Paper Title.

Journeys in Space and Time. Assessing the link between Acheulean handaxes and genetic explanations.

Author.

John McNabb

Author affiliation.

Department of Archaeology.

University of Southampton.

Southampton

Hampshire, UK.

SO17 1BJ

Corresponding Author.

John McNabb. scarab@soton.ac.uk

Abstract.

In a recent paper Corbey and colleagues argued that there may be a genetic component to Acheulean handaxe manufacture across the Old World. They mention innovative work by Stephen Lycett and Noreen von Cramon-Taubadel who argued that assemblages of handaxes will show less handaxe shape variability the further they are away from Africa. This is because handaxe shape conforms to a genetic model of loss of diversity resulting from serial bottlenecking. The model linked material culture to hominin demography. Here I argue that there is no loss of shape with time and geographical distance from Africa, merely a tacking of outline form across potential morphological space as a result of a number of different factors which will vary with place and time. I use a modified version of Lycett and von Cramon-Taubadel's methodology, and 2D geometric-morphometrics to show this.

Keywords.

Acheulean, handaxe, geometric-morphometrics, genetics, culture, Olduvai Gorge, Oldupai Gorge

1. Introduction.

In a recent paper Corbey and colleagues suggested there was a genetic component to handaxe making, positing that these iconic artefacts may be explained by a ‘soft’ genetic argument, one which admits a role for social environment mediating a genetic predisposition (Corbey, et al., 2016). In their paper Corbey et al. cited the work of Stephen Lycett and Noreen von Cramon-Taubadel (Lycett, 2008, Lycett and von Cramon-Taubadel, 2008) in support of their argument. Some years ago, these two researchers presented an intriguing hypothesis that various handaxe shapes were being lost as hominins moved further away from Africa (using Oldupai Gorge as a hypothetical African origin point for the Acheulean). This loss in handaxe shapes was measured against distance between Oldupai and a certain number of Acheulean sites in Western Asia, India, Pakistan and Europe. Loss of shape was quntified by the calculation of the amount of variability present in handaxe shape at each site (see below). The loss of variability with distance was analogous to an iterative founder effect were genetic lineages (unique alleles or suites of them) are lost with increasing distance from a population dispersal centre by repeated population crashes (serial bottlenecking).

If I have understood their argument correctly, population geneticists only employ a loss of alleles by bottlenecking as an explanatory device when natural selection, or any other selective mechanism, is not at work. In other words, the variation in the population is selectively neutral. Under these circumstances changes in allele frequency are a result of neutral drift. Population crashes are one form of stochastic sampling under neutral drift. So Lycett and von Cramon-Taubadel’s model was ultimately rooted in hominin demography and was considered a better explanation of changes in Acheulean handaxe shape than the more traditional explanations of changing mental templates, differences in strong social learning, and raw material variability.

Corbey et al. do not dwell on the details of Lycett and von Cramon-Taubadel’s work, merely noting it as a further proof of their argument that Palaeolithic material culture can have a genetic component to its character. In this paper I would like to suggest that the genetic analogy of handaxe shape changing with distance from Africa is not supported by the evidence and so does not strengthen Corbey et al.’s argument.

2. A theoretical concern.

Lycett and von Cramon-Taubadel (2008) argue that nearly 50% of the variation in their data can be explained by handaxe shape loss due to geographical distance from Africa, meaning that almost half of the variation has to be explained by other factors. They suggest seven; raw material, selection, cultural transmission between different groups, inaccuracies in elements of their model, lithic samples not reflecting true range of original variance, new shapes introduced (cultural mutation) and population movements back toward Africa countering the serial effect with increasing difference.

The 50% of the variance in shapes that is to be explained by distance requires neutral (i.e. stochastic/non-directional) selection to explain the shape loss. If shape loss is truly analogous to bottlenecking across geographical space, then there cannot be any outside influence on handaxe shape. In other words, anything that would in any way precondition hominins to favour one handaxe shape over another (directional selection) would invalidate the 50% of the model that distance does explain.

> "Selection…[natural and/or cultural]… of any kind would have the effect of directing artefact variation in a manner that would not conform directly to the assumptions of an iterative founder effect model." (Lycett and von Cramon-Taubadel 2008, 557. My brackets.)

The stochastic character of the process is nicely illustrated by the Wikipedia entry for 'genetic drift' and is reproduced in Figure 1. Under a completely random sampling strategy there are major changes in the frequency of alleles/handaxe shapes across the iterations. The drift is non-directional (no outside influence on shape) and it is obvious that particular variants are being lost with each iteration, changing the overall structure of the population significantly. A population crash would remove a number of alleles/knappers from a social group, as well as their end products which are used as templates for others to copy. With the number of effective role models for young knappers reduced, overall variability in handaxe shape is diminished. Any interference in such a process, say the deliberate removal of a few shapes, or the inclusion of more examples of one particular shape (i.e. cultural selection because of function or group traditions of practice) would slant the result.

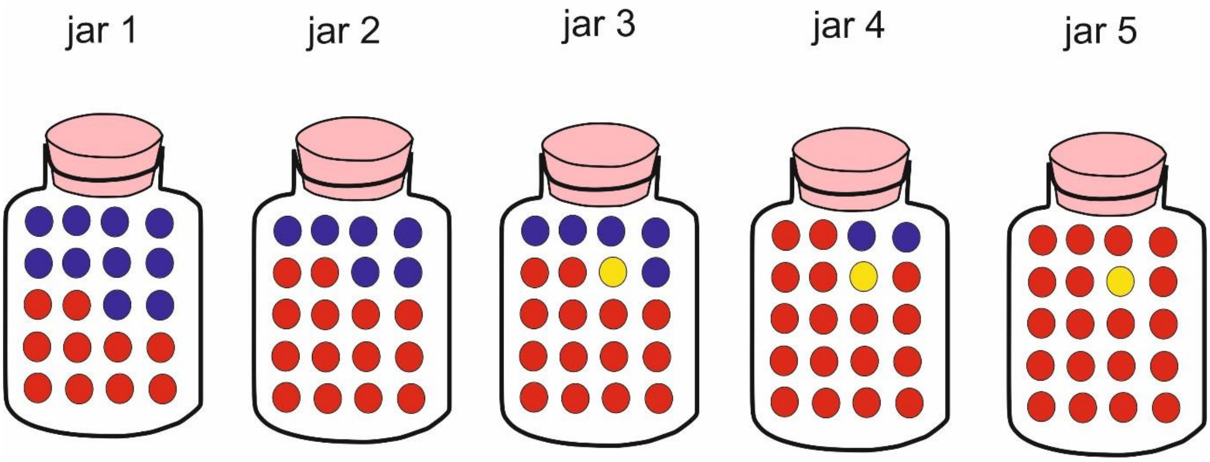

Figure 1. Random sampling in a neutral environment - one where there is no outside influence on handaxe shape/allele frequency. The first jar contains twenty marbles, ten red and ten blue. A marble is drawn at random from the first jar and then returned to it - this is the original gene pool/pool of overall handaxe shapes. An equivalent coloured marble is placed in the second jar - this is iteration 1. The process is then repeated until jar 2 is full (twenty marbles). Based on purely random sampling the allele/handaxe shape frequency has changed. The process is then repeated for iteration 2/jar 3 - twenty marbles are selected from jar 2 and returned to that jar (the gene pool of 2), and equivalent colours placed in jar 3 until it too has twenty marbles. The yellow marble is a random mutation/new handaxe shape. Repeating the process (for two more iterations/jars) continues to stochastically shuffle gene/handaxe frequencies. A key element in this is that there are no outside influences (natural selection/cultural preference) on the sampling process. Image redrawn after Wikipedia. https://en.wikipedia.org/wiki/Genetic_drift. In public domain. Image created by By Gringer - Own work, CC BY-SA 3.0. https://commons.wikimedia.org/w/index.php?curid=23655974.

Figure 1 should be in colour and can be in 1 column.

Here is my theoretical concern. In my opinion every handaxe ever made had a social or cultural influence upon it. No assemblage of handaxes was ever completely free of a cultural bias (selection). Handaxes will always reflect a directionality in their form, whether the knapper was the group's most reliable handaxe maker, some Palaeolithic teenage rebel kicking against accepted norms, or an experienced pro who ends up with something unusual just because they were having a bad day. There is always a directional selection at work on handaxe shape and this applies to the 50% of Lycett and von Cramon-Taubadel's data that they claim is explained by stochastic sampling. It isn't.

From almost their first conscious memory young *Homo erectus* or *Homo heidelbergensis* grew up watching others make, use, break, re-sharpen, reuse and abandon handaxes, and then do it all again the next day. By the time they came to start knapping for themselves they were already intimately familiar with the process of manufacture, the end result and its intended use. They learnt by imitation (process copying, but in this case with a knowledge of the end state as well, Cory Stade pers. comm.). They just needed the practice and the personal experience. The influence of peers and elders would be critical. We may never know just how much young knappers copied the handaxes of older knappers in the group as they learnt their craft, but group size would influence the number of viable role models available. The larger the group the more variability in potential outlines, and opportunities for personal experimentation (Mithen, 1994, Shennan, 2000).

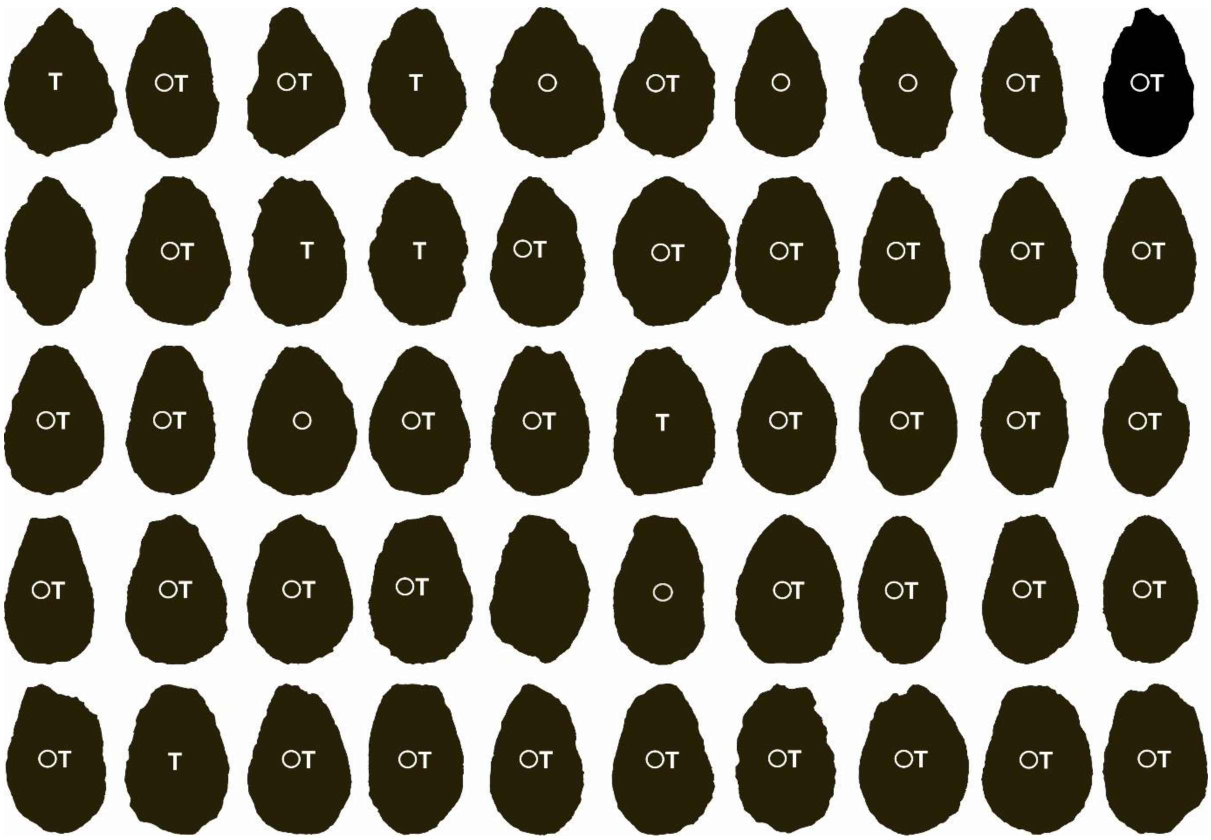

Figure 2. Silhouette of 50 Boxgrove handaxes, chosen from the Marshall *et al*. database, and selected by random number generator. They are positioned from left to right and from top to bottom on the basis of the width of the tip at Roe's B1 (width of tip at 20% of length down from tip). Narrowest top left and widest bottom right. A white circle indicates a handaxe with a cutting edge all the way around the circumference, or nearly so. A white T represents a tranchet. Handaxes not to scale.

Figure 2 need not be in colour and should cover 2 columns

Because of the fine resolution in the data from Boxgrove (Pope and Roberts, 2005, Roberts and Parfitt, 1999), it affords a glimpse of the process set, in my opinion, in the inferred context of a small group (Pope and Roberts, 2005). The Unit 4c land surface was open for no more than 100 years (Roberts and Parfitt, 1999), perhaps encompassing less than five generations (on the assumption a generation was c. 20 years – a heuristic figure). Young knappers would have been influenced by their parents, grandparents and older siblings, and other non-family members in the group who fell into these equivalent age categories. They would have grown up watching handaxes being made all around them. Figure 2 shows a randomly chosen selection of 50 outline shapes of Boxgrove Unit 4c handaxes. Their bauplan (*sensu* Gowlett and Lycett 2008 – here taken to be a hand held LCT, extensively thinned by soft hammer, with a cutting edge all around, tapering in the upper third, and more often than not with a tranchet) is repeated in almost all of the silhouettes. I would suggest this was because a century was not enough time for that basic outline to change. In any case it was the outline of a tool very much fit for purpose - butchery and carcass processing (Mitchell, 1996). We may infer from the very conservative repetition of the bauplan that there were little/no outside influences to encourage change. Although individuals did push the boundaries of shape a little (or made imperfect copies), they never strayed too far beyond the bauplan. I suggest that group size was too small for innovation and change to take hold.[1]

I would argue that here we have the best evidence available for the social influences on handaxe making and the fact that every handaxe ever made, to a greater or lesser extent, will have a directionality imposed on it by the very fact it was made by someone who grew up in a social group of knappers. Boxgrove represents one end of a spectrum, but even in larger groups and on palimpsests of longer duration, the handaxes will still reflect social learning.

Directionality (cultural selection) of some sort is inherent in the outline shape of all Acheulean handaxes.

3. A chronological concern.

Lycett and von Cramon-Taubadel (2008) suggest that factoring in chronology would be a potentially fruitful approach for further investigation. This has been attempted with their variance data in Figure 3. Sources for dating are referenced in the caption to the figure. It would be a reasonable expectation of their model that if variance decreased with geographical

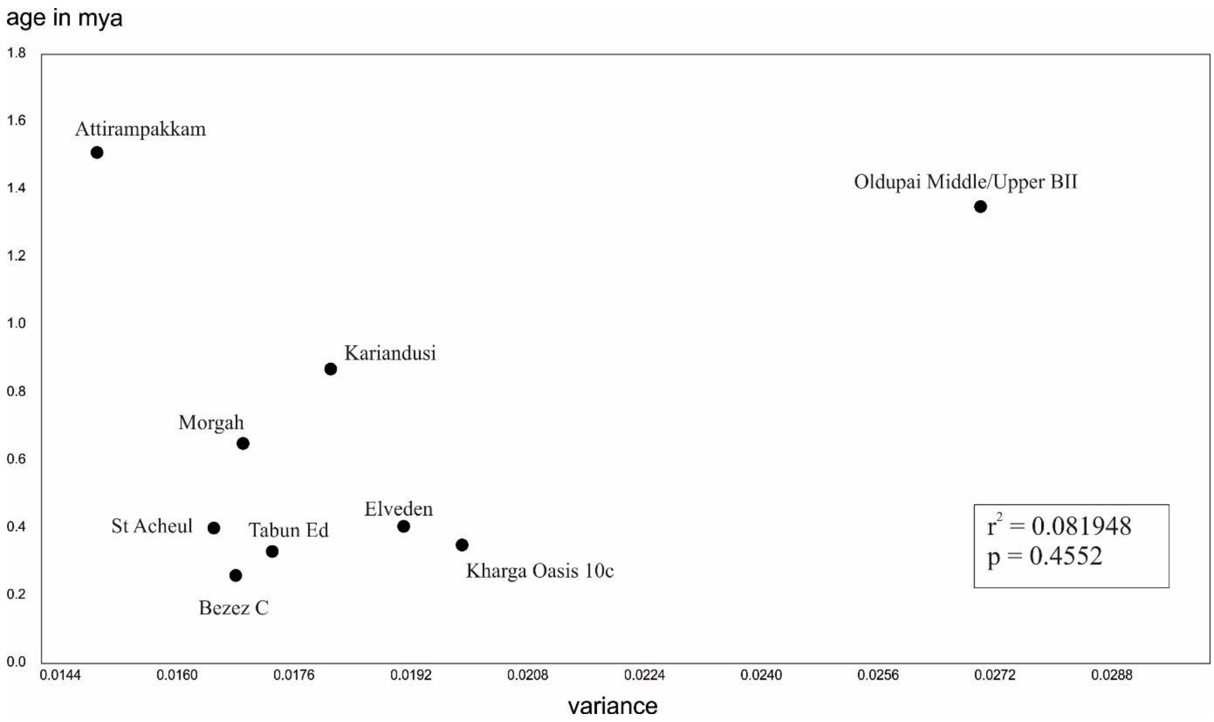

Figure 3. Scattergram showing relationship between Lycett and von Cramon Taubadel's calculations of the variances in shape in handaxe assemblages set against time. Dates from following; **Attirampakkam** – 1.51 mya (Pappu, et al., 2011), **Elveden** – 0.405 mya date for MIS 11c (Ashton, et al., 2016), **St Acheul** 0.4 mya (Moncel, et al., 2015), **Bezez C** 0.25 mya mid-point of range 0-2 – 0.3 mya (A. Shaw pers comm.), **Tabun Ed** – 0.331 mya (Culley, et al., 2013), **Kharga Oasis** 0.35 mya (Churcher, et al., 1999), **Morgah** 0.65 mya mid-point of 0.5 – 0.8 mya range based on geological association (Salim, 2008), **Kariandusi** 0.87 mya midway between range 0.78 – 0.960 mya (Durkee and Brown, 2014), **Oldupai Middle and Upper Bed II** 1.35 mya average of range 1.1 – 1.6 mya (McHenry, et al., 2016). Lewa, included in Lycett and von Cramon-Taubadel's original data is omitted here because it is currently undated.

Figure 3 need not be in colour and should cover 2 columns distance, it would also decrease with time as groups of hominins moved progressively further away from Africa. From the figure it is clear that this is not the case. The two oldest sites, Oldupai Bed II and Attirampakkam in India, actually bracket the younger ones in terms of handaxe shape variance, with the Indian site, slightly older than Oldupai, having the lowest variance of all. The broadly contemporary assemblages from Elveden and St Acheul (c. 0.40 mya), and those from Tabun layer Ed and Kharga Oasis layer 10c (c. 0.35-0.33 mya), show very different degrees of shape variance. From these data increasing loss of variance with time would not be supported.

4. Handaxe shape.

Limited experimentation on my part with the methodology proposed by Lycett for the assessment of handaxe shape (Lycett, et al., 2006), and the use of the geometric mean to eliminate size (*ibid*), suggests both work very well. However, arising from this was the concern that the method was not actually showing *loss* of shape so much as tracking how shape was changing in more subtle ways.

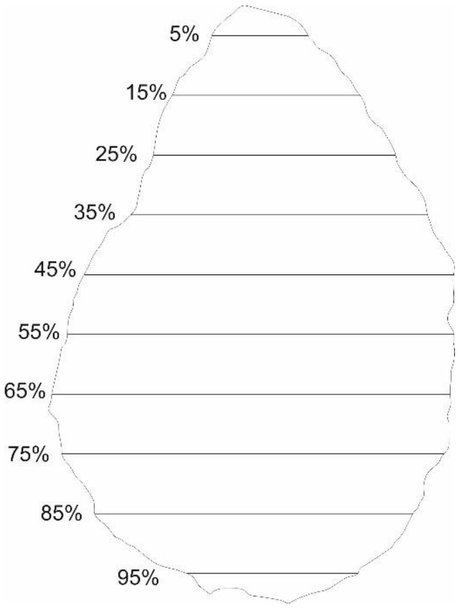

Figure 4. Schematic illustrating the widths measured every 10% of length down a handaxe beginning at the 5% mark.

Figure 4 can be black and white and cover 1 column

Lycett and von Cramon-Taubadel do not give a list of the shapes they see as being lost with geographical distance from Africa. By this I mean the typological shapes identified by Bordes for example (Bordes, 1961), or those of Wymer (Wymer, 1968) or Kleindienst (Kleindienst, 1962). These are difficult to quantify with any real consistency, despite attempts by Roe (Roe, 1968), Isaac (Isaac, 1977), or by Bordes himself who tried to put quantitative boundaries on his different types (*ibid*). Instead, Lycett and von Cramon-Taubadel calculate the variance in handaxe shape once their metric measurements for each axe have been adjusted to remove the influence of size by factoring in the geometric mean. Variance becomes a measure for the degree of variability in overall handaxe shape at the assemblage level.

For the sake of brevity I have adapted and simplified Lycett's method to illustrate my point. Whereas they took a series of lengths and widths in order to fix outline shape, I have just taken widths at every 10% of length down a handaxe, beginning at the 5% position down from the tip. This is shown in Figure 4. The widths were then size adjusted using the geometric mean. The variance, following their formulae, was calculated for each assemblage. Three assemblages were chosen on the basis of them being broadly contemporary at c. 0.5 mya; Boxgrove in England (Roberts and Parfitt, 1999) at the northern pole of the Acheulean world, Oldupai Gorge site HK Bed IV (Leakey, 1951) representing the middle, and Cave of Hearths at the southern Acheulean pole (Mason, 1988, McNabb and Sinclair, 2009). The total range of variance for each site, for each width location, is shown in Figure 5, see Table 1 for sample sizes.

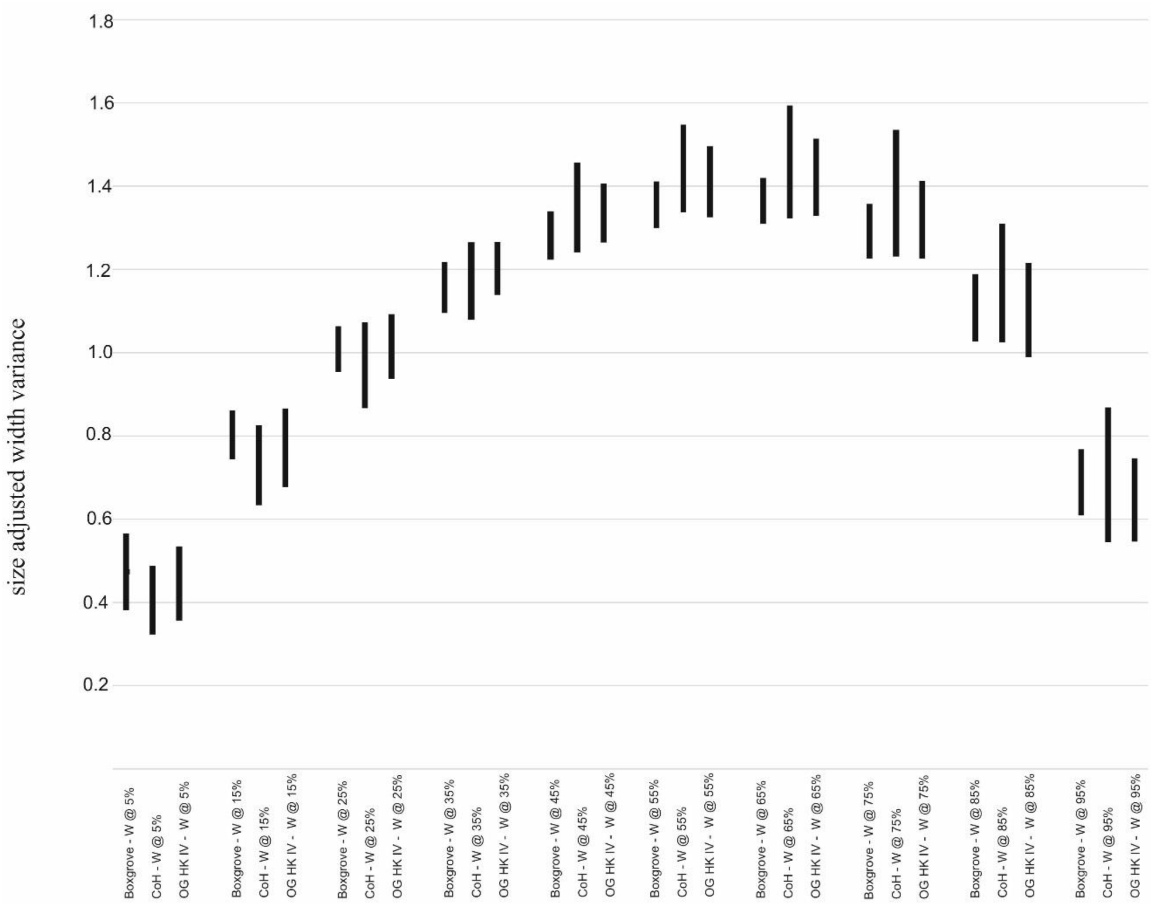

Figure 5. Variance ranges for Cave of Hearths Bed III, Oldupai Gorge Bed IV site HK and Boxgrove Unit 4c, for width, measured in millimetres (as in Figure 4), and size adjusted using the geometric mean as suggested by Lycett et al. 2006.

Figure 5 can be in black and white and should cover 2 columns

As an assemblage, Boxgrove has the lowest overall variance of the three sites - 0.04209. The figure reflects this. Boxgrove's tips (5% mark) are the most variable between the assemblages but then Boxgrove's widths below the tip all show a lower degree of variability, until the base which is slightly more variable.

Site	Handaxe sample used in this paper	Sample used in which analysis/ Figure	Sample used in which analysis/ Figure

Boxgrove Unit 4c	N = 37 randomly sampled from Marshal et al. database (n = 183)	Figure 5 Analysis of variance ranges	Figure 7-12 same handaxes used in 2DGM
Cave of Hearths Bed III	N = 33 sample from McNabb 2009. All available Bed III handaxes used	Figure 5 Analysis of variance ranges	Figure 7-12 same handaxes used in 2DGM
Oldupai Bed IV site HK	N = 35 randomly sampled from Marshal et al. database (n =115)	Figure 5 Analysis of variance ranges	Figure 7-12 same handaxes used in 2DGM
Oldupai Gorge Middle and Upper Bed II handaxes from various locations	N = 32 photographs and illustrations from Leakey 1971 and de la Torre and Mora 2005, 2014. Identifications follow de la Torre and Mora		Figure 7-12 used in 2DGM
Oldupai Gorge Bed II site EF-HR	N = 24 photographs and illustrations from Leakey 1971 and de la Torre and Mora 2005, 2014. Identification follow de la Torre and Mora		Figure 7-12 used in 2DGM

Table 1. Sample sizes of handaxes from Acheulean assemblages used in the two analyses in this paper. For references see text and bibliography.

Since size has been removed from the equation, low variance at every point down the Boxgrove handaxes' widths here shows the knappers at Boxgrove were producing axes to a relatively standardised template. The reasons for this have already been suggested; a narrowly time constrained palimpsest, a conservative pattern of social learning that precluded much innovation, and little or no outside contact with other hominin groups. In other words, the variance is tracking a socially imposed restraint on shape. Oldupai Bed IV and Cave of Hearths have larger variances as whole assemblages, 0.07513 for the former and 0.14206 for the latter. Both are palimpsests. HK IV was partially collected and partially excavated by Louis Leakey (1951), and Cave of Hearths was a palimpsest that built up inside a cave, where occupation occurred on a talus and on the cave floor. It was excavated by Revil Mason (Mason, 1962, Mason, 1988). With these sites it is not possible to assess how strong the patterns of social learning were over time, how long the surfaces were used for, or even whether one or more groups of knappers were responsible for the assemblage compilation. Figure 5 certainly shows how much more variable the South African cave assemblage is, reflecting a tendency of its knappers to make handaxes with much wider lower halves. This may be a reflection of the greater emphasis placed on converging tips, itself a possible reaction to an abundance of natural slabs and flakes available locally (McNabb, 2009).

Earlier I suggested that no handaxe or assemblage of them was entirely free of cultural selection, to use Lycett and von Cramon-Taubadel's phrase. Here, I believe variance is tracking the interplay between temporal resolution, and how closely knappers matched each other's work at an assemblage level. However, the use of a single summary statistic masks the true character of variability in handaxe shape. Apart from the 5% and 15% ranges at Boxgrove, Figure 5 shows that Oldupai and Cave of Hearths include the ranges present in Boxgrove, but extend them. So it is not so much that shape has been lost (in this methodology), as shape has become culturally stable at one site, while at the other two the same range of shapes are present but added to, though whether this is cultural or a result of other factors is not possible to say. Set a single value against geographical distance and it is easy to see how a measure of variance might give the impression of a net loss of shape over space and time. What I think their method actually tracks is shifts in the distribution of length and width in an assemblage – variability *across* shape and not variability *of* shape[2].

To be clear here. Lycett's methodology for characterising shape is a good one and works well, as does the correction for size, and to be fair I have not used their full methodology or the same sites as they used. So the above is not intended as a direct critique, but an illustration of a broader principle. My concern is with the use of a summary statistic allied to geographic distance that makes changes in shape look like loss of shape. A better analogy may be the tacking of a yacht to catch the wind. Handaxe assemblages tack across a surface of potential shape variability, each tack a response to something (culture, raw material, blank form etc.) and possibly something analogous to drift (copying errors, individual experimentation) in the absence of other cultural influences. The surface of potential shape variability may be similar to the zones of latent solutions suggested by Tennie and colleagues (Tennie, et al., 2016). Importantly, and another reason for not considering a genetic analogy valid for handaxe shape, is that outline shape can easily tack back towards former shapes as circumstances change, and reacquire old outline preferences. But this cannot happen in genetics as I understand it. Once a lineage with its unique collection of alleles has been lost, that's it, it is gone forever.

5. 2D geometric-morphometric analysis of handaxe outline.

The Acheulean meridian just described, looked at three sites of a broadly contemporary age. An explanation for Boxgrove's lower variance has been suggested, and the Cave of Hearth's variance, higher than Oldupai, has also been noted. The fact that these sites are all contemporary is not a problem as Lycett and von Cramon-Taubadel imply that variances should always be higher in Africa than elsewhere.

> "It should be noted that the model is compatible with both single and multiple dispersals of Acheulean populations from Africa, since the same basic relationship (i.e. between geographic distance from Africa and reduced within-group variance) should be evinced independently of how frequently any such dispersal(s) took place. (Lycett and von Cramon-Taubadel, 554).

I have not included any measures of distance. I will take it for granted that Boxgrove and Cave of Hearths are a long way from northern Tanzania.

To underscore the point that assemblage variance resembles tacking across a surface of potential shape variability, rather than a loss of outline form, it is necessary to build time depth into the analysis. This enables a broader perspective on shape in relation to differences in time and space. 2D geometric-morphometrics (2DGM), using fixed landmarks, is an ideal analytical tool for the study of variability in outline shape as the fixed landmarks allow the actual outline itself to be the focus of comparison.

A small sample of handaxes from Oldupai Middle and Upper Bed II, and a separate sample of LCTs from EF-HR have been included in the 2DGM analysis. These provide the time depth. The Bed II handaxes date from <1.66 mya (Tuff IIA) to c. 1.48 or 1.33 mya (Tuff IID) (de la Torre, 2016), and are those identified by Mora and de la Torre (de la Torre, 2016, de la

Torre and Mora, 2005, de la Torre and Mora, 2014) as being true handaxes. Those from EF-HR, originally considered by Leakey (Leakey, 1971) as handaxes, and from the earliest Acheulean site in the gorge (c. 1.4 mya), have been re-identified by Mora and de la Torre as large scalloped-edged cutting tools – LCTs certainly, but not handaxes *sensu stricto* (i.e. not showing deliberate thinning and shaping). This was on the basis of technological re-analysis. The sample of axes from Boxgrove, Cave of Hearths and Oldupai Bed IV HK, as above, were also included. Details of handaxe frequencies etc. are given in Table 1.

Recent advances in 2D geometric-morphometrics have made available sophisticated techniques for the assessment of shape in formats that are relatively simple to use and at the same time account for size differences. I will not attempt a literature review of the subject here but useful overviews and references are presented in the following (Buchanan and Collard, 2010, Costa, 2010., Iovita and McPherron, 2011, Lycett and Chauhan, 2010, Lycett, et al., 2010, Serwatka, 2015). Handaxe images from Boxgrove and Oldupai HK Bed IV were digitised from photographs in the Marshall *et al*. database (Marshall, et al., 2002), from my own work on the Cave of Hearths (McNabb, 2009), and for EF-HR and Oldupai Bed II (various sites) from illustrations and photographs in Leakey (1971) and Mora and de la Torre (de la Torre and Mora, 2005, de la Torre and Mora, 2014). I fully acknowledge that the diverse sources are not ideal but these were the only data available that suited my requirements. The images were processed and fixed landmarks applied using tpsUtil32 and tpsDig32, and the data was processed in the statistical software PAST version 3.11 (Hammer, et al., 2001) and subjected to PCA. The landmark points chosen are shown in Figure 6. An important consideration in this kind of analysis is how to orientate the axe for consistency in analysis. PAST will perform Procrustes on landmark data which includes standardising orientation. However I chose not to perform this aspect of the Procrustes, preferring to adopt a typological orientation (as in Figures 2 and 4) which involves aligning the handaxe with the narrowing end taken as the tip. While some

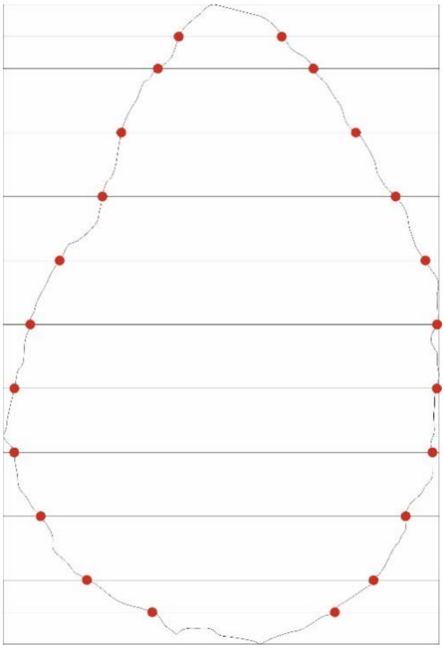

Figure 6. Locations of the 2D geometric-morphometric fixed landmarks for a handaxe.

Figure 6 can be black and white and sit in 1 column

inter-observer error will be inevitable I firmly believe this typological orientation is archaeologically more valid than allowing the software to orientate the axe in a potentially unrealistic way. As it was, the analysis, when complete, was run again with the full Procrustes treatment. The same PCA distribution pattern was noted for the Procrustes orientated handaxes as that for the typological orientation, except that the data was mirrored. The point cloud from the right hand side of the PCA appeared on the left, and that from the bottom was at the top. This suggests the preferred orientation in PAST is maximum length, which the typological orientation closely approximates anyway.

6. Results.

At first glance the convex hulls (lines joining outer points in a distribution) for the five sampled assemblages in Figure 7 would seem to confirm Lycett and von Cramon-Taubadel's thesis, that with distance (and time in the case of Oldupai Bed IV), handaxe shapes are being lost. The black outer line encompasses the distribution for the Oldupai Bed II handaxes, and the convex hulls for the remaining four assemblages fall within it, like nested Russian dolls.

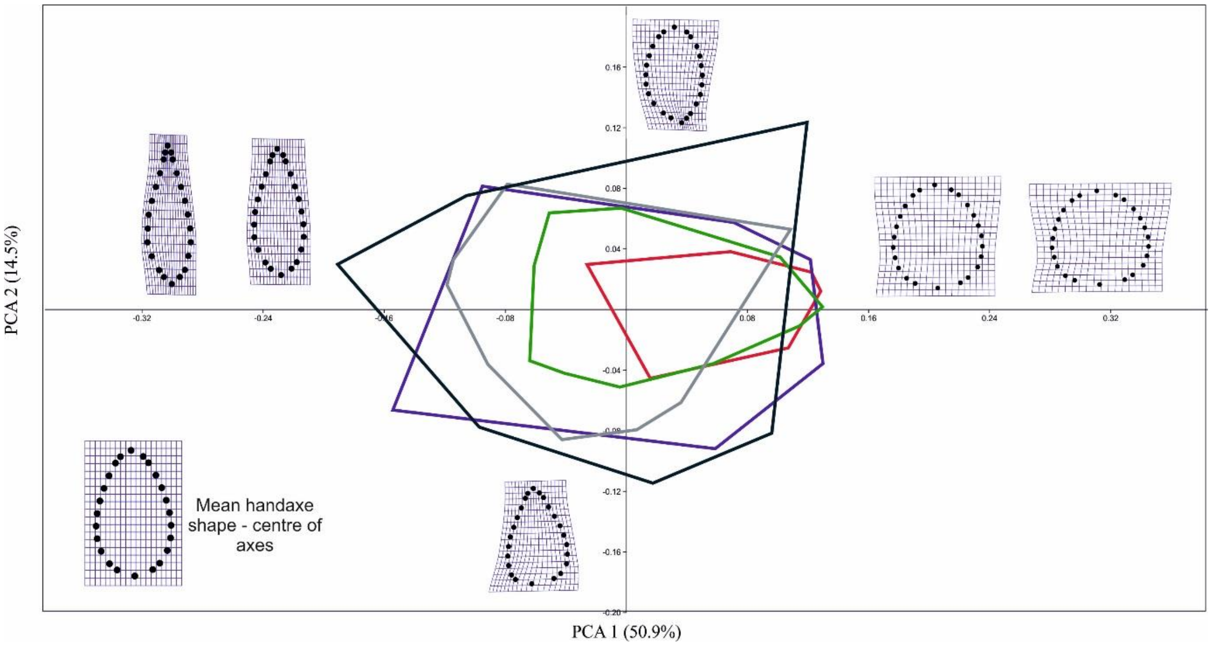

Figure 7. Convex hulls generated from the PCA point distribution with points removed for clarity. Convex hulls (lines joining outer points of a point distribution) for Oldupai Gorge Bed II handaxes (thick black outer line), Cave of Hearths Bed III (blue line), Oldupai Gorge Bed II EF-HR (grey line), Oldupai Gorge Bed IV site HK (green line) and Boxgrove (red innermost line). Thin plate splines show shape changes along axes.

Figure 7 should be colour and cross 2 columns

But the actual pattern is more complicated than this. Figure 8 shows this clearly. Two assemblages are shown, the sample of LCTs identified by de la Torre and Mora as true handaxes from a number of localities in Oldupai Middle and Upper Bed II (black line and black crosses), and a series of LCTs, not interpreted as handaxes, from EF-HR (grey solid line and grey diamonds).

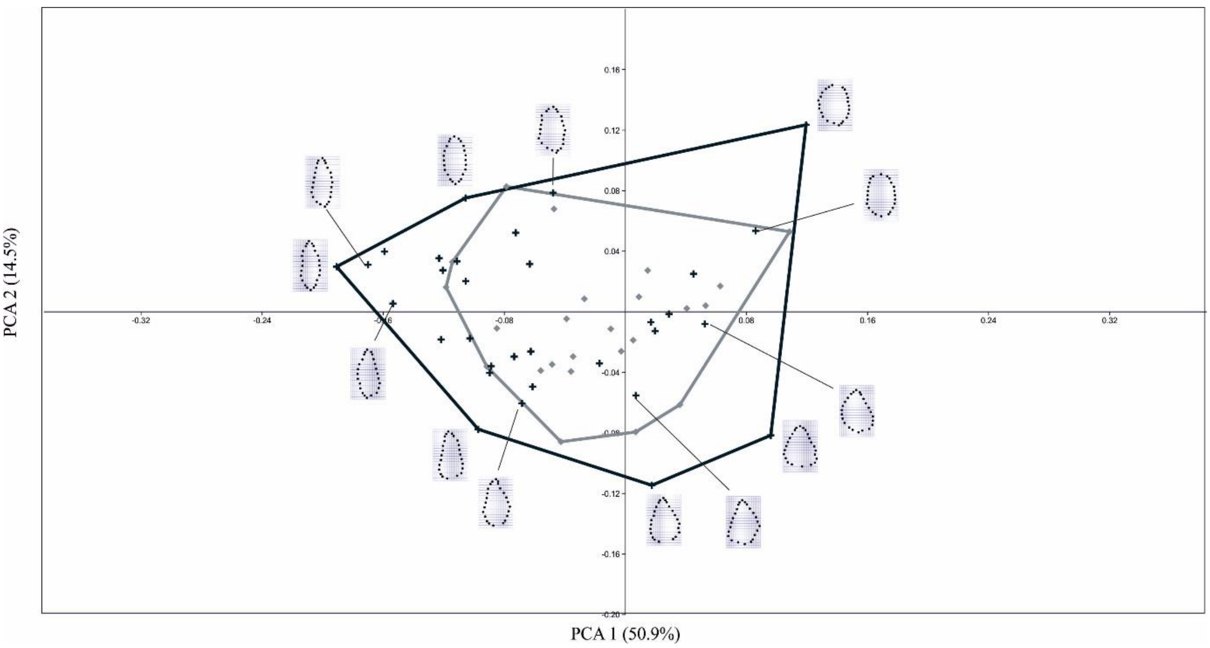

Figure 8. Convex hulls for Oldupai Gorge Bed II handaxes (thick black outer line) and LCTs from Oldupai Gorge Bed II EF-HR (grey inner line). Black crosses are Bed II handaxes and grey diamonds are EF-HR LCTs. Thin plate splines show the limits of variation in reconstructed handaxe shape for the Bed II handaxes, and are not to scale.

Figure 8 should be in colour and cross 2 columns

Thin plate splines (the co-ordinate transformation from the main sources of variation) on Figure 8 show that shape is not being lost between the two convex hulls (black and grey), rather there are subtle shifts as shape drifts from long and narrow outlines (black crosses on left hand side of the figure) to shorter and wider shapes (black crosses on right hand side) with the position of maximum width higher (above PCA 1) or lower (below PCA 1). It might be argued that the EF-HR LCTs should not be included for comparison, as they are not true handaxes, but they nevertheless represent shaped LCTs from Bed II. The key point here is that two groups of artefacts show a pattern that could be interpreted as a loss of shape. In fact what these two broadly contemporary data sets, from the same place, actually show is a drift in parts of the outline – not a loss of specific shapes *sensu stricto*, but more subtle shifts in the distribution of width across the surface area of individual axes. The TPS's reveal that the elongated and *wide tipped points* of the handaxes of the Bed II sites (black crosses on left) form one end of a continuum. At the opposite end are the more pointed and wide based LCTs of EF-HR (grey diamonds). It should also be noted that the singe outlier of the Bed II handaxes in the top right quadrant enhances the impression of shape loss. Remove it and Bed

II and EF-HR look much more similar with the difference being the handful of elongated and wide tipped handaxes on the left side of the Bed II distribution.[3]

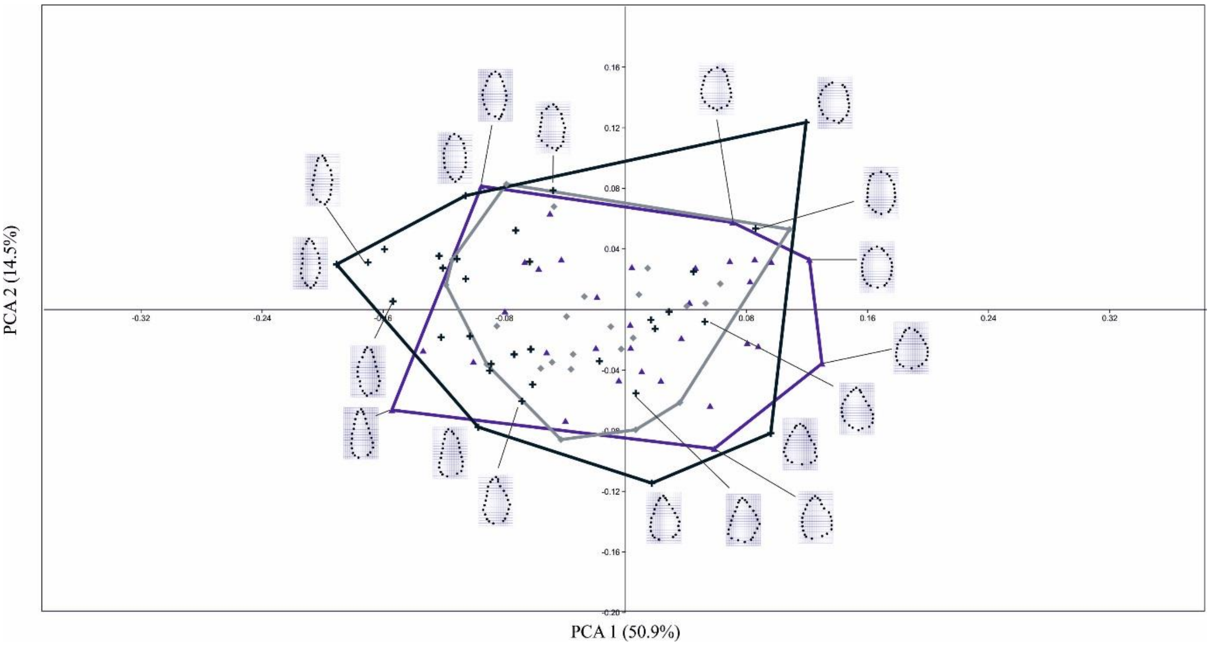

Figure 9. Convex hull for Cave of Hearths Bed III (blue line and blue triangles). The convex hulls for Oldupai Bed II handaxes (black solid line, black crosses) and EF-HR (grey line and diamonds) are retained from previous figures for ease of comparison. Thin plate splines show the outside of the range of handaxe shape variation all three sites. TPS outlines not to scale.

Figure 9 should be in colour and cross 2 columns

Moving to the southern pole of the Acheulean range, the Cave of Hearths Bed III shows a wide distribution of shapes, Figure 9, as diverse in its own way as the original convex hull (black solid line) for Oldupai Bed II. The wide tipped elongated handaxe shapes in Oldupai Bed II (top left corner) are not present at the Cave of Hearths, but a small number of elongated outlines with a wider base and more tapering point are (bottom left Figure 9). Most of the other potential shapes are easily encompassed within the convex hulls.

The majority of the Cave of Hearths handaxes are located in the lower half of the overall distribution, ranging in a band from narrow and more pointed with a wider base (lower left), arcing up through the more cordiform shapes to the more ovate outlines with rounded tips and bases (top right) and which have points of maximum width in the middle third of the axe. Again although a small number of the narrow and more elongated shapes are absent from

Cave of Hearths, the results do not really support a substantial loss of shapes between the two sites. More than half a million years of Acheulean handaxe making actually sees the range shift over slightly to the right hand side of the diagram.

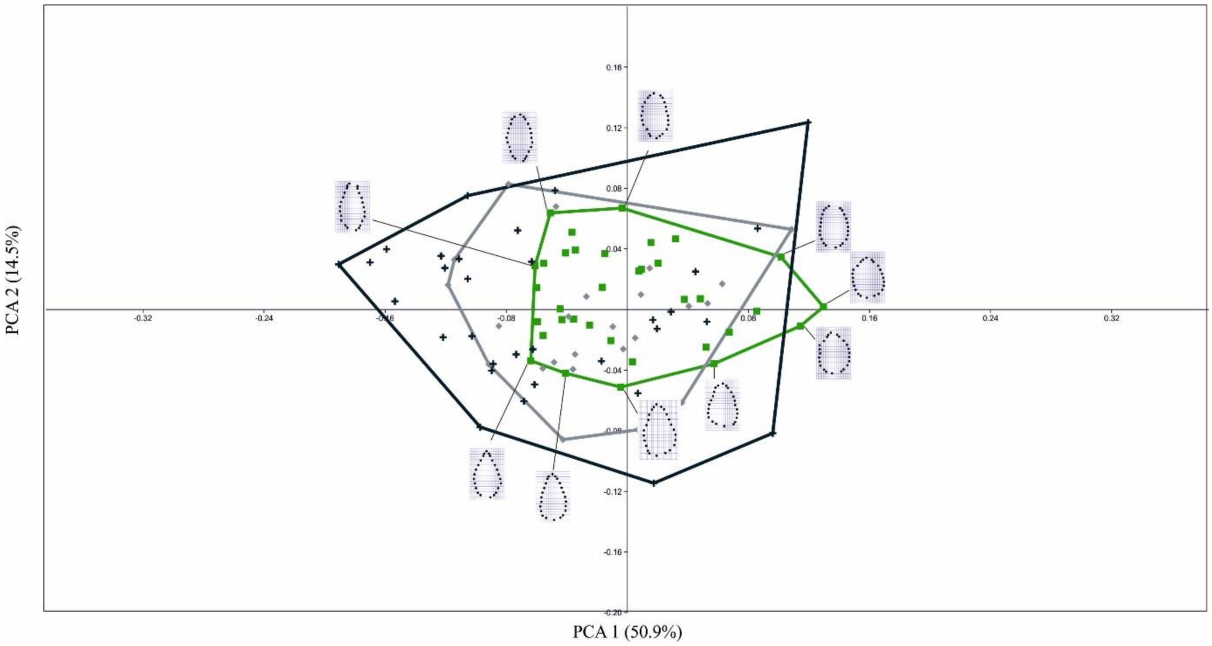

Figure 10. Convex hull for Oldupai Gorge Bed IV site HK (green line and green squares). The convex hulls for Oldupai Bed II handaxes (black solid line, black crosses) and EF-HR (grey line and diamonds) are retained from previous figures for ease of comparison. Thin plate splines show the outside of the range of handaxe shape variation at HK IV. TPS outlines not to scale.

Figure 10 should be in colour and cross 2 columns

It is with Oldupai Bed IV, site HK, that the possibility of loss of shape becomes more plausible. Figure 10 reveals a much tighter concentration of the data cloud and a distribution shifted toward the right of the diagram. At HK Bed IV the narrow and more pointed handaxes of Bed II are lacking. In terms of the broader and more convex ovate-like outline shapes, the small sample here seems to have acquired a new extension to shape range as the Bed IV convex hull passes beyond the limit of the Bed II shapes. So although losing shape at one end of the diagram, we are gaining new shapes at the other, as did the Cave of Hearths for that matter.

How is this pattern to be explained? Certainly not by geographic distance, and unfortunately the scale of resolution for Leakey's collection and excavation (1951) does not allow us to impose a Boxgrove-like interpretation on the conservative spread of shapes in HK Bed IV.

The original images in the Marshall et al. database (Marshall, et al., 2002) show a preponderance of quartzite handaxes on flakes and tabular blanks with a cutting edge round all or most of the handaxe. I suspect that here the more conservative distribution is a function (at least in part) of a bauplan not unlike that of Boxgrove – making handaxes with a cutting edge all or most of the way around the edge. However, this is something that will need to be tested with larger samples and detailed observation.

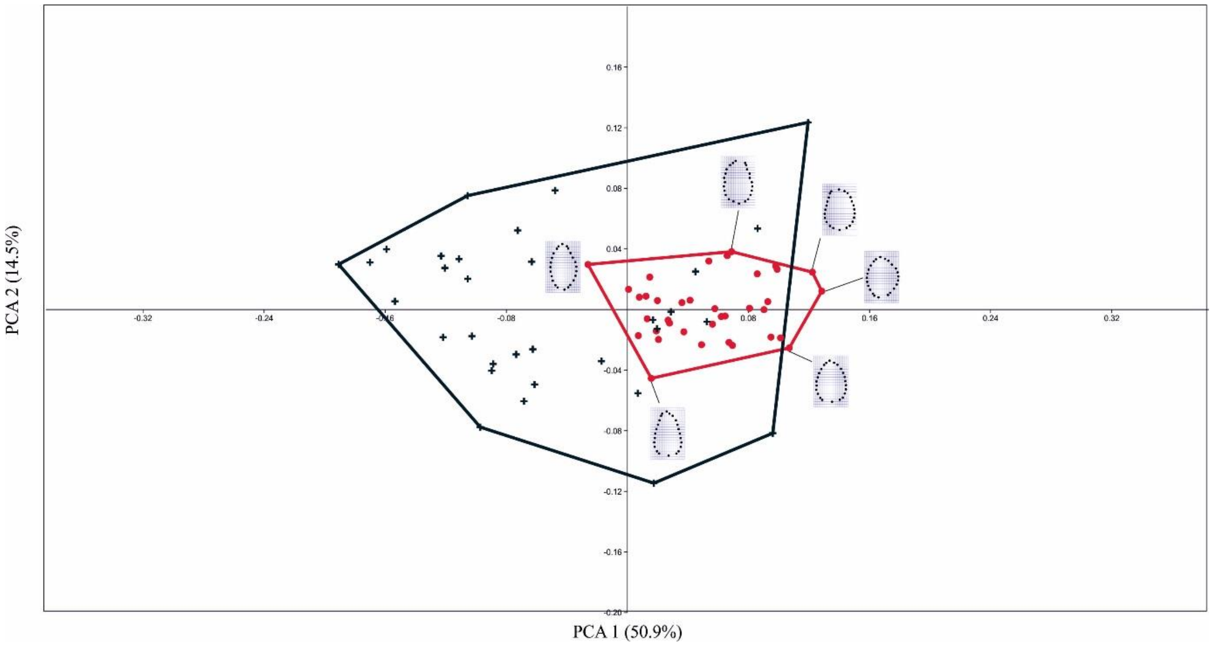

Figure 11. Convex hull for handaxe assemblage from Boxgrove Unit 4c (red line and red dots). The convex hulls for Oldupai Bed II handaxes (black solid line, black crosses) is retained from previous figures for ease of comparison. Thin plate splines show the outside of the range of handaxe shape variation at Boxgrove Unit 4c. TPS outlines not to scale.

Figure 11 should be in colour and cross 2 columns

Boxgrove Unit 4C, Figure 11, would be the clearest case for a loss of shape with distance from Oldupai. In this sampled assemblage the convex hull occupies a very specific part of the available outline space, namely that of wider and more convex edged shapes with a focus on maximum width toward the junction of the middle third of the axe with its basal segment, and up into the middle third. As with Cave of Hearths and Oldupai Bed IV handaxe shapes move beyond the limits set by Oldupai Bed II.

I have explored a number of univariate approaches to studying Boxgrove’s handaxes over the years and in almost all cases the Boxgrove distribution comes out as the most tightly constrained in any inter-site comparison. This GM2D exercise is no different. Overall

Boxgrove shows less variation in outline shapes, though this does not mean that variability is not present, it is (Figure 2). It is merely embedded in a more tightly constrained bauplan (Ashton and McNabb, 1994, Lycett and Gowlett, 2008) than is seen elsewhere.

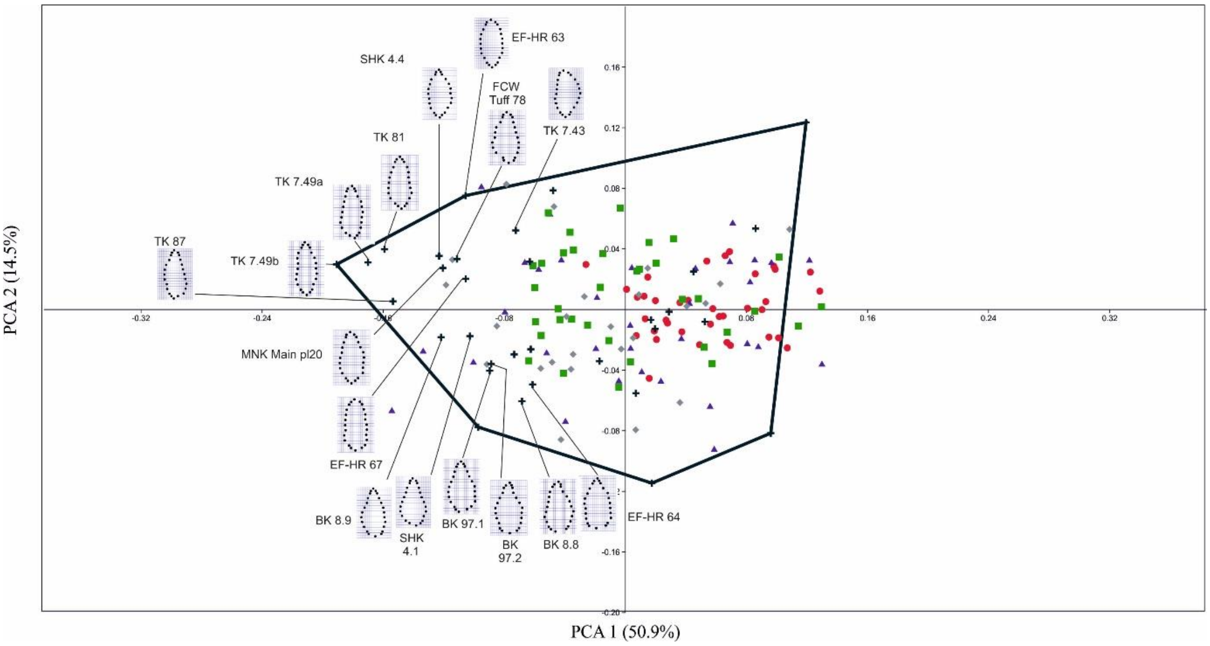

Figure 12. Convex hull for Oldupai Gorge Bed II handaxes (black line) with the point distribution of Oldupai Bed II (black crosses), Oldupai Bed II EF-HR (grey diamonds), Cave of Hearths Bed III (blue triangles), Oldupai Gorge Bed IV HK (green squares) and Boxgrove (red circles). The thin plate splines show the variation in handaxe shapes on the left hand side of the diagram in the area where Boxgrove and Oldupai Bed IVs' handaxe shapes are not represented.

Figure 12 should be in colour and across 2 columns

7. Discussion.

In my opinion the 2DGM shows four handaxe assemblages whose outlines tack across a surface of potential shape variability. In some cases there is clustering of shapes toward a particular zone, whereas in other cases there is a more even spread. In at least one case that clustering may be a direct result of a socially imposed direction in handaxe shape, thus invalidating a genetic analogy involving loss of shape in a selectively neutral material culture environment. One or more explanations may cover the other assemblages.

In Figure 12 the thin plate splines for the left hand side of the overall distribution have been added to the diagram, and the data points for each assemblage have been added as well. The handaxes from Oldupai Bed II in the top left hand corned are from site TK, and were made on quartzite slabs, and from Oldupai Bed II sites SHK and MNK Main Occupation. As this figure shows these are not completely different shapes, but they are quite wide in the upper third, more so than the overlapping Cave of Hearths and Oldupai Bed II on the lower left. So not a loss of shape here, just the addition of extra variability that may reflect the rhomboidal knapping approach seen in a number of Oldupai Bed II sites (de la Torre and Mora 2005) where the handaxe point is established through very localised bifacial flaking. Here the shape tacking may be crossing a part of the surface where blank form (slabs of tabular quartzite) is influencing tip shape, explaining why this zone is less populous. The similarity in distribution is supported by a pairwise MANOVA between Oldupai Bed II handaxes and those from Cave of Hearths, see Table 2. The strength of similarity between Oldupai Bed II and EF-HR, as well as EF-HR to Cave of Hearths is even greater as the p values in Table 2 show. The EF-HR 'knives' as de la Tore and Mora describe them were orientated in the same typological way to the other handaxes and the parity in results makes it easier to understand why Leakey (1971) would have thought them handaxes particularly given her belief they were early in age and therefore typologically would have looked cruder.

A statistically significant similarity between the Oldupai Bed IV material and that from Boxgrove is not surprising given the overlapping ranges in Figures 10 and 11, Table 2, but what is a little surprising is the statistical similarity between Oldupai Bed IV and Boxgrove on the one hand, and Cave of Hearths, EF-HR and Oldupai Bed II on the other given the disparity in dispersion in these sites, though the degree of similarity is lower as the p values reflect, Table 2.

One other factor that contributes to the impression of loss of shape in Figures 7-12 is that they only represent the first two principle components (65.4% of the variation). PCA 3 and 4 (10.3% & 5.4% respectively) and PCA 5 and 6 (4.4% & 3.1%) show significant outliers for the Bed II and Cave of Hearths, but also show the main concentrations of handaxe shapes in each assemblage overlapping each other. In other words no separation from left to right in these axes. For good measure, the PCA scores (n=48) were subject to neighbour joining cluster analysis in PAST (using Euclidean values for similarity indices and the final branch option for the rooting of the tree; data and results not presented). Four basic shape zones were defined tacking across the overall zone of latent possibilities defined in Figures 7-12, roughly from left to right. The four zones did not respect assemblage boundaries (i.e. convex hulls), again showing no loss of shape was present, just a drift as shapes gradually shifted toward more convex edges.

Pairwise significance values (p) generated by MANOVA in PAST	Boxgrove	Cave of Hearths Bed III	Oldupai Bed IV, site HK	Oldupai Bed II, site EF-HR	Oldupai Bed II handaxes, various sites
Boxgrove		0.38741	0.97386	0.80046	0.42447
Cave of Hearths Bed III			0.5419	0.91505	0.59204
Oldupai Bed IV, site HK				0.93666	0.75902
Oldupai Bed II, site EF-HR					0.96764
Summary of MANOVA generated in PAST	Wilks' Lambda – 0.06887 df1 – 192 df2 – 437.7 F – 2.178 P (same) 1.724E-11				

Table 2. Summary and pairwise significance values (p) of MANOVA conducted on PCA scores from handaxes in all 5 sites. All 48 PCA values included in calculation.

8. Conclusion.

This paper has assessed whether Corbey et al. (2016) can use Lycett and von Cramon-Taubadel's (Lycett, 2008, Lycett and von Cramon-Taubadel, 2008) assertions that handaxes lose shape with geographical distance from Africa following a genetic analogy of serial bottlenecking. In this author's opinion they cannot because specific shapes are not lost, they tack across a spectrum of possibilities probably reflecting differing local and social circumstances. In the case of the assemblages chosen here a mixture of social learning and assemblage taphonomic factors influenced the patterns seen, as did the choice of which assemblages to study. Had I chosen Swanscombe Middle Gravels or Furze Platt (Roe, 1981, Wymer, 1968), two further English Acheulean sites, with an emphasis on pointed handaxes, the drift in shape would have returned to reoccupy the left hand side of the diagram, demonstrating that handaxe shapes can be reintroduced, and 'rediscovered', unlike genetic lineages, which cannot.

It is difficult in a paper of this nature to avoid looking like you are 'having a go' at fellow researchers, just because you have a different point of view. I am not. I have a great respect for Lycett and von Cramon-Taubadel's clever and enviously prolific output. In this instance I do not agree with their conclusions or the use others have made of them, but my aim is not to extend the critique beyond that. If debate is stimulated on this topic then all the better.

- Lycett's handaxe shape methodology works very well and does define outline shape efficiently.
- The inclusion of the geometric mean as a scaling factor also works well and is an important contribution.
- The use of a summary statistic to describe handaxe shape loss is not appropriate as it hides the real character of variability
- Handaxe shapes are a product of a number of factors which include social learning and traditions of knowledge, as well as blank nature, and raw materials. While handaxe shape certainly changes over time and space, shapes are never irrevocably lost. Further factors are our ability to recognise the nature of assemblages, their taphonomic history, and factor these into our explanatory models.
- Genetic processes are not a viable explanatory framework for changing form in handaxe shape.
- This paper makes no comment on the broader discussion about the relationship of culture to genes.

9. Notes.

1. One reviewer queried the appropriateness of using Boxgrove in this way as the scenario presented was an unproven hypothesis. Fair point. Here I use it as an example to show how

an assemblage with low diversity could be a product of invariant social learning unaffected by intra-group influences.

2. One reviewer made the following comment. “What I expected to find here, but did not see, is a graph showing that variance is related to where you are in the shape space. This seems to be the thesis of the paper. Shape tacks across shape space and this in turn effects variance. But I didn’t see the data to link those two ideas.”

This is a good point. I have to be honest here, I am not quite sure of how to answer this. I suspect shape space will vary with the samples used (see below). There is no fixed point at which a modal value of shapes for an assemblage will be accompanied by a particular variance value. Variance for me is the amount of variability present between individual axes within an assemblage – at Boxgrove for example its smaller, at Cave of Hearths and Oldupai Bed II its greater. It is not impossible to have two assemblages with very different modal shapes, some outline overlap at the limits of the two distributions, yet both have an identical and small variance value because the amount of dispersion in shape away from the modal outline is relatively small in each case. So whether variance and position in shape pace can actually be linked is not yet clear to me.

This is a point I think that can be explored in a later paper with larger samples and more sites.

3. The comment about the influence of a single significant outlier on the patterning in the data highlights a good point raised by both anonymous referees, namely sample size and assemblage frequency. Both noted that the patterns would change with bigger assemblages and more of them; one writing that small samples were ‘sensitive to additional information’. This was the case in Lycett and von Cramon-Taubadel’s data and my own. It is a point I am sure none of us would disagree with. Both referees suggested including more sites to fill in the white spaces between the convex hulls. Although I completely agree with these observation I decided not to add more sites in the end. My point here is that even with a small number of sites it is still possible to demonstrate that variability in handaxe shape is a complex issue with a number of different explanations driving the pattern at different times and different places.

My intention is to seek funding for a bigger project starting with handaxe outline in Britain and using more sites and larger samples. At which point the issues raised by the referees will be clearly engaged with.

10. Acknowledgements.

I would like to express a considerable debt of thanks to Christian Hoggard for sharing his knowledge with me and taking the time to teach me about 2DGM. There is great satisfaction in watching the taught become the teachers. I am also extremely grateful to the two anonymous referees whose insightful comments and criticisms greatly improved this paper. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

10. References.

Ashton, N., Lewis, S.G., Parfitt, S.A., Davis, R.J., Stringer, C., 2016. Handaxe and Non-Handaxe Assemblages During Marine Isotope Stage 11 in Northern Europe: Recent Investigations at Barnham, Suffolk, UK, Journal of Quaternary Science 31, 837-843.

Ashton, N., McNabb, J., 1994. Bifaces in Perspective, in: Ashton, N., David, A. (Eds.), Stories in Stone. Lithic Studies Society Occasional Paper 4., The Lithics Studies Society, Oxford, pp. 182-191.

Bordes, F., 1961. Typologie du Paleolithique Ancien et Moyen., Delmas, Bordeaux.

Buchanan, B., Collard, M., 2010. A Gometric Morphometrics-Based Assessment of Blade Shape Differences Among Paleoindian Projectile Point Types from Western North America, Journal of Archaeological Science 37, 350-359.

Churcher, C.S., Kleindienst, M.R., Schwarcz, H.P., 1999. Faunal Remains from a Middle Pleistocene Lacustrine Marl in Dakhleh Oasis, Egypt: Palaeoenvironmental Reconstructions, Palaeogeography, Palaeoclimatology, Palaeoecology 154 301-312.

Corbey, R., Jagich, A., Vaesen, K., Collard, M., 2016. The Acheulean Handaxe: More Like a Bird's Song than a Beatles' Tune?, Evolutionary Anthropology 25, 6-19.

Costa, A.G., 2010. A Geometric Morphometric Assessment of Plan Shape in Bone and Stone Acheulean Bifaces from the Middle Pleistocene Site of Castel di Guido, Latium, Italy, in: Lycett, S.J., Chauhan, P.R. (Eds.), New Perspectives on Old Stones: Analytical Approaches to Paleolithic Technologies, Springer, New York, pp. 23-41.

Culley, C.V., Popescu, G., Clark, G.A., 2013. An analysis of the compositional integrity of the Levantine Mousterian facies, Quaternary International 300, 213-233.

de la Torre, I., 2016. The Origins of the Acheulean: Past and Present Perspectives on a Major Transition in Human Evolution, Phillosphical Transactions of the Royal Society Series B 371, http://dx.doi.org/10.1098/rstb.2015.0245.

de la Torre, I., Mora, R., 2005. Technological Strategies in the Lower Pleistocene at Olduvai Beds I & II, ERAUL 112, Liege.

de la Torre, I., Mora, R., 2014. The Transition to the Acheulean in East Africa: an Assessment of Paradigms and Evidence from Olduvai Gorge (Tanzania), Journal of Archaeological Method and Theory 214, 781-823.

Durkee, H., Brown, F.H., 2014. Correlation of Volcanic Ash Layers Between the Early Pleistocene Acheulean Sites of Isinya, Kariandusi, and Olorgesailie, Kenya, Journal of Archaeological Science 49, 510-517.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. Paleontological Statistics Software Package for Education and Data Analysis, Palaeontologia Electronica 4 (1), 9.

Iovita, R., McPherron, S.P., 2011. The Handaxe Reloaded: A Morphometric Reassessment of Acheulean and Middle Palaeolithic Handaxes, Journal of Human Evolution 61, 61-74.

Isaac, G.L., 1977. Olorgesailie: Archaeological Studies of a Middle Pleistocene Lake Basin in Kenya., University of Chicago Press, London.

Kleindienst, M.R., 1962. Components of the East African Acheulean Assemblage, Actes du IVe Congres Panafricain de Prehistoire et de l'Etude du Quaternaire, 81 - 103.

Leakey, L.S.B., 1951. Olduvai Gorge, Cambridge University Press, Cambridge.

Leakey, M.D., 1971. Olduvai Gorge: Excavations in Beds I and II 1960 - 1963., Cambridge University Press, Cambridge.

Lycett, S.J., 2008. Acheulean Variation and Selection; Does Handaxe Symetry Fit Neutral Expectations?, Journal of Archaeological Science 35, 2640-2648.

Lycett, S.J., Chauhan, P.R., 2010. New Perspectives on Old Stones: Analytical Approaches to Palaeolithic Technologies, Springer, New York.

Lycett, S.J., Gowlett, J., 2008. On Questions Surrounding the Acheulean Tradition, World Archaeology 40, 295-315.

Lycett, S.J., von Cramon-Taubadel, N., 2008. Acheulean Variability and Hominin Dispersals: A Model-Bound Approach, Journal of Archaeological Science 35, 553-562.

Lycett, S.J., von Cramon-Taubadel, N., Foley, R.A., 2006. A Crossbeam Coordinate Caliper for the Morphonetric Analysis of Lithic Nuclei: A Description, Test and Empirical Examples of Application Journal of Archaeological Science 33, 847-861.

Lycett, S.J., von Cramon-Taubadel, N., Gowlett, J.A.J., 2010. A Comparative 3D Geometric Morphometric Analysis of the Victoria West Cores: Implications for the Origins of Levallois Technology, Journal of Archaeological Science 37, 1110-1117.

Marshall, G.D., Gamble, C.G., Roe, D.A., Dupplaw, D., 2002. Acheulian biface database., http://ads.ahds.ac.uk/cfm/bifaces/bf_query.cfm ADS, York.

Mason, R.J., 1962. Prehistory of the Transvaal., Witwatersrand University Press, Johannesburg.

Mason, R.J., 1988. Cave of Hearths, Makapansgat, Transvaal, Archaeological Research Unit Occasional Paper No 21. University of the Witwatersrand, Johannesburg.

McHenry, L.J., Njau, J.K., de la Torre, I., Pante, M.C., 2016. Geochemical “Fingerprints” for Olduvai Gorge Bed II Tuffs and Implications for the Oldowan–Acheulean Transition, Quaternary Research 85, 147-158.

McNabb, J., 2009. The ESA Stone Tool Assemblage from the Cave of Hearths, Beds 1-3, in: McNabb, J., Sinclair, A. (Eds.), The Cave of Hearths: Makapan Middle Pleistocene Research Project: Field Research by Anthony Sinclair and Patrick Quinney, University of Southampton Series in Archaeology Number 1. Archaeopress, Oxford, pp. 75-94.

McNabb, J., Sinclair, A., 2009. The Cave of Hearths: Makapan Middle Pleistocene Research Project: Field Research by Anthony Sinclair and Patrick Quinney 1996-2001, University of Southampton Series in Archaeology Number 1. Archaeopress.

Mitchell, J.C., 1996. Studying Biface Butchery at Boxgrove: Roe Deer Butchery with Replica Handaxes, Lithics 16, 64-69.

Mithen, S., 1994. Technology and Society During the Middle Pleistocene: Hominid Group Size, Social Learning and Industrial Variability, Cambridge Archaeological Journal 4, 3-32.

Moncel, M.H., Ashton, N., Lamotte, A., Tuffreau, A., Cliquet, D., 2015. The Early Acheulean of North Western Europe, Journal of Anthropological Archaeology 40, 302-331.

Pappu, S., Gunnell, Y., Akhilesh, K., Braucher, R., Taieb, M., Demory, F., Thouveny, N., 2011. Early Pleistocene Presence of Acheulian Hominins in South India. , Science 331, 1596-1599.

Pope, M., Roberts, M., 2005. Observations on the Relationship Between Palaeolithic Individuals and Artefact Scatters at the Middle Pleistocene Site of Boxgrove, UK, in: Gamble, C., Porr, M. (Eds.), The Hominid Individual in Context, Routledge, Abingdon, pp. 81-97.

Roberts, M.B., Parfitt, S.A., 1999. Boxgrove. A Middle Pleistocene Hominid Site at Eartham Quarry, Boxgrove, West Sussex, English Heritage.

Roe, D.A., 1968. British Lower and Middle Palaeolithic Handaxe Groups., Proceedings of the Prehistoric Society 34, 1 - 82.

Roe, D.A., 1981. The Lower and Middle Palaeolithic Periods in Britain, Routledge and Kegan Paul, London.

Salim, M., 2008. Palaeolithic in the Soan Valley Rawalpindi, Pakistan, in: Anon (Ed.), Culture of Nomadic Peoples of Central Asia, International Institute for Central Asian Studies. URL http://s3.amazonaws.com/academia.edu.documents/32359671/Culture_of_nomadic_people_of_Central_Asia.pdf?AWSAccessKeyId=AKIAIWOWYYGZ2Y53UL3A&Expires=1485450918&Signature=0zW9NlGBVgqjuIn2Dc1tAnySpgk%3D&response-content-disposition=inline%3B%20filename%3DGocebe_Kulturunde_Mevsim_Adlari_Kirgizca.pdf#page=176. Last accessed 26.01.2017, Samarkand, pp. 175-179.

Serwatka, K., 2015. Shape Variation of Middle Palaeolithic Bifacial Tools from Southern Poland; A Geometric Morphomatric Approach to Keilmessergruppen Handaxes and Backed Knives, Lithics 35, 13-25.

Shennan, S., 2000. Population, Culture History, and the Dynamics of Culture Change, Current Anthropology 41, 811-835.

Tennie, C., Braun, D.R., Premo, L.S., McPherron, P., 2016. Chapter 11. The Island Test for Cumulative Culture in the Paleolithic, in: Haidle, M.N., Conard, N.J., Bolus, M. (Eds.), The Nature of Culture: Based on an Interdisciplinary Symposium 'The Nature of Culture', Tübingen, Germany, Springer Science and Buisness Media, Tübingen, pp. 121-133.

Wymer, J.J., 1968. Lower Palaeolithic Archaeology in Britain, John Baker Publishers Ltd., London.