made with retouched flakes, but if well preserved, they can be differentiated in more than 80% of cases. The diagnostic criteria of cut marks made with handaxes are presented.

2. Method and sample

2.1. Experimental sample and analytical methodology

A total of eight long bones (humerus, femur, radius, tibia) from deer carcasses obtained in legal organised hunting parties were used for the present study. Bones were butchered with metal knives and subsequently, they were buried for six months to remove remains of grease, tendons and periostium. When recovered, bones were utterly defleshed. Then, the bones were washed and the surface of each bone was carefully examined with hand lenses under a strong light to isolate cut marks made with knives, by colouring them with permanent markers. Then a series of cut marks were made with four different handaxes at specific angles (straight and oblique), applying a single stroke with a swinging motion running perpendicular to the axis of the bone for each mark, following a frontal-caudal direction according to the position of the butcher. Defleshed bones were selected over fleshed bones because the angle of artefact impact on bone surface could be better controlled than if using a fleshed animal. However, as a control measure, some fleshed long bones of deer were also defleshed using the same experimental handaxes to compare the resulting marks with those imparted on the defleshed bone sample and the characteristics documented in the latter (see below) were also present in similar frequencies in the former. Two limbs were used (6 bones) and defleshing proceeded with the intention of imparting marks on bone surfaces, which were initially covered by flesh and periostium. The resulting number of marks ($n = 47$) did not differ significantly in most of the variables used (t tests yielded p values $> .05$) from the cut marks created on defleshed bones. The only exception was the number of multiple marks, whose range in the fleshed sample varied from 2 to 6 marks, slightly more reduced than in the defleshed sample and also significantly different from cut marks imparted with retouched flakes ($p = .000$).

The following variables determined the structure of the experiment: the type of handaxe (4 different types varying in size and edge; Fig. 1), and the angle of impact (perpendicular [90°], oblique [45°]) (Bello and Soligo, 2008). Each of the four handaxes selected was different from the others in size (from 10 cm to 22 cm), raw material (flint, fine grained and coarse-grained quartzite), edge thickness (from 4 mm to 8 mm, measured at 5 mm from the edge) and angle (from 55° to 71°). The measurements of thickness and angle were produced by averaging 5 measurements of the edge length. If including the minimum and maximum values of the angles measured, these ranged from 49° to 74°. The selection of the four types of handaxes was based on handaxe morphological diversity across the lower and middle Paleolithic. The small format in flint (handaxes 1 and 2) is typical of the Mousterian. The larger formats are typical of the Acheulian (handaxes 3 and 4), which include the very elaborated forms with intentionally bifacially flaked edges (handaxe 3) and the less elaborated forms (handaxe 4), where there are partial or complete natural edges resulting from previous flaking prior to the detachment of the blank.

The work was divided into two different experimental blocks aimed at determining if handaxe type or angle type (and their interaction) had any influence on the final appearance of cut marks. This was done to uncover the extent of the variability of the handaxe-imparted cut mark sample and determine if the diagnosis elaborated could be defined as exclusive of the use of handaxes. If positive, then it would be appropriate to be compared with cut marks made with flakes (simple and retouched).

The resulting cut marks were clearly differentiated from cut marks made with simple flakes (see below). Therefore, the multivariate comparison was directly made with cut marks made with retouched flakes, as these present similar morphology to cut marks made with handaxes. A total of 212 cut marks made with handaxes (50 marks from each handaxe, except handaxe 2, which was used to create 62 marks) and 105 cut marks made with retouched flakes were analysed. Marks with the retouched flakes are drawn from the sample described in Domínguez-Rodrigo et al. (2009).

Mark analysis was carried out according to the following protocol: First, all marks were identified by naked eye and numbered. Then marks were studied with hand lenses and using

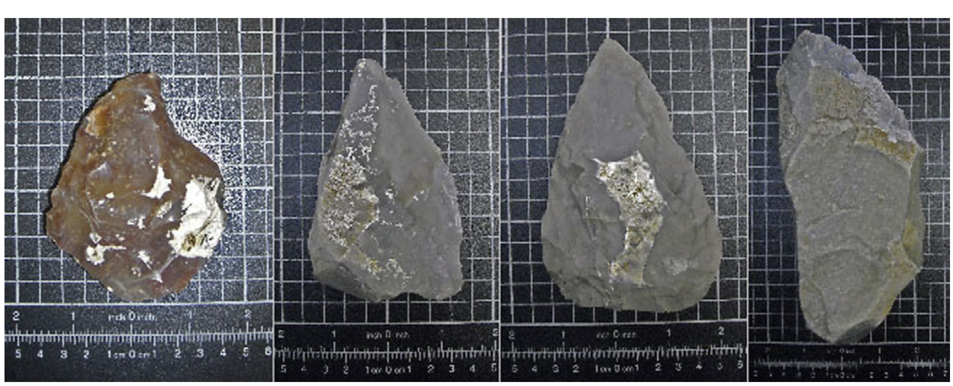

Fig. 1. Four different types of handaxes used for the experiments. They represent different degrees of sizes and edge retouch.

Table 1
Definition of the variables used for the present analysis. For a more detailed definition see Domínguez-Rodrigo et al. (2009).

1. Trajectory of the groove.	Straight (a), curvy (b) or sinuous (c). This variable is applied to the outline of the mark, without taking into account the presence of barb – when it is present – at the end of the mark.
2. Barb.	Presence (a), or absence (b)
3. Shape of the groove.	Narrow V-shape (a) and wide V-shape (_/) (b). In V its shape is deeper than wide. In the case of _/ the base of the groove is horizontal, and it is wider than deep.
4. Symmetry of the groove (in cross-section).	Symmetrical (a); asymmetrical (b)
5. Shoulder effect.	Presence (a), or absence (b)
6. Presence of flaking on the shoulders of the groove.	Presence (a), or absence (b). In some cases flaking inside the groove of the mark can be identified.
7. Extent (width) of flaking.	Over more (a) or less (b) than one-third of the trajectory of the shoulder or inside the groove of the mark. It can be absent (c).
8. Internal microstriations.	Presence (a) or absence (b)
9. Microstriations trajectory.	Continuous (a), or discontinuous (b)
10. Shape of the microstriation trajectory.	Straight (a) or irregular (b) (curved, sinuous, or in combination).
11. Location of microstriations.	On the walls of the groove (a), on the bottom (b) or on both (c).
12. Number of internal grooves of the mark.	We counted the number of internal grooves which appear inside the mark. This multiple occurrence of grooves is due to possible confluence of two or more marks in one single parallel mark. These can be created due to the irregular edges of handaxes (Figs. 3 and 5)
13. Fork-shaped mark.	We define this type of marks as those marks that connect with each other by intersecting in a branched or fork shape. These marks have been made with a single stroke, and they form a unique body of several marks (Fig. 3)
14. Multiple mark.	We define this type of mark as a set of multiple marks produced by a single stroke that are not in contact with each other. These marks have been made in a single stroke (Fig. 4).
15. Number of fork-shaped marks	Number of marks in contact with the main groove of the cut mark.
16. Number of multiple marks	Number of marks occurring near the main groove of the cut mark.

a binocular microscope (Motic) with magnifications of 20×–40× and a digital camera incorporated (MC V3), which transfers high-resolution images in .mix, .bmp and .jpeg formats into a computer. The images were thus downloaded directly to a computer and processed with Motic Image Plus 2.0 software. Each mark was observed by the authors to confirm the identification of characteristics in each of the variables analysed.

For the microscopic analysis of the morphology, both internal and external, of cut marks, we used the protocol that was previously designed to differentiate trampling marks from cut marks (Domínguez-Rodrigo et al., 2009), although we readjusted this protocol for the present study, and removed some variables that explained a very small amount of variance or were only appropriate when comparing cut marks with trampling marks but were not useful when comparing only cut marks. The resulting variables used for this study – and defined in (Domínguez-Rodrigo et al., 2009) – can be seen in Table 1. Four new variables not reported in Domínguez-Rodrigo et al. (2009) have been added. They are the presence or absence of fork-shaped marks – identified by Domínguez-Rodrigo et al. (2009) as multiple intersecting marks in cut marks created with retouched flakes (Figs. 2 and 3) – and multiple marks, defined as multiple non-intersecting marks that accompany the main groove, caused by the winding profile of the artefact edge when retouched (Fig. 4). Frequently, both types of marks were documented together (Fig. 4b). The other two variables involved the number of fork-shaped marks and multiple marks generated per cut mark set in one single stroke.

2.2. Statistical methodology

In order to differentiate handaxe-imparted cut marks from those created using retouched flakes, it was necessary to create a two-level analysis. The first analytical level was aimed at creating analogical signatures that were not dependent on the type of handaxe used or the angle of stroke. The second analytical level involved comparing the diagnostic variables obtained in the previous analysis across the samples of handaxe-made cut marks and those from cut marks made with retouched flakes.

In order to select the most influential variables to discriminate cut mark results according to biface type and angle of stroke (perpendicular vs. oblique), a principal component analysis (PCA) was used. PCA synthesizes the sample variance contained in a set of variables into factors. These factors explain most of the variance and classify each variable according to its contribution (communality) to the factorial solution (Hair et al., 1998). The final scoring was obtained though a rotated matrix, selecting Varimax as the rotation method. Each variable used was transformed from nominal into numerical and then standardized previously to running the analysis.

However, even if there is some debate to the effect of the use of samples with normal or non-normal distributions and

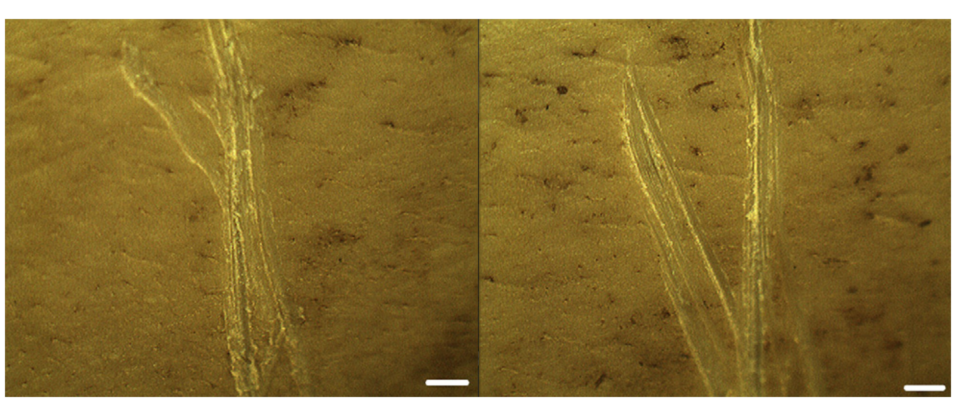

Fig. 2. Two common types of fork-shaped marks; sometimes marks intersect into one broad groove (right) and other times marks intersect into more than one groove (left). Scale = 500 μm.

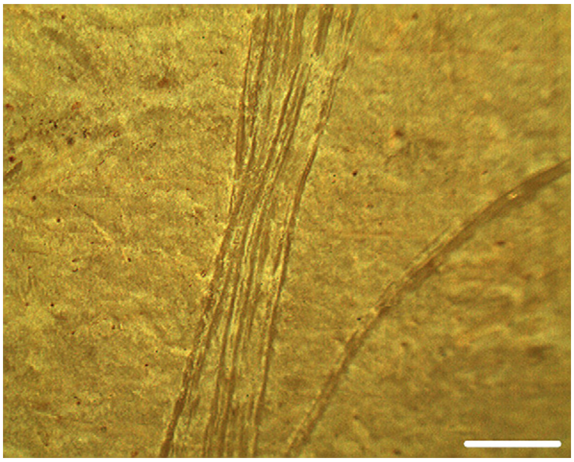

Fig. 3. Close-up detail of a common patter of fork-shaped cut mark created with handaxes. Multiple marks intersect into multiple grooves. The intersection can be straight, as most marks in this image, or with a curved parabole (mark on the right). All the grooves in this image were created simultaneously by a single stroke. Scale = 1000 μm.

heterocedastic vs. homocedastic variance in PCA (Hair et al., 1998), all the variables were inspected for skewness and normality. Kolmogorov–Smirnov (with Lilliefors' modification) and Shapiro–Wilk's tests were use to this effect. All the variables showed a non-normal distribution. Instead of applying just logarithmic and square-rooted transformations, a robust approach to the sample was used to avoid the bias introduced by the use of non-normal samples (since even with transformations several variables still remained non-normal). Robust methods allow estimating the matrix of variances–covariances of variables using robust estimators, which overcome the biases introduced by skewed distributions (Wilcox, 2005). Percentage bend correlations, Winsorized correlations and biweight midcovariances use *M*-estimators which, if applied to a robust component analysis, increases its reliability (Wilcox, 2005). The robust component analysis used for the present study is based on a robust covariance matrix using the "con.mve" or the "con.mcd" functions of the "mva" and "lqs" modules of the R library.

The most influential variables, determining most of the sample size, were then selected for a comparative analysis on the influence of handaxe type and angle of the stroke in the final set of characteristics of the resulting cut marks. For this comparative analysis, a general linear model was applied through a classical two-way ANOVA univariate analysis. However, given the sensitivity of this type of analysis to non-normal samples, we used the standardized values in the classical ANOVA test only as a comparative framework for a robust ANOVA analysis using robust parameters also in R (2009). This was done by using Welch's test with trimmed alpha values (and winsorized sampling quasi-variances) and Snedecor F, instead of Fisher's *F*. Significant differences of variable interaction are marked by *F* values being higher than the critical point values. As a comparative control, X^2 tests were also applied, given the original categorical nature of some of the variables. However, this latter non-parametric test is less powerful, since it frequently admits as different samples which are not when using a more robust estimator (Hair et al., 1998).

After this was done, to separate those variables that were influenced by handaxe type from those that were not and could, thus, be potentially used as a referential framework, a discriminant analysis was carried out comparing the sample of cut marks produced with handaxes with that reported from experiments with retouched flakes (Domínguez-Rodrigo et al., 2009). The reason for comparing both types of marks is their overall structural similarity. Cut marks produced with handaxes can be differentiated from those made with simple flakes by section shape, the amount of shoulder effect and associated flaking, as well as by the virtual lack of fork-shaped marks or multiple marks in the latter type. These features, though, have been documented in cut marks created with retouched flakes (Domínguez-Rodrigo et al., 2009). The question remains as to whether that prevents cut marks with these characteristics from being correctly attributed to tool type (handaxe versus small retouched flake). If the answer is positive, then potential butchery cut marks produced with handaxes will not be taphonomically identifiable.

The discriminant analysis applied used Box's equality of covariance matrices and Wilk's lambda for testing the equality of group means. The variables used were standardized and those with non-normal distribution were log-transformed. The sample was then inspected for heterocedasticity and multicolinearity (by using correlation in covariance matrices). The procedure selected was stepwise instead of entering all the predictor variables together because of its higher reliability in discriminating functions by using those variables that are more determinant and discarding those with low and non-significant contribution to the resulting model. The method selected for the creation of centroids and classification of cases was Mahalanobis' distance, instead of Wilk's lambda, because it is more appropriate for a stepwise method (Hair et al., 1998), since it is based on the generalized squared Euclidean distance, which fits better uneven variances. Mahalanobis' D^2 performs a stepwise analysis similar to the stepwise multiple

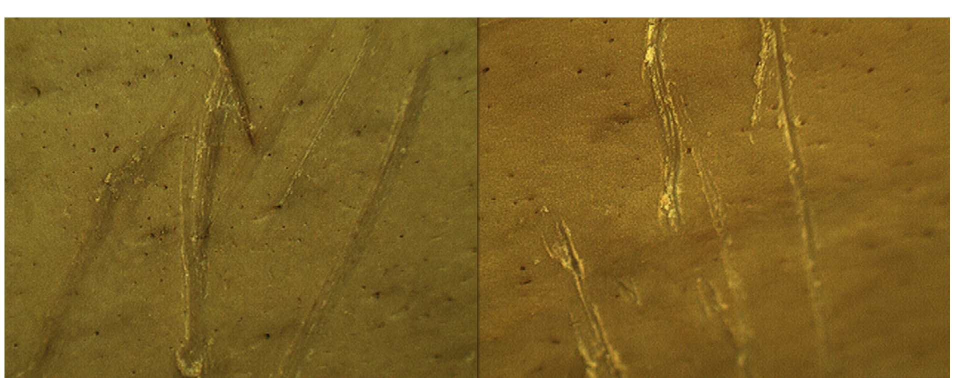

Fig. 4. Examples of multiple marks created by a single stroke. They can show diverse orientation (left) or parallel orientation (right). Also, they can combine multiple with fork-shaped marks (right). Scale = 500 μm.

regression. The stepwise method allows the selection of variables to create a best-fit model by maximizing Mahalanobis' D^2 in between groups.

3. Results

Cut marks made with handaxes are very broad and comparatively shallow in proportion. They are characterized by a _/ –shaped or trapezium-shaped section, whose base is horizontal, being the groove wider than deep (Figs. 2 and 5). They also show shoulder effect and very frequently flaking occurs on the shoulder edge extensively (Fig. 6). This contrasts with the V-shaped section of cut marks made with simple flakes, with less flaking on shoulder (Domínguez-Rodrigo et al., 2009). There is a curious similarity in the morphology of cut marks created with simple and retouched flakes, when compared to cut marks created with metal knives with simple steel blades and those with serrated blades. The simple steel blades create deep V-shaped grooves with regular shoulders, whereas the serrated edge produces more open and shallow grooves with poor definition of the edges and irregular shoulders (Greenfield, 1999, 2000, 2002, 2005). Greenfield (1999, 2005) also documented that retouched flakes (scrapers) also show a similar morphological pattern to that reported for marks made with metal knives with serrated edges. In the former case, grooves are shallow, with sloping edges, and the largest side of the groove is more irregular than in marks made with metal knives.

3.1. Identification of variables that can be used to recognise cut marks produced by handaxes

Two morphological features that characterize cut marks made with handaxes are almost non-documented in cut marks created with simple flakes: the presence of fork-shaped marks, that is intersecting marks, and multiple marks, that is, parallel marks that occur separately from each other's shoulder edges. Both types of features, especially the former, have also been documented in cut marks made with retouched flakes, which also show similar cross-section morphology (Domínguez-Rodrigo et al., 2009). Therefore, the challenge is to discriminate between cut marks made with handaxes from those made with smaller retouched flakes, since both tools share the same property of an irregular and winding edge, which accounts for most of these features.

The robust PCA made with R yielded a 2-component solution, which explained 92.2% of the total sample variance. The first component (accounting for 78.2% of the variance) was explained by the presence and number of fork-shaped marks per cut mark (score = .985). The second component was also almost exclusively

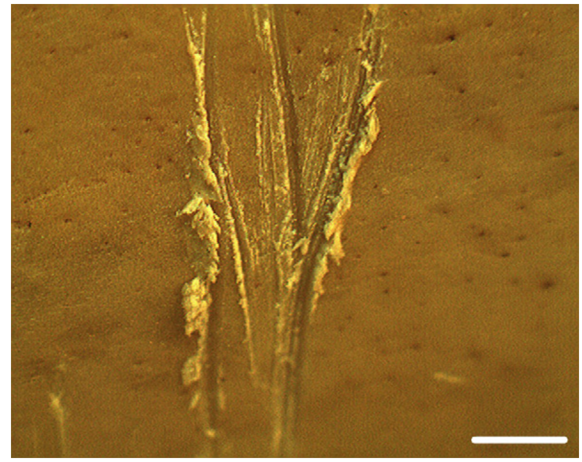

Fig. 6. Example of flaking on the shoulders of a fork-shaped mark. Scale = 1000 μm.

composed of the number of multiple marks per cut mark (score = .987). Either by removing these variables and conducting a PCA on the remainder or by using a third factor with all the variables together, the presence of flaking and flaking width also accounted for a smaller portion of the sample variance.

As a comparative measure, an initial exploratory PCA in which normality of each variable was not considered yielded a two-factor solution which explained a smaller amount of variance (42%) and selected the same variables. The first component scored high on fork-shaped marks and flaking, whereas the second was mostly focused on multiple marks. However, the small amount of variance explained and a low KMO measure of sample adequacy (0.52) were enough to discard this classical PCA when compared to the robust PCA, despite the similar results of both tests.

Therefore, it seems that the bulk of variables other than those affecting multiple marks, fork-shaped marks and flaking are homogeneously distributed in the sample and have a lower explanatory power than the selected variables.

Subsequently, a classical two-way ANOVA analysis was performed on the selected variables, using a general linear model (Table 2). The resulting model yielded a positive interaction between angle and handaxe type in the flaking frequencies (sig. = .000). This was supported when observing that handaxe type and angle of stroke also played independently a significant role (sig. = .000). Perpendicular strokes created a higher presence of flaking. Handaxe 3 produced a significantly higher amount of flaking than handaxes 1 and 4 (Table 2).

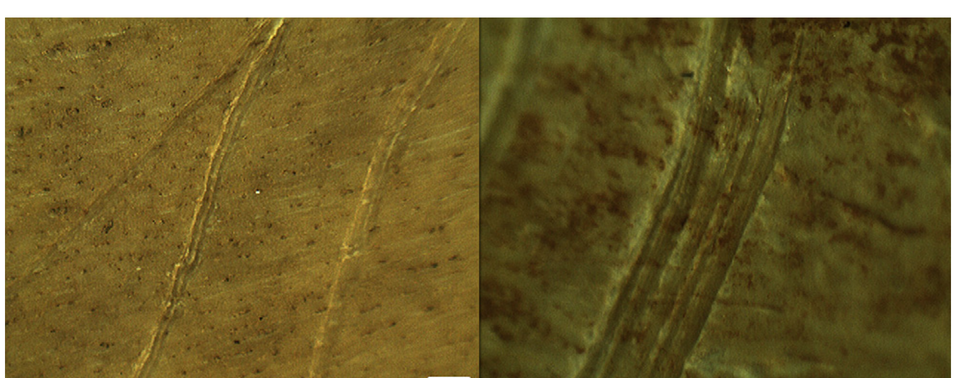

Fig. 5. Examples of the broad section of the grooves of cut marks created with handaxes, with multiple inner smaller grooves. Scale = 500 μm (left), 1000 μm (right).

Table 2
Results of the ANOVA analysis testing the interaction of handaxe type and angle type according to the variables that explain the largest portion of variance and post hoc tests to analyse the pairwise interaction of handaxe types.

Variables (handaxe × angle)	*F*	Sig.	Dunnett T3 (sig.) (handaxe types)	Games-Howell (sig.) (handaxe types)	*R*-square
Flaking	11.670	.000	(1 × 3) (3 × 4)	(1 × 3) (3 × 4)	.245
Flaking length	10.091	.000	–	–	.148
Fork-shaped marks	2.073	.105	(2 × 4) (3 × 4)	(2 × 4) (3 × 4)	.132
Multiple marks	1.011	.394	–	–	.079
n. of Fork-shaped marks	3.707	.013	(1 × 2) (1 × 3) (2 × 4) (3 × 4)	(1 × 2) (1 × 3) (2 × 4) (3 × 4)	.279
n. of Multiple marks	0.305	.789	–	–	.096

Post hoc tests Dunnett T3 and Games-Howell were selected because equal variances were not assumed. Numbers in parentheses indicate the comparison of handaxe types that created values in each variable that were significantly different.

The extent of the flaking created also varied significantly when comparing handaxe types and angle of stroke together (sig. = .000). However, it was more due to the type of handaxe (sig. = .026) than to the type of angle of stroke (sig. = . 325). In contrast to this assertion, pot-hoc tests did not detect any significant difference when equality of variances was not assumed (Table 2).

The frequency of fork-shaped marks was the same when considering handaxe type and angle of stroke jointly (sig. = .105). Only when considering handaxe type separately (sig. = .03) some differences were detected, but they were mostly due also to the marks created by handaxe 4.

The frequency of multiple marks was unaffected by either handaxe type or angle type (sig. = .394). This could potentially be a good indicator for differentiating cut marks imparted with handaxes from cut marks created with other stone tool types.

The opposite can be observed in the combination of handaxe type and angle of stroke when considering the number of resulting fork-shaped marks (sig. = .000). This can also be documented when considering handaxe type (sig. = .000) or angle (sig. = .000) separately. Each handaxe leaves a different mean number of this type of marks and perpendicular strokes generate more of these marks than oblique strokes. Therefore, the number of marks per stroke would initially not seem to be a good discriminating variable, especially given its *R*-square value.

This is not documented in the variable quantifying the number of multiple marks. No difference is documented according to handaxe type of angle type (sig. = .789). This renders the use of multiple marks as a potential good discriminating variable, since it is not dependent on the type of tool or the angle of tool use.

These interpretations have to be taken with extreme precaution because the sample is heterocedastic and also because they are derived from the variance of a very small portion of the sample according to *R*-square values (<30%). If a robust ANOVA analysis is applied, to overcome these biases, the results show some differences (Table 3).

A X^2 test shows more similarities with the classical ANOVA than with the robust ANOVA analysis. The robust test shows that there is no interaction between handaxe type and angle of stroke, but the former plays a significant role in the amount of flaking, whereas there is no difference in angle. The robust test ratifies the inferences from classical ANOVA regarding the influence of handaxe but contradicts that angle of stroke has any significant impact in the frequency of flaking occurring on cut marks.

Regarding the extent of flaking along each mark and the frequencies of fork-shaped marks and multiple marks, the outlying behaviours documented by classical ANOVA and X^2 tests are corrected with a robust ANOVA test and, as a result, no significant differences are documented according to handaxe type, angle of stroke or the interaction of both.

As occurred with the classical ANOVA test, the number of fork-shaped marks per cut mark is strongly dependent on the handaxe type and the angle of stroke. This is, therefore, a variable not to be used alone (but in combination with other variables, see below) as a single reference since it may vary according to stone tool type.

A confirmation that these variables can be used as indicators of what cut marks made with handaxes look like irrespective of the type of handaxe used can be obtained if the sample is studied through a multiple discriminant analysis (Table 4). The resulting model is based on the number of multiple marks, flaking and number of fork-shaped marks, with non-significant sigma values. The structure matrix shows that the highest contribution to the first factor come from the number of fork-shaped marks (.85), the second factor is explained by the number of multiple marks (.9) and the third factor is accounted for by flaking (.6). The discriminant factors obtained have low canonical correlations (<.5) and explain less than 20% of the dependent variable, thus showing an intense overlap in the characteristics of the variables selected for all four handaxe types (Fig. 7). This is further supported by the high error margin in the classification of cases: only 45% of the original group cases were correctly classified. With such a poor resolution, the model indicates that the variables which account for most of the variance are not sufficiently different to discriminate among handaxe types, as suggested by the robust ANOVA analysis.

In summary, flaking (together with the extent of flaking) and, especially, the frequencies of cut marks that are multiple (irrespective of their numbers in a single cut mark) and, to a lesser extent, fork-shaped (in combination with the previous variables) seem to be unaffected by handaxe type or angle of stroke and can potentially be good discriminatory indicators to differentiate marks created with handaxes.

Table 3
Results of the robust ANOVA analysis testing the interaction of handaxe type and angle type and both variables separately, according to the variables that explain the largest portion of variance. Chi-square test results are also shown as a contrast.

Variables (handaxe × angle)	*F*	Critical point	Handaxe type[a]	Angle of stroke[a]	Chi-square (handaxe × angle)
Flaking	5.591	7.205	6.918 (**.009**)	2.026 (.178)	65.334 (**.000**)
Flaking length	3.732	4.791	2.905 (.08)	0.219 (.646)	329.808 (**.000**)
Fork-shaped marks	2.921	4.845	1.944 (.09)	0.0403 (.98)	3.011(.08)
Multiple marks	1.921	2.523	0.945 (.67)	0.734 (.52)	2.984 (.62)
n. of Fork-shaped marks	91.877	44.322	39.161 (**.000**)	18.399 (**.000**)	683.278 (**.000**)
n. of Multiple marks	4.901	6.201	2.726 (.09)	5.992 (.07)	147.149 (**.000**)

[a] Numbers in parentheses indicate the sigma values in each of the two variables. Values in bold are statistically significant.

Table 4
Multiple discriminant analysis selecting the most influential variables to differentiate among handaxe types. Notice that the sigma values show that all handaxe types overlap intensively.

Variables entered/removed[a, b, c, d]							
Step	Entered	Min. *D* squared					
		Statistic	Between groups	Exact *F*			
				Statistic	df1	df2	Sig.
1	*n*. of Multiple marks	.004	2.00 and 4.00	0.112	1	208.000	.738
2	Flaking	.144	2.00 and 3.00	2.326	2	207.000	.100
3	*n*. of Fork marks	.161	2.00 and 3.00	1.726	3	206.000	.163

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is entered.
[a] Maximum number of steps is 16.
[b] Minimum partial *F* to enter is 3.84.
[c] Maximum partial *F* to remove is 2.71.
[d] *F* level, tolerance, or VIN insufficient for further computation.

Table 5
Discriminant analysis used for selecting the most discriminant variables to differentiate between cut marks made with handaxes and those made with retouched flakes.

Variables entered/removed[a, b, c, d]							
Step	Entered	Min. *D* squared					
		Statistic	Between groups	Exact *F*			
				Statistic	df1	df2	Sig.
1	*n*. of Multiple marks	2.344	Handaxe and retouched flake	164.627	1	315.000	1.330E-30
2	*n*. of Fork marks	3.448	Handaxe and retouched flake	120.679	2	314.000	1.318E-39
3	Fork marks	3.635	Handaxe and retouched flake	84.551	3	313.000	4.329E-40
4	Shoulder	3.752	Handaxe and retouched flake	65.232	4	312.000	4.812E-40
5	Flaking	3.862	Handaxe and retouched flake	53.547	5	311.000	5.374E-40

At each step, the variable that maximizes the Mahalanobis distance between the two closest groups is entered.
[a] Maximum number of steps is 16.
[b] Minimum partial *F* to enter is 3.84.
[c] Maximum partial *F* to remove is 2.71.
[d] *F* level, tolerance, or VIN insufficient for further computation.

3.2. *Comparison between cut marks produced by handaxes and retouched flakes*

The morphology of handaxe cut marks is most similar to those marks created with retouched flakes as discussed above (Domínguez-Rodrigo et al., 2009). They are broader than deeper in absolute values, and have more intense shoulder-effect associated marks, in the form of fork-shaped marks (mostly documented previously in cut marks made with retouched flakes) and multiple marks. These features are marginally (some of them non-)documented in cut marks made with simple stone flakes. A discriminant analysis applied to differentiate handaxe cut marks from retouched flake cut marks produced very useful results to differentiate these marks. The sample of 212 cut marks made with handaxes and the sample of 105 cut marks made with retouched flakes were used for the comparative analysis. An initial exploratory analysis showed some cases of multicolinearity; for example, flaking and flaking extent were highly and significantly correlated (.90). Therefore, some of the correlated variables with the lowest influence on the sample set were discarded. A final stepwise analysis yielded a model based on a discriminating function that accounted for 50% of variance of the dependent variable, with an eigenvalue of .86 and a canonical correlation of .70. The standardized canonical discriminant function coefficients for the variables selected for the model are in order of importance (Table 5): number of multiple marks (.70), number of fork-shaped marks (.42), frequency of fork-shaped marks (.28), flaking (.20) and shoulder effect (−.26).

A casewise statistical analysis showed that 82.3% of cases were correctly classified (Tables 6 and 7). Therefore, the reliability of the variables selected by the model (Table 4) for discriminating between both types of stone tools is fairly high. Cut marks made with handaxes show a high frequency of multiple and fork-shaped marks (>95%) with a higher number of multiple marks (which in cut marks made with retouched flakes average <2 [mean = 1.01] and for handaxes is 3 or higher [mean = 3.1] per cut mark) and of fork-shaped marks (cut marks made with retouched flakes average

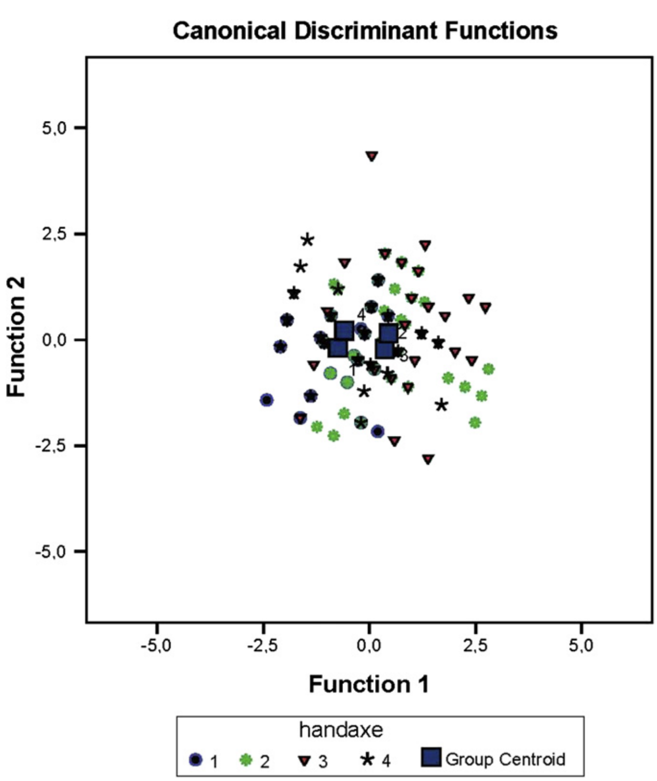

Fig. 7. Plot of the canonical discriminant functions of the properties of cut marks made with four different types of handaxes in a two-function solution. Notice the intense overlap of the signatures of cut marks made with the four handaxes. The centroids are so close together that marks overlap on the center of the plot. The discriminant variables selected in a stepwise method appear in Table 4.

Table 6
Classification results of cut marks according to the discriminant variables selected in Table 5.

Classification results[a]					
		Tool type	Predicted group membership		
			Handaxe	Retouched flake	Total
Original	Count	Handaxe	170	42	212
		Retouched flake	14	91	105
	%	Handaxe	80.2	19.8	100.0
		Retouched flake	13.3	86.7	100.0

[a] 82.3% of original grouped cases correctly classified.

Table 7
Distribution of the main variables used to differentiate among marks created by various tool types and trampling (see Domínguez-Rodrigo et al., 2009). Data are in percentages. Variables in bold indicate their discriminatory value, starting from bottom (trampling) to top (cut marks made with handaxes).

Tool type	Trajectory	Barb	Groove shape	Shoulder	Shoulder flaking	Flaking extent	Microstriations	Microstriation trajectory	Microstriation shape	Microstriation location	Fork-shaped marks	Multiple marks	*n.* of Fork-shaped marks	*n.* of Multiple marks	Microabrasion
Handaxe	Straight = 90	Present = 0.9	*V* = 8.4	Present = 77	**Present = 74.1**	Absent = 25	Present = 99.6	**Continuous = 62.5**	**Regular = 59.7**	**Wall = 15**	**Present = 83.5**	**Present = 93**	**Range = 2–9**	**Range = 2–10**	Present = 0
	Curvy = 5.1	Absent = 99.1	_/ = 91.6	Absent = 23	**Absent = 25.9**	>1/3 = 34	Absent = 0.4	**Discontinuous = 47.5**	**Irregular = 40.3**	**Bottom = 15.7**	**Absent = 16.5**	**Absent = 7**			Absent = 100
	Sinuous = 4.9					<1/3 = 41				**Both = 69.3**					
Retouched flake	Straight = 97	Present = 5.7	*V* = 5.7	Present = 74.3	**Present = 51.4**	Absent = 11.4	Present = 100	Continuous = 100	Regular = 100	Wall = 2.9	**Present = 41.9**	**Present = 61**	**Range = 1–2**	**Range = 1–3**	Present = 0
	Curvy = 0	Absent = 94.3	_/ = 94.3	Absent = 25.6	**Absent = 48.6**	>1/3 = 40	Absent = 0	Discontinuous = 0	Irregular = 0	Bottom = 88.6	**Absent = 58.1**	**Absent = 39**			Absent = 100
	Sinuous = 2.9					<1/3 = 48.6				Both = 8.6					
Simple flake	Straight = 93.5	Present = 10.2	***V* = 96.7**	**Present = 32.9**	**Present = 14.6**	**Absent = 85.4**	Present = 77.2	Continuous = 100	Regular = 100	**Wall = 73.2**	Present = 1	Present = 0	0	0	Present = 2.4
	Curvy = 6.5	Absent = 89.8	**_/ = 3.3**	**Absent = 67.1**	**Absent = 85.4**	**>1/3 = 14.6**	Absent = 22.8	Discontinuous = 0	Irregular = 0	**Bottom = 0**	Absent = 99	Absent = 100			Absent = 97.6
	Sinuous = 0					**<1/3 = 0**				**Both = 4.1**					
Trampling	**Straight = 29.8**	Present = 2.4	***V* = 4**	**Present = 5.9**	**Present = 2.7**	**Absent = 0.7**	Present = 75	**Continuous = 67.3**	Regular = 82.8	Wall = 2.8	Present = 0	Present = 0	0	0	**Present = 99.6**
	Curvy = 16.7	Absent = 97.6	**_/ = 96**	**Absent = 94.1**	**Absent = 97.3**	**>1/3 = 1.9**	Absent = 25	**Discontinuous = 32.7**	Irregular = 17.2	Bottom = 87.2	Absent = 100	Absent = 100			**Absent = 0.4**
	Sinuous = 53.4					**<1/3 = 97.3**				Both = 10					

<1 [mean = 0.6] and for handaxes is 3 or higher [mean = 2.99] per cut mark). Flaking and shoulder effect are also most frequently represented in marks made with handaxes (50% more) than in cut marks resulting from the use of retouched flakes.

4. Discussion and conclusions

Quantification plays a crucial role in determining taphonomic agents of bone modification. In the present case, some marks created by handaxes could potentially mimic those imparted by smaller retouched flakes (<20%). The determination of the effector (*senso* Gifford-Gonzalez, 1991) in this case depends more on quantification of complete assemblages (or a random selection thereof), instead of the identification of these ambiguous marks from single specimens. Therefore, selecting what variables are quantified becomes an important task, as this will eventually determine their discriminatory value.

This applies to all types of studies of bones bearing butchery marks. Quantification of cut-marked bones has been a traditional procedure in taphonomic and zooarchaeological studies. Although the wide degree of variability in frequencies of cut-marked specimens has led some researchers to view cut mark studies with scepticism (Lyman, 2005), others argue that such a range of variability can be understood by a small number of inter-related variables (namely, those resulting from bone fragmentation, preservation and deletion) (Domínguez-Rodrigo et al., 2009). It has recently been suggested that this can be overcome if cut-marked NISP is replaced by cut-marked MNE (Otarola-Castillo, 2010), but even if this would provide a smaller and more even range of cut-marked bone frequency, it would not be taphonomically useful to infer prehistoric butchery behaviours. For instance, there are no actualistic analogs to interpret cut mark frequencies tallied per MNE. If there were, they would probably not be very useful since radically opposing behaviours such as hunting (producing a high number of cut marks on a single bone) and passive scavenging (maybe producing one single cut mark on the same element) would show the same frequencies of cut-marked bones when cut marks are tallied per element instead of per specimen according to bone section (Domínguez-Rodrigo, 1997). Therefore, the way quantification is carried out determines the possibility of interpreting butchery behaviours when using frequencies of cut-marked bone.

The present work shows that quantification is also important for interpreting cut marks as the result of using specific tool types during butchery. When certain features are tool-specific, then interpreting the effector is just a matter of presence/absence of such signatures. However, frequently, interpretation is based on the frequency of occurrence of a determined characteristic or an inter-related set of features. Quantification of cut marks can, thus, have a great potential for differentiating among different tool types, especially when their signatures overlap. This is the case of cut marks created with retouched flakes and handaxes, given their apparent similarity. In order to differentiate between both types of marks, the present study has produced a reduced number of variables, which correctly discriminates more than 80% of marks created with both stone tool types. These variables are: number of multiple marks, number of fork-shaped marks, frequency of fork-shaped marks and multiple marks, and extent of flaking on the groove shoulder. This latter variable may be not very useful for discriminatory purposes on samples of fossil cut-marked bone, since flaking and exfoliation (together with microstriations) are very easily destroyed by biostratinomic and diagenetic processes (Behrensmeyer et al., 1986). The other variables, in contrast, can be easily recognized despite these potential biases. Marks created with handaxes showed in more than 95% of cases fork-shaped marks and multiple marks. Fork-shaped marks in cut marks made with retouched flakes usually occur in the form of one (most common) or two (more marginally) additional marks adjoining the main groove (see Figure 13 in Domínguez-Rodrigo et al., 2009), whereas in cut marks created with handaxes, they usually occur with a minimum of two additional marks (three on average) and very frequently include several more. Something similar can be documented in multiple marks. They usually occur in more than one mark, which is the most common pattern for cut marks made with retouched flakes.

If these diagnostic criteria are combined with the descriptive characteristic of cut marks made with handaxes (broader grooves, with more internal grooving [see Figs. 2 and 3]) a good analogical description of how a cut mark made with a handaxe looks like can be provided. This has the potential of enabling archaeologists to test when (and if) handaxes were used for butchery purposes along the human evolutionary process.

Acknowledgements

We wish to thank J. Yravedra, R. Barba, A. Pérez García and M. Prendergast for their comments to an earlier version of this manuscript or parts thereof. We are also deeply indebted to the comments made by Silvia Bello and two anonymous reviewers on an earlier draft of this paper.

References

Behrensmeyer, A.K., Gordon, K.D., Yanagi, G.T., 1986. Trampling as a cause of bone surface damage and pseudo-cutmarks. Nature 319, 768–771.
Bello, S.M., Soligo, C., 2008. A new method for the quantitative analysis of cutmark micromorphology. Journal of Archaeological Science 35, 1542–1552.
Bello, S.M., Parfitt, S.A., Stringer, C., 2009. Quantitative micromorphological analyses of cut marks produced by ancient and modern handaxes. Journal of Archaeological Science 36, 1869–1880.
Bromage, T.G., Boyde, A., 1984. Microscopic criteria for the determination of directionality of cutmarks on bone. American Journal of Physical Anthropology 65, 359–366.
Bunn, H.T., 1981. Archaeological evidence for meat-eating by Plio-Pleistocene hominids from Koobi Fora, Kenya. Nature 291, 574–577.
Clark, D., 1959. The Prehistory of Southern Africa. Penguin, London.
Clark, D., Haynes, C.V., 1970. An elephant butchery site at Mwanganda's village, karonga, Malawi, and its relevance for Paleolithic archaeology. World Archaeology 1, 390–411.
Cole, S., 1963. The Prehistory of East Africa. Mentor Books, New York.
Davidson, I., Noble, W., 1993. Tools and language in human evolution. In: Gibson, K., Ingoll, T. (Eds.), Tools, Language and Cognition in Human Evolution. Cambridge University Press, Cambridge, pp. 363–388.
Domínguez-Rodrigo, M., 1997. Meat-eating by early hominids at the FLK 22 Zinjanthropus site, Olduvai Gorge, Tanzania: an experimental approach using cut mark data. Journal of Human Evolution 33, 669–690.
Domínguez-Rodrigo, M., Yravedra, J., 2008. Why are cut mark frequencies in archaeofaunal assemblages so variable? A multivariate analysis. Journal of Archaeological Science 36, 884–894.
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, 289–299.
Domínguez-Rodrigo, M., de Juana, S., Galán, A.B., Rodríguez, M., 2009. A new protocol to differentiate trampling marks from butchery cut marks. Journal of Archaeological Science 36, 2643–2654.
Fisher, J.W., 1995. Bone surface modification in zooarchaeology. Journal of Archaeological Method and Theory 1, 7–65.
Gifford-Gonzalez, D.P., 1991. Bones are not enough: analogues, knowledge, and interpretive strategies in zooarchaeology. Journal of Anthropological Archaeology 10, 215–254.
Greenfield, H.J., 1999. The origins of metallurgy: distinguishing stone from metal cut marks on bones from archaeological sites. Journal of Archaeological Science 26, 797–808.
Greenfield, H.J., 2000. The origins of metallurgy in the Central Balkans base on the analysis of cut marks on animal bones. Environmental Archaeology 5, 93–106.
Greenfield, H., 2002. Distinguishing metal (steel and low-tin bronze) from stone (flint and obsidian) tool cut marks on bone: an experimental approach. In: Mathieu, J.R. (Ed.), Experimental Archaeology: Replicating Past Objects, Behaviours, and Processes. Archaeopress, Oxford, pp. 35–55. BAR S1035.
Greenfield, H. J., 2005. The origins of metallurgy at Jericho (Tel es-Sultan): a preliminary report on distinguishing stone from metal cut marks on mammalian remains. In: edited by Hijlke Buitenhuis, Choyke A.M., Martin L,

Bartosiewicz L., Mashkour M. (Eds.), In Archaeozoology of the Near East VI (Proceedings of the 6th Sixth International Symposium on the Archaeozoology of Southwestern Asia and Adjacent Areas Conference), vol. 123. ARC-Publication, Rijksuniversitit, Groningen, The Netherlands, pp.183–191.

Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 1998. Multivariate Data Analyses. Prentice Hall, White Plains.

Howell, F.C., 1966. Observations on the earliest phases of the European Lower Paleolithic. American Anthropologist 68, 88–201.

Isaac, G. Ll., 1977. Olorgesailie. Archaeological Studies of a Middle Pleistocene Basin in Kenya. Chicago University Press, Chicago.

Jones, P.R., 1980. Experimental butchery with modern stone tools and its relevance for paleolithic archaeology. World Archaeology 12, 153–165.

Jones, P.R., 1994. Results of experimental work in relation to the stone industries of Olduvai Gorge. In: Leaky, M., Roe, D. (Eds.), Excavations in Beds III, IV and the Masek Beds. Olduvai Gorge, vol. 5. Cambridge University Press, Cambridge.

Keeley, L.H., 1980. Experimental Determinations of Stone Tool Uses: A Microwear Analysis. University of Chicago Press, Chicago.

Kohn, M., Mithen, M., 1999. Handaxes: products of sexual selection? Antiquity 73, 518–526.

Leakey, L., 1936. Stone Age Africa. Oxford University Press, Oxford.

Lyman, R., 2005. Analyzing cut marks: lessons from artiodactyl remains in the northwestern United States. Journal of Archaeological Science 32, 1722–1732.

Machin, A.J., 2008. Why handaxes just aren't that sexy: a response to Kohn & Mithen (1999). Antiquity 82, 761–766.

Mitchell, J.C., 1995. Studying biface butchery at Boxgrove: roe deer butchery with replica handaxes. Lithics 16, 64.

Mitchell, J.C., 1997. Quantitative image analysis of lithic microwear on flint handaxes. Microscopy Analysis 61, 15–17.

O'Brien, E.M., 1981. The projectile capabilities of an Acheulian handaxe from Olorgesailie. Current Anthropology 22, 76–79.

Otarola-Castillo, E., 2010. Differences between NISP and MNE in cutmark analysis of highly fragmented faunal assemblages. Journal of Archaeological Science 37, 1–12.

Potts, R., 1989. Olorgesailie: new excavations and findings in the early and middle Pleistocene contexts, southern Kenya Rift Valley. Journal of Human Evolution 18, 477–484.

Potts, R., Shipman, P., 1981. Cutmarks made by stone tools on bones from Olduvai Gorge, Tanzania. Nature 291, 577–580.

R Development Core Team, 2009. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Roe, D., 1994. A metrical analysis of selected sets of handaxes and cleavers from Olduvai Gorge. In: Leaky, M., Roe, D. (Eds.), Excavations in Beds III, IV and the Masek Beds. Olduvai Gorge, vol. 5. Cambridge University Press, Cambridge.

Shipman, P., Bosler, W., Davis, K.L., 1981. Butchering of giant geladas at an Acheulian site. Current Anthropology 22, 257–268.

Walker, P.L., Long, J.C., 1977. An experimental study of the morphological characteristics of tool marks. American Antiquity 42, 605–616.

Walker, P.L., 1978. Butchering and stone tool function. American Antiquity 43, 710–715.

Wilcox, R.R., 2005. Introduction to Robust Estimation and Hypothesis Testing. Elsevier Academic Press, London.