From Side to Side:

Symmetry in Handaxes in the British Lower and Middle Palaeolithic.

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Abstract

The Acheulean is defined by its iconic tool type, the handaxe, and a suite of other large cutting tools (LCTs). These tools retain information on technical and procedural practices concerned with the manufacture of these butchery tools and carcass processing knives. The Acheulean straddles the period in which more ancient hominin species (*H. erectus* and *H. heidelbergensis*) give way to archaic *H. sapiens* (*sensu lato*) amongst whom the ancestor of modern humans may be found. The roots of modern behaviour may be present in these handaxe making hominin species, and the handaxes themselves, through proxy data such as bilateral symmetry, may chart hominin cognitive evolution as researchers such as T. Wynn and F. Coolidge (2016), amongst others, have argued. But the search for the earliest consistent application of symmetry, and its persistence thereafter has been hampered by the lack of large datasets, spanning the temporal extent of the Acheulean, and analysed through a single consistent methodology.

Our paper has two aims. The first, and in the absence of a large comparative data set of earlier Acheulean handaxes, is to assess the degree to which symmetry is consistently applied to the making of handaxes in the later Acheulean (=<0.5 mya), a time when bilateral planform symmetry should already be an integral component in handaxe making. The dataset we select is the British Acheulean from MIS 13 – MIS 3/4. To the best of our knowledge this is the first time handaxe symmetry has been assessed on a large body of British Acheulean handaxes. Our second aim is to present a relatively simple and low tech methodology for the analysis of handaxes

and their symmetry that is widely available and does not require expensive equipment or specialist software/technical knowledge. It works from orthogonal handaxe photographs which many researchers will already have. From such data it may be possible to begin to construct the larger datasets necessary to answer symmetry related questions regarding cognitive evolution. This offers us the opportunity to raise a number of key methodological questions which we believe ought to be debated by researchers before the generation of appropriate datasets begins.

Key words

Acheulean, Handaxe, Symmetry, Middle Pleistocene, Hominin, *Homo heidelbergensis*

1.0. Introduction.

The Acheulean is the name given to a stone tool assemblage type recognised by the presence of its iconic tool – the handaxe, one of a suite of large cutting tools (LCTs) which also includes cleavers, picks, trihedrals and unifaces (Clark, 1994; Wymer, 1968). However, the Acheulean is also defined by technological practices associated with the manufacture of LCTs, such as the making of large flake blanks often from cores with a prepared surface (Sharon, 2007), and marginal thinning, commonly with a soft hammer or billet to impose deliberate shape on the LCT (Newcomer, 1971). Good introductions to handaxes are present in a number of references (de la Torre, 2016; Emery, 2010; Goren-Inbar and Sharon, 2006; Machin, 2009; Newcomer, 1971).

The oldest Acheulean yet discovered is at Konso in Ethiopia and Kokiselei 4, West Turkana, Kenya, both of which date to 1.75 mya (Beyene et al., 2013; Lepre, 2011). From this point onwards, handaxes become the defining artefact of the Acheulean found across the Old World from Spain to China, and from South Africa to the English Midlands. The appearance of *Homo ergaster* in Africa, (Lepre and Kent, 2015) at about c. 1.9 mya (KNM-ER 2598), and its more widespread presence after c. 1.6 mya (KNM-ER 3733; Lepre and Kent, 2015) is suggestive of a link between this new hominin and the Acheulean 'package' - a new tool technology to meet the needs of new behavioural adaptations. The emergence of the Acheulean may help fill the fossil gap which currently exists for the erectines between KNM-ER 2598 and 3733 (Lepre and Kent, 2015).

Footnote. Mya = millions of years ago; my = million years; kya = hundred thousand years ago; ky = hundred thousand years; MIS = marine isotope stage.

Traditionally, handaxes are thought to have been made in Africa by two hominin species, *H. ergaster/erectus* and *H. heidelbergensis* (= *H. rhodesiensis*). In Europe handaxes were made by *H. heidelbergensis* (Manzi, 2016; Profico et al., 2016), although the chronology of the Heidelbergs in Europe may be subject to change given recent palaeogenetic advances (Meyer et al., 2016; Meyer et al., 2014). *H. neanderthalensis* is also a European handaxe maker (Ruebens, 2014; Ruebens et al., 2013), but new cultural labels are applied to the Late Pleistocene Neanderthal handaxes (e.g. Mousterian of Acheulean Tradition rather than Acheulean). Anatomically modern humans may continue to make handaxes once they emerge in Africa (Clark et al., 2003), a pattern possibly seen elsewhere (Shipton et al., 2013).

This hominin evolutionary trajectory is often portrayed as a single upward cline, a slope of gradual development as for example in the iconic Social Brain graph (Dunbar et al., 2014; Gowlett et al., 2012), although a more punctuated interpretation is possible (McNabb and Cole, 2015; Shultz et al., 2012).

In these interpretations the Acheulean (here broadly defined as handaxe making by hominins other than Neanderthals and anatomically modern humans) is often seen as an evolving material culture accompaniment to biological development. Early handaxes are described as crude and poorly shaped, lacking much - if any - sense of symmetry in their planform (Hodgson, 2010; Hodgson, 2015; Wynn, 2002). Later Acheulean handaxes, appearing towards the end of the Acheulean, supposedly show much higher degrees of symmetry accompanying regularity in planform outline (Clark, 1994; Clark, 2001; Wynn and Coolidge, 2016). Potentially, these later Acheulean handaxes may reflect the increasing capacity of material culture to carry symbolic meaning (Lycett, 2008).

The Acheulean then, in its broadest definition, is a key period in human evolution as it sees the emergence of some of the cognitive faculties that will later contribute to the 'modernity' of *Homo sapiens*. Wynn has explicitly linked what he sees as stages in handaxe development to evolving hominin cognition and spatial awareness, connected with more sophisticated hunting (Wynn, 2002), and evolving hominin neural architecture (Wynn and Coolidge, 2016). He argues that a threshold was crossed at c.1.8 mya with the deliberate imposition of shape on raw material. Whereas the preceding Oldowan tools *acquired* form fortuitously through the production of flakes, the earliest Acheulean handaxes had clear form deliberately *imposed* upon them. This imposition of shape in its earlier stages was an 'attention to shape' (Wynn, 2004), through an awareness of the balance of surface area either side of a mid-line. By 1.0 mya attendance to shape was becoming more prevalent. A second major threshold had been crossed by >=0.5 mya when that awareness of symmetrical balance reflects congruence, an exact mirroring of opposing edges. Wynn posits that from this point on bilateral planform symmetry is commonly accompanied by cross-sectional symmetry in long profile and across the width too (looking from the tip down). With a three dimensional concept of symmetry now present, knappers were even able to produce deliberately asymmetric LCTs on occasion – broken symmetry.

Persistent bilateral symmetry in planform down the long axis of a handaxe is then one of the hall-marks of cognitive evolution.

In light of the above, there are a number of research questions that could be asked of the Acheulean which would focus on temporal changes in its character over the 1.5+ mya lifespan of this phenomenon. However, two of us (JM and JC) have elsewhere noted the difficulties in finding appropriate data in which to study long-term changes in handaxe symmetry over time (McNabb and Cole, 2015). Ideally, long sequences with large assemblages from single sites are necessary, and lots of them; but they are scarce. Currently some of the best are in the Awash Valley, Ethiopia, Melka Kunture, Ethiopia, and Oldupai Gorge, Tanzania (Beyene et al., 2013; Clark et al., 2003; de la Torre and Mora, 2005; de la Torre and Mora, 2014; Gallotti and Mussi, 2017; Leakey and Roe, 1994; Schick and Clark, 2003).

2.0. The research question.

As the data to meaningfully compare earlier and later Acheulean handaxes with each other does not yet exist, what other questions may be addressed with the data that is available to us? The question we chose to ask was:

Is bilateral planform symmetry consistently applied in the British Acheulean?

Why is this question important?

Firstly, the time period covered here is nearly 0.35 my (MIS 13-7), and longer if the Late Pleistocene Neanderthal site of Lynford is included (nearly 0.5 mya). It may cover one emerging hominin lineage (*H. neanderthalensis*), or two partially contemporary ones with an ancestor descendent relationship (*H. heidelbergensis – H. neanderthalensis*). The mean brain size of *H. heidelbergensis* is c. 1256.6 cm^3 and that of Neanderthals c. 1421.23 cm^3 (Dunbar et al., 2014). If handaxe planform symmetry is a viable proxy for cognitive evolution – then changes in handaxe manufacture should reveal evidence of progressive development even in this later segment of the Acheulean's history, in effect, the tail end of the evolutionary trajectory. Our research question therefore asks whether we should expect relatively high levels of symmetry, consistently present, at this later stage of the trajectory? The difficulty of poor comparative data is fully acknowledged here.

If we do see greater evidence of symmetry and congruence in later Acheulean assemblages, then we need data to support this, but to the best of our knowledge this does not yet exist. The identification of a consistent presence of higher degrees of symmetry across the British Acheulean will help in highlighting any earlier vs later Acheulean contrasts when those data become available.

There is an alternative perspective that may be taken into account. The European Middle Pleistocene hominin lineage(s) do not directly contribute to the evolution of modern humans – this occurs in Africa (Hublin et al., 2017; Stringer, 2011; Stringer and Galway-Witham, 2017). However, in focusing on a region away from the direct line of *sapiens* evolution we will provide important comparative data for the character of material culture of our actual ancestor when that lineage becomes clearer. The last common ancestor of Neanderthals, modern humans and their putative Heidelberg ancestor predates 600 kya (Viola and Pääbo, 2013). Did a capacity for symmetry occur independently in two diverging branches, or did a common heritage express itself in similar patterns of diachronic development? Our research question will not answer these directly, but we hope it will provide data that will help define and address the issues as research continues. As such focusing on symmetry in the later British Acheulean will help clarify the character of an evolutionary trend within the Acheulean of the Old World.

Ultimately, behavioural and cognitive studies of any hominin lineage, whether extinct cousin or direct ancestor, remain interesting in their own right.

3.0. The Study of Handaxe Symmetry in the Acheulean.

There have been a number of attempts over recent years to quantify and interpret the presence of symmetry on Acheulean assemblages. Methodologically, one of the most successful has been the flip test developed by Hardaker and Dunn (Hardaker and Dunn, 2005), which has seen usage in a number of different contexts (Shipton and Clarkson, 2015; Underhill, 2007), and other techniques have also been promoted (Lycett, 2008). In addition, there have been a number of theoretical stances that have sought to extract behavioural meaning from Acheulean handaxes. We will give a brief summary for some of the main positions here, but recently Hodgson (2015) and McNabb and Cole (2015) provide useful additional references and critiques.

Saragusti and Sharon (1998) applied their Continuous Symmetry Measure to three Lower Palaeolithic handaxe assemblages from Israel. They found that symmetry did increase over time. However only three sites were included and sample sizes were small. With commendable honesty they admitted their samples fell below statistically acceptable levels. Subsequently, a different shape methodology allowed Saragusti et al. to revisit their earlier conclusions with larger samples and more sites. Their original results for their three assemblages were replicated (Saragusti et al., 2005) but the inclusion of two younger assemblages from Tabun layer E produced unexpected results when the handaxes showed symmetry ranges comparable with the much older sites. They concluded – "the picture emerging is more complex than a simple monotonic increase in the degree of symmetry over time" (Saragusti et al., 2005: 846).

An agenda-setting paper by Wynn (2002), has already been noted, see above. Here it is worth emphasising that Wynn made it clear that in the first and earliest of the thresholds he argued for, bilateral symmetry was not always present, and when it was, it was not always consistently applied. Rather, it was a mirroring of one edge onto the other around the long axis of the LCT – a 'qualitative reversal'. Sometimes this took the form of mirroring a natural edge outline from one side, through flaking on the other.

Commentators on Wynn's 2002 paper from a variety of disciplines elicited a mixed reaction. For some, symmetry in handaxes was an emergent property generated by the extensive flaking of a handaxe (Coventry and Clibbens, 2002), while others suggested that the recognition of symmetry was an ancient faculty reflecting the way visual stimuli were processed by the brain (Deręgowski, 2002; Reber, 2002). A number of other commentators echoed the idea that the capacity for/reaction to symmetry was conditioned by automatic responses from primal neurological structures in the hominin brain. The upshot was that archaeologists should not assume the presence of symmetry in material culture was conscious or culturally learned.

In 2004 McNabb and colleagues (McNabb et al., 2004) argued that strong cultural influences on handaxe making could not be detected in the South African Acheulean, because regularities in manufacture and finished form could not be identified in handaxes and cleavers. The premise was that strong social learning resulting from group living would impose consistent patterns in the making and finish of material culture (Mithen, 1994). Symmetry was a part of this expected socially generated conformity. The results of their analysis showed that the only consistent patterns of regularity were in LCT tip shapes. These authors defined symmetry in two ways (McNabb et al., 2004): *Absolute symmetry*, when one edge of an LCT's outline was an exact mirror image of the other, was rare. However, it was seen more frequently on particular segments of an axe - tip, middle or base. *Near symmetry* was more common in South African Acheulean assemblages echoing Wynn's first stage of Acheulean evolution (Wynn, 2002). While near symmetry was considered deliberate, it resulted from a need to balance the distribution of surface area either side of the midline, more out of a desire for regularity than a conscious need to create a symmetrical handaxe. Proof of this was offered through observations on manufacture. The infrequent instances of absolute and near symmetry were delivered through the least regular and consistent approaches to thinning and shaping. The vast majority of South African Middle Pleistocene handaxes did not show any symmetry at all.

Although symmetry was not the main point of the McNabb et al. paper, the method of assessing it was criticised (Machin and Mithen, 2004) as it was a 'by-eye' test. Symmetry was either present or absent as judged by subjective visual criteria. The lack of scientific replicability, and potential for inter-observer error were also highlighted (Underhill, 2007). While completely in sympathy with these views, two of us (JM and JC) remain convinced that any planform symmetry imposed by Acheulean knappers was realised through visual appreciation. Hominins held an axe up, made a value judgement, and then acted on it by further trimming of the outline edge if necessary. They repeated the process until satisfied. Visual assessment of the results of that process remains a legitimate form of analysis (Cole, 2015; McNabb, 2009). In commenting on McNabb et al., Wynn (2004) suggested a recasting of their perception of LCT symmetry. He argued that hominins 'attend' to shape. This resonates with both Wynn (2002) and McNabb et al.'s position that hominins were consciously aware of the distribution of spatial area, either side of a mid-line, but did not consciously impose bilateral symmetry. Wynn's useful default position heuristic would therefore be realised through the visual appreciation of 'balance' as just described.

Handaxe symmetry has also been seen as a way of increasing the functionality of the tool, improving its ability to act as a butchery knife (see Nowell and Chang, 2009 for a discussion of this and relevant references). Many of these interpretations have been largely anecdotal, such as Matt Pope's insightful comments on using an asymmetrical handaxe during the butchery of a deer carcass (Machin et al., 2007). The use of handaxes in butchery and carcass processing is now well attested (Jones, 1981, 1995; Keeley, 1980; Mitchell, 1996; Schick and Toth, 1993) though they may have had different uses in different circumstances (Binneman and Beaumont, 1992). A series of experiments by Anna Machin (Machin et al., 2007) tested the concept that planform symmetry and cutting-edge symmetry improved the performance of a handaxe as a butchery tool. The results were at best statistically weak, and symmetry seemed to play little to no part in improving tool performance.

Symmetry was also a key component in the so-called 'sexy handaxe theory' of Mithen and Kohn (Kohn, 1999; Kohn and Mithen, 1999). This debate has a long history, frustrating scholars and editors alike, and does not need to be discussed in detail here. A good summary and references are presented by Spikins (Spikins, 2012). The theory proposed that Darwinian sexual selection accounted for form and symmetry in handaxes. They were material culture proxies for biological indicators of individual phenotypic fitness. Symmetry in outline form was one of the 'signals' encoded into handaxes. The better the handaxe made, the better the health, status and reproductive fitness of the maker. While acknowledging the importance of symmetry to the visual recognition system of humans and primates, Nowell and Chang (2009) cited a body of literature that disputed the direct link between body and facial symmetry, and its link to mate choice. In short, the overall role of symmetry in eliciting positive reactions to potential mates, a clear pre-requisite for the sexy handaxe theory, was not conclusively demonstrated (Hodgson, 2009; Hodgson, 2010; Nowell and Chang, 2009; Nowell and Chang, 2010). The role of material culture in acting as an extended phenotype was therefore called into question (Machin, 2008; Machin, 2009; Machin et al., 2007). For the moment, the sexy handaxes remain unselected wallflowers.

Viewing the handaxe as an extended phenotype sparked off a number of other interpretations in which symmetry played a role. In these cases interpretations still fall under the banner of indicator theory, handaxes still advertise something about their makers, only now divorced from sexual selection. Penny Spikins (Spikins, 2012) has proposed the 'trustworthy handaxe theory'. Material culture is linked to hominin reciprocity and altruism. She suggests that handaxes are visual adverts of an individual's reliability and stability, both important qualities in considering a social alliance/coalition partner; that, and the ability to rein in selfish actions. For Spikins the better made and 'finished' looking a handaxe is, then the more the knapper is showing that he or she has the qualities necessary to make a reliable coalition member. A skilfully made and well-finished symmetrical handaxe resonates with the character traits that announce a reliable team player.

Machin (2009) also argues that the handaxe is an advertisement, but now location is important. Different activities, imbued with different levels of social significance take place at spatially discreet locations across the landscape. These determine just what kind of LCT is made and how much effort is put into it. At kill/scavenging sites it is speed and efficiency in carcass processing that is important, and if a knapper wishes to impress, then he or she must make a tool that gets the job done with a minimum of fuss. The audience are adult males and adolescents learning the ropes. Symmetry would not be so important here. However, at locations where members of the group remain behind while the hunt is on, and to which the hunters will return bringing meat, the audience and social dynamic is very different. Here handaxe making might reflect a greater emphasis on finesse, appearance and symmetry. Social factors become important with aesthetics advertising social desirability and perhaps status. However, at quarries and other raw material procurement sites where skilled knappers instruct learners, a different dynamic is at play. Both teachers and pupils desire to make the finest handaxes possible in order to justify their positions as able instructors and adept learners.

Underpinning these two interpretations of handaxes and the role of symmetry is the idea that the production, appearance, and possibly use of a well-made handaxe induces an emotional response in both knapper and audience. Machin (2009) asserts this is craftsmanship and it sits at the root of the later aesthetic experience in humans – not art as such, but the beginning of the capacity for it. Hodgson (2011) also sees the roots of aesthetic appreciation nascent in the increasing symmetry he argues is present across the Acheulean time range. This is a common theme in symmetry studies - Spikins (2012) expresses similar thoughts. Mithen (2008) unambiguously links the modern sense of aesthetic pleasure in looking and handling a finely made symmetrical handaxe to an emotional hangover from the Palaeolithic. A symmetrical handaxe is an "echo of the Stone Age past, of a time when these objects played a key role in sexual display and to which our modern minds remain attuned" (Mithen, 2008: 768). These echoes resonate with Tensorer (Tensorer, 2006; Tensorer, 2009) who asserts that the late Acheulean handaxes from Nadaouiyeh in Syria are a *form* of art as they express the balance and harmony that underlies all future artistic expression. This is achieved through symmetry and a visually striking finished appearance, even if the handaxes do not at this point in time carry any further social meaning. This nascent artistic sense is also implied in Edwards' (2001) belief that the visually striking regular and parallel flake scar patterns seen on handaxes from Kalambo Falls can only be deliberate.

At its heart, Kohn and Mithen's sexy handaxe theory was an attempt to bring material culture into the province of evolutionary biology. A younger generation have furthered this agenda (Lycett, 2015; Lycett and Von Cramon-Taubadel, 2015). These ideas revolve around the way knowledge of handaxe making is passed on, from one generation to the next. This transference of information and experience is akin to genetic inheritance (with some important differences acknowledged). Handaxe symmetry was integrated into this by Lycett (2008) and Lycett and Von Cramon-Taubadel (2008). They suggested that as geographical distance from Africa increased, handaxe assemblages in India, the Near East and the UK showed a loss of diversity in shape similar to a loss of genetic variability experienced by populations as they suffered repeated bottlenecking along migration routes (Lycett and Von Cramon-Taubadel, 2008). Their data suggested that there was no selective pressure on handaxes – particular shapes were not being preserved just because they were functionally effective. Rather, handaxe shape was free to vary along 'historical and social' lines, so that as local groups became extinct, so did various LCT shapes and the variations based on them favoured by those groups. The argument was then developed (Lycett, 2008) by the inclusion of symmetry. The regression equations (shape+symmetry vs geographical distance from Africa) now showed an even poorer correlation. Lycett argued this was cultural selection – while handaxe shape was a product of historical tradition, and not selection, there was a deliberate focus on a narrower range of more symmetrical handaxe shapes. This was consistent with, and an explanation for, an increase in symmetry over time.

Despite an enthusiastic defence of evolution in handaxe form, appearance and symmetry over time by Hodgson (2015), most of the instances he cites do not really support his arguments (McNabb and Cole, 2015). The use of powerful 3D recording methods by Grosman et al. (2011) and Couzens (2012) certainly involve robust methodologies that would be ideal for the assessment of handaxe symmetry. In the former case the use of surface finds renders concepts of progression difficult to accept, and in the latter case only two sites are involved, and Couzens himself believed that function rather than progression explained the differences between the two chronologically distinct South African Acheulean assemblages he studied. Likewise Shipton (2013) presented a sophisticated methodology well suited to the assessment of shape and symmetry, but small sample sizes and undated or surface assemblages made identification of evolution and progression in symmetry premature (Hodgson, 2015; McNabb and Cole, 2015). Another paper quoted by Hodgson (2015) is Shipton, et al. (2013). Here Hodgson suggests the authors have discovered a seamless transition from the Acheulean into the Middle Palaeolithic, but this is not the case. A single late Acheulean site at Nakjhar Khurd in the Middle Son valley in India shows clear differences in the finish of its handaxes when compared with the much more symmetrical and refined ones found with Levallois and other Middle Palaeolithic elements at other sites in the region. Indeed, aspects of the knapping involved in making these latter bifaces resembled techniques employed in the flaking of prepared cores. This raises the distinct possibility that some later assemblages with handaxes may not be Acheulean *sensu stricto*, but represent a facies of 'Middle Palaeolithic with handaxes' which would not be directly comparable with the Acheulean (heuristically defined in this paper as handaxes not made by Neanderthals or modern humans, and perhaps lacking Levallois - see above). These fascinating Indian assemblages are Late Pleistocene in age.

The question of whether handaxes in the Far East are a result of independent invention, or are a result of some form of contact between China and Korea, and the western Acheulean is important (Kuman et al., 2016; Li et al., 2014, 2016; Lycett and Bae, 2010; Lycett and Norton, 2010; Norton and Bae, 2008; Norton et al., 2006), though not one to be tackled here. In many ways independent invention would provide an interesting foil to the supposed evolution of the Acheulean in Africa and in Europe: would the two areas experience similar patterns of diachronic change or not, and what might those patterns imply for cognitive evolution, and the presence and evolution of symmetry? The sites date from the middle Middle Pleistocene to the Late Pleistocene. Li and colleagues argue that more data is required before cultural connections (of whatever sort) or independent invention can be established (Kuman et al., 2016; Li et al., 2014). Current studies support a difference between the handaxes from east and west, but do not support any increase in symmetry over time as present in the handaxe samples from successive river terraces in the Danjiangkou Reservoir Region (Li et al., 2016). Here the levels of symmetry present are variable – argued to be an emergent property from the imposition of shape by the knappers.

4.0. Initial Considerations

The focus of the bilateral planform symmetry methodology developed here is the quantification of the degree of overlap at the handaxes' edges or margins, when one side (edge) of the handaxe is superimposed on the other (mirrored) around a mid-line.

This serves to highlight the importance of the axe's cutting edge as opposed to those parts of the outline which are unsuitable for cutting with (see Figure 1 and 2). Rather than classify handaxes by their shape as is traditional (Roe, 1981; Wymer, 1968), we have classified them by the location and extent of cutting edge along the margin. We are therefore making two assumptions; handaxes were made to be used, and the edge and/or tip was the primary focus for the knapper as it was being made. We interpret the handaxe as a hand held knife for butchery and carcass processing (Machin et al., 2007; Mitchell, 1996; Roe, 1981; Wymer, 1968), amongst other possible uses.

A handaxe is defined as a bifacial or unifacial tool, showing invasive thinning and shaping, whose tip (clearly made by thinning/shaping) narrows in planform. The thinning and shaping may be via large flakes removed from the edge leaving deep, concave or 'scalloped' flake-scars. Alternatively the thinning and shaping may have been realised via smaller shallower scars confined to the edge which overprint previous removals, or a mixture of both. Thinning and shaping may be hard hammer, soft hammer or both.

Cleavers, trihedrals, picks etc. are excluded from this analysis. This allows us to focus analysis on a body of LCTs that are directly comparable in their basic form, purpose and basic technique of manufacture. Other LCTs will be the subject of later papers. Neither are we downgrading the importance of handaxe shape and we hope to include it as a distinct variable in a later paper as well.

Cutting edge is defined in a qualitative manner. It is any edge, at least in part made by shaping with a percussor, with which a cutting function could be performed. Cutting is defined in its broadest sense "…to open up or incise…with a sharp edge or instrument…" (Collins Paperback English Dictionary, 1986). Wide edge angles, typically => 70° (personal observation) would not be considered cutting edges, nor would cortical or thick natural edges. Based on the 472 handaxes included in this study, 22 patterns of cutting edge extent and location were identified – See Figure 2.

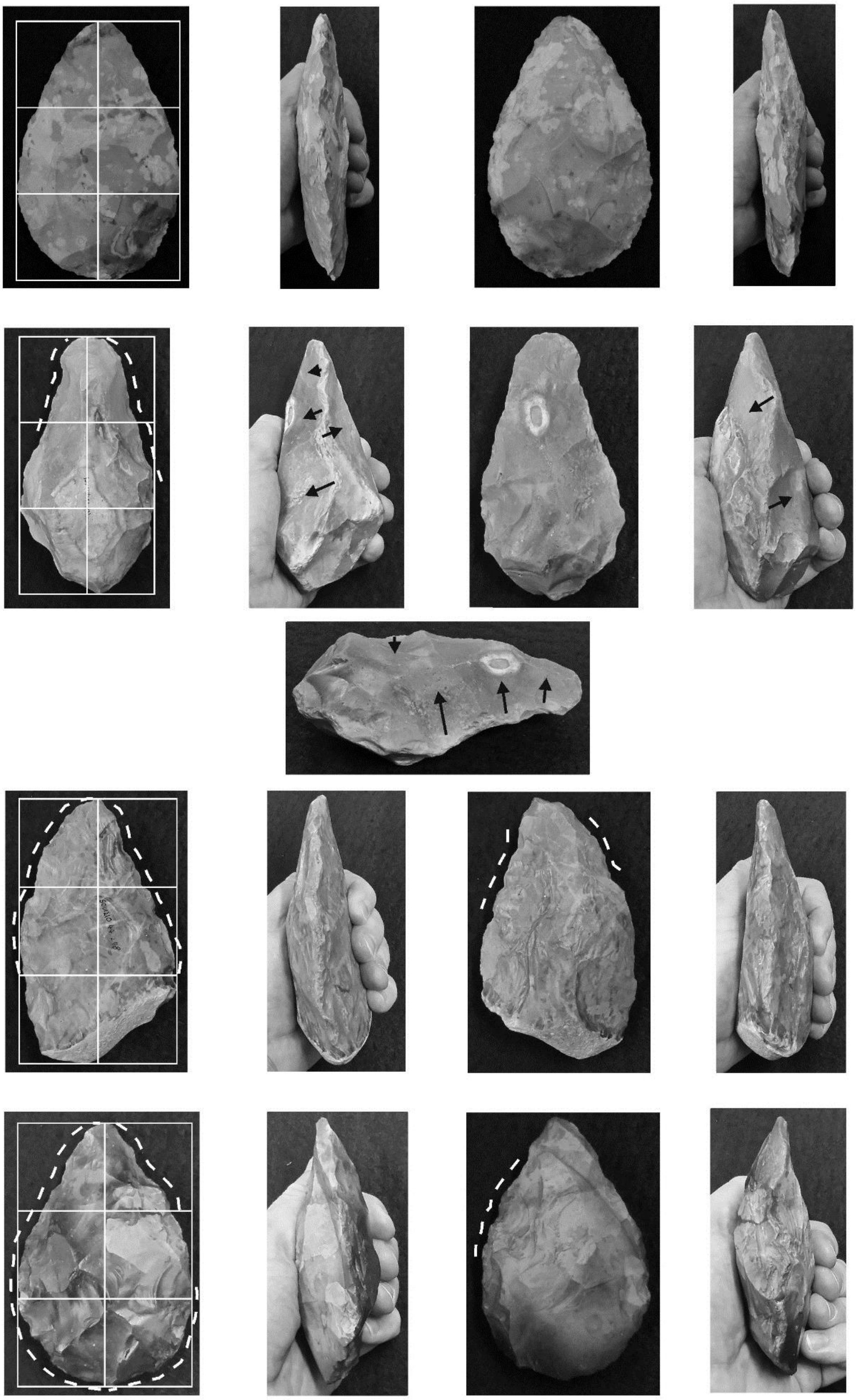

Figure 1. A series of images of handaxes designed to convey the variety of edges incorporated under the term cutting edge as used in this paper. See text for more details. **Four images on the top row**. A replica of a Boxgrove type handaxe made by James Dilley. Size - 151.02x95.73x30.10 mm. The handaxe has a cutting edge all around and is therefore edge pattern 1 (Figure 2). The cutting edge here is made up of medium and small removals (medium >15 mm in axial length; small =<15 mm) taken from the edge as part of process of thinning and shaping. The majority of the edge and the shape/symmetry is imposed via small removals. JM private collection. **Four images on second row and single image on third row**. Unprovenanced handaxe from Southampton Museum (SOU1210/44/182; currently curated by CAHO, Southampton Archaeology Department). Size – 129.42x70.05x57.18 mm. Handaxe has a cutting edge at tip and on one middle segment and is edge pattern 10. Dotted line on image with a grid indicates position and extent of cutting edge. Cutting edge is made up of large concave 'scalloped' flake scars taken from the edge as indicated on profiles by black arrows and on the single image in row 3. There are a few areas along the edge where small flakes have been removed to modify a short length (at tip and on edge). Butt is roughly flaked but edges are wide and deemed unsuitable for cutting. **Four images on row 4** are of an unprovenanced handaxe from Southampton Museum (SOU1210/44/248; currently curated by CAHO, Southampton Archaeology Department). Size – 138.39x81.77x40.11 mm. The cutting edge is on the tip and the middle segments and is edge pattern 11. The position and extent of the cutting edge is shown by the dotted line in the image with a grid. Here small and medium scars have been taken from the edge. Asymmetry on this axe is deliberate as there is a concentration of thinning and final shaping scars at the two points indicated by the doted lines on the third image from the left. Concentration on these two areas is shown by the piling up of shallow hinge fractures which cut into earlier thinning scars. **Four images in row 5** of an unprovenanced handaxe. Size – 112.92x72.64x35.29 mm. A cutting edge is present on both segments of the tip, the base and on one middle segment, cutting edge pattern 8. The location and extent of the cutting edge is indicated by the dotted line on the image with a grid. The handaxe is made on a flake with the dorsal in the left hand/gridded image (distal on left side of that image). The non-cutting edge in the middle of one edge represents bifacial removals intended to remove the flake's butt (right hand image and dotted area on ventral face second image from right). The cutting edge is made up of small and medium scars, taken from the edge unifacially on the flake's former dorsal face. A few regularising scars are present on the ventral away from the butt. JM private

collection. We have not distinguished between different types of cutting edge in this iteration of the method, but may do so in future.

Figure 1 should be B&W or grayscale across two columns

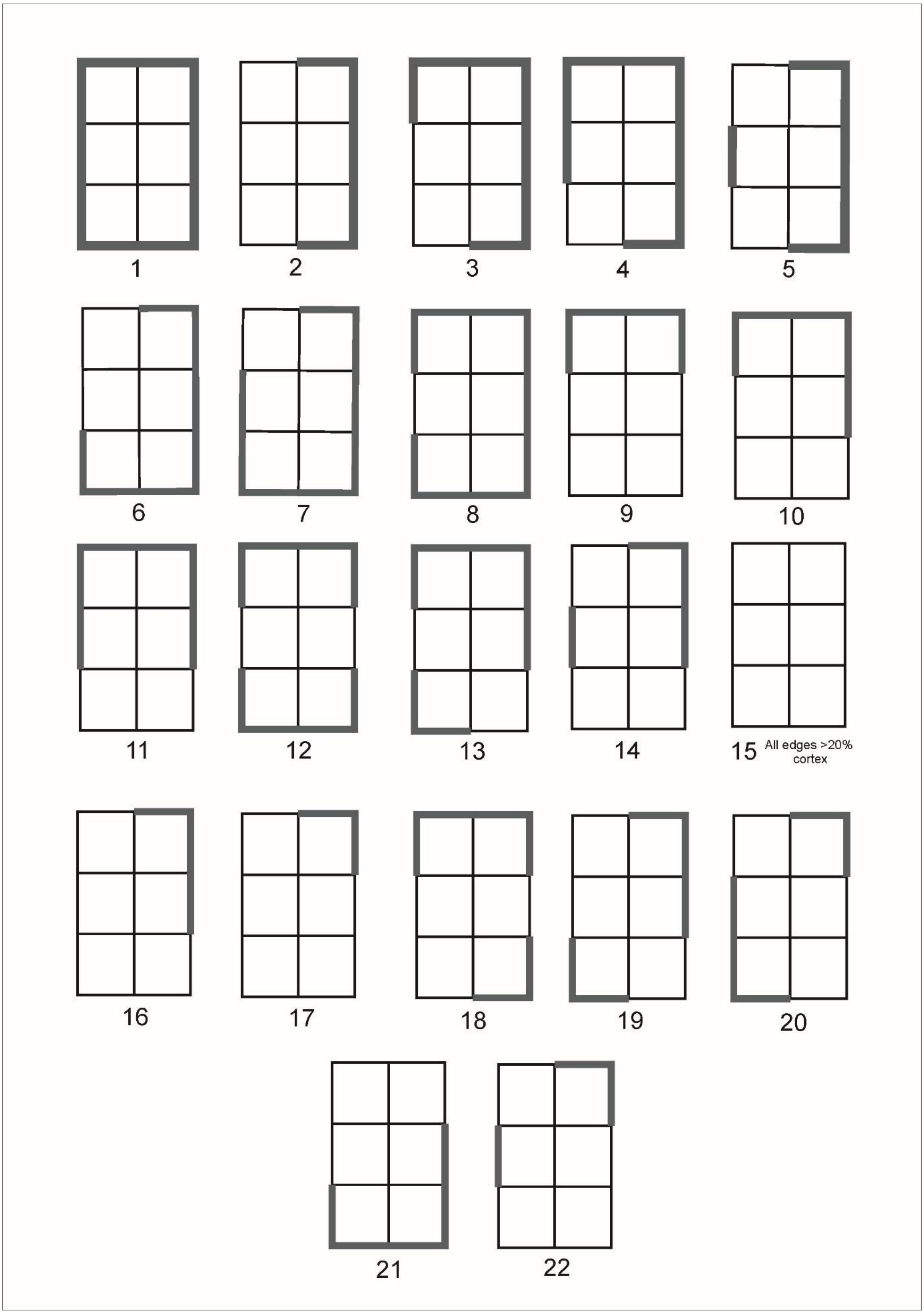
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Figure 2. The twenty two different patterns of handaxe cutting edge noted in the sample of handaxes used in this study (see text for more details). The patterns reflect the *location and extent of cutting edge* on the handaxe's margin. To qualify as a cutting edge, the edge must firstly conform to the definition of a cutting edge as described in the text. Then a 2x3 grid was imposed on each handaxe. The tip of the handaxe is at the top of the grid. The second criteria for identification required that the cutting edge extended 80% or more of the length of the edge in each of the grid's segments. This was assessed subjectively, by eye. In the figure the thick line on the grid indicates the position of the cutting edge. For example cutting edge pattern 11 represents a cutting edge, covering more than 80% of the edge in both of the tip segments and both of the middle segments of the handaxe, but not on the basal ones. Pattern number 10 has a cutting edge on the tip (both segments) and down one middle segment only. The right and left sides on the figures do not correspond to the right and left edges of the handaxes – for example edge pattern 19 has a cutting edge on one tip segment and the adjacent middle segment (either right or left edge) and on one basal segment (which would have to be on the opposite edge).

Figure 2 should be B&W or grayscale across two columns

From analysing the percentage frequencies of occurrence of the 22 edge cutting patterns, it was clear that the handaxe sites could be subdivided into four assemblage groups, these are presented in Figure 3. Initially handaxes with a cutting edge almost all of the way around the circumference of the handaxe were included in group 1, but later separated out because the group 1/edge pattern 1 signal is so strong. It is of course possible to arrange the data into other configurations, but the groupings in the figure appear the most parsimonious.

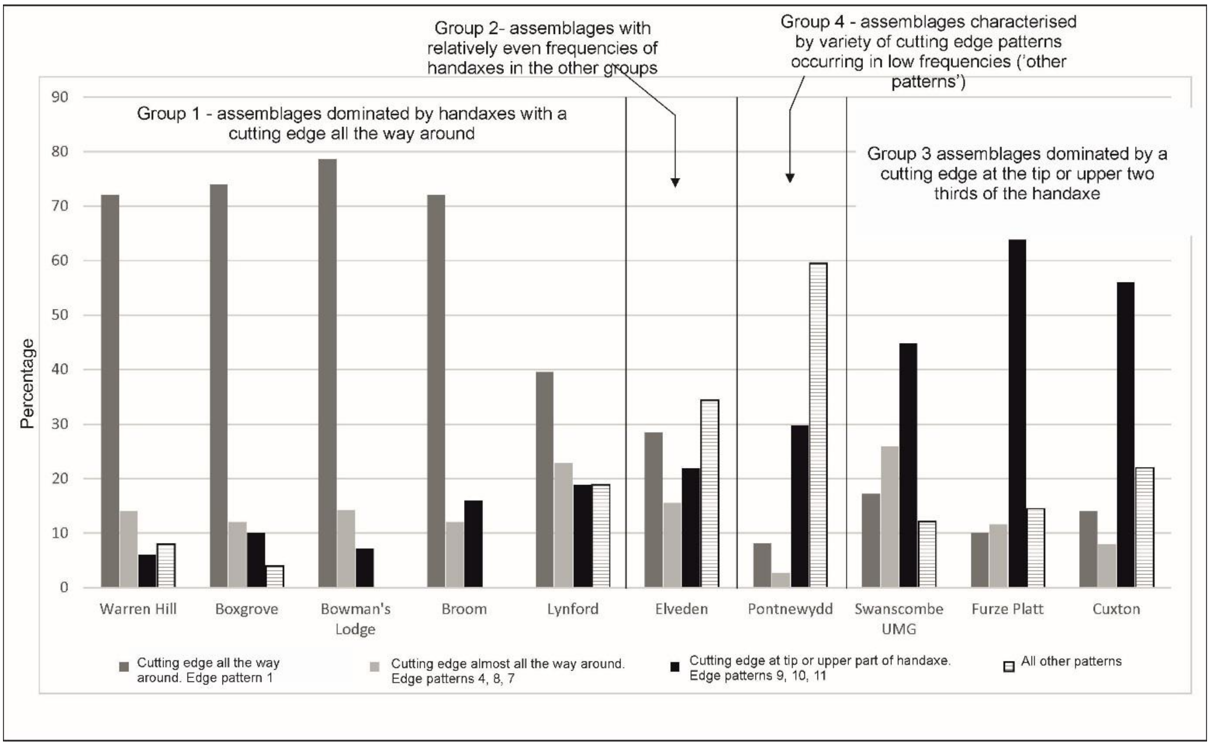

Figure 3. Block diagram showing the four assemblage groups created from an analysis of which handaxe cutting edge pattern or patterns (Figure 2) dominates in particular assemblages. Dominance here refers to =>15% separation between the most frequent cutting edge pattern and the next most frequent one. Assemblages in group 4 do not show a dominance of a single edge cutting pattern. In these assemblages the most frequent signature is the occurrence of occasional and infrequent patterns.

Figure 3 should be B&W/grayscale and cover 2 columns

A key element in the methodology is positioning the mid-line around which the two halves of the handaxe will be mirrored. Figure 4 demonstrates two possible locations for this axis. What is here called the natural mid-line is a position for the axis at 50% of the maximum width of the handaxe. It has the advantage of being easily replicable. Its suitability for the handaxe from Boxgrove with a cutting edge all the way around, Figure 4A, and other handaxes like it is evident. However, as Figure 4B demonstrates, the natural mid-line is not a suitable axis for the pointed handaxe from Cuxton. More appropriate in this case is the imposed mid-line as it is termed here. This reflects a longitudinal axis that bisects the natural tapering of the handaxe's tip, where the knapper actually focused attention. In this sense, the imposed mid-line has more in keeping with the eyeball methodology for appreciating symmetry published by one of us (JM) many years ago (McNabb et al., 2004). We believe bilateral symmetry between cutting edges in the Acheulean would have been established through visual examination and correction by reference to the imposed mid-line. It can be applied to either of the handaxes in Figure 4, which the natural mid-line can not.

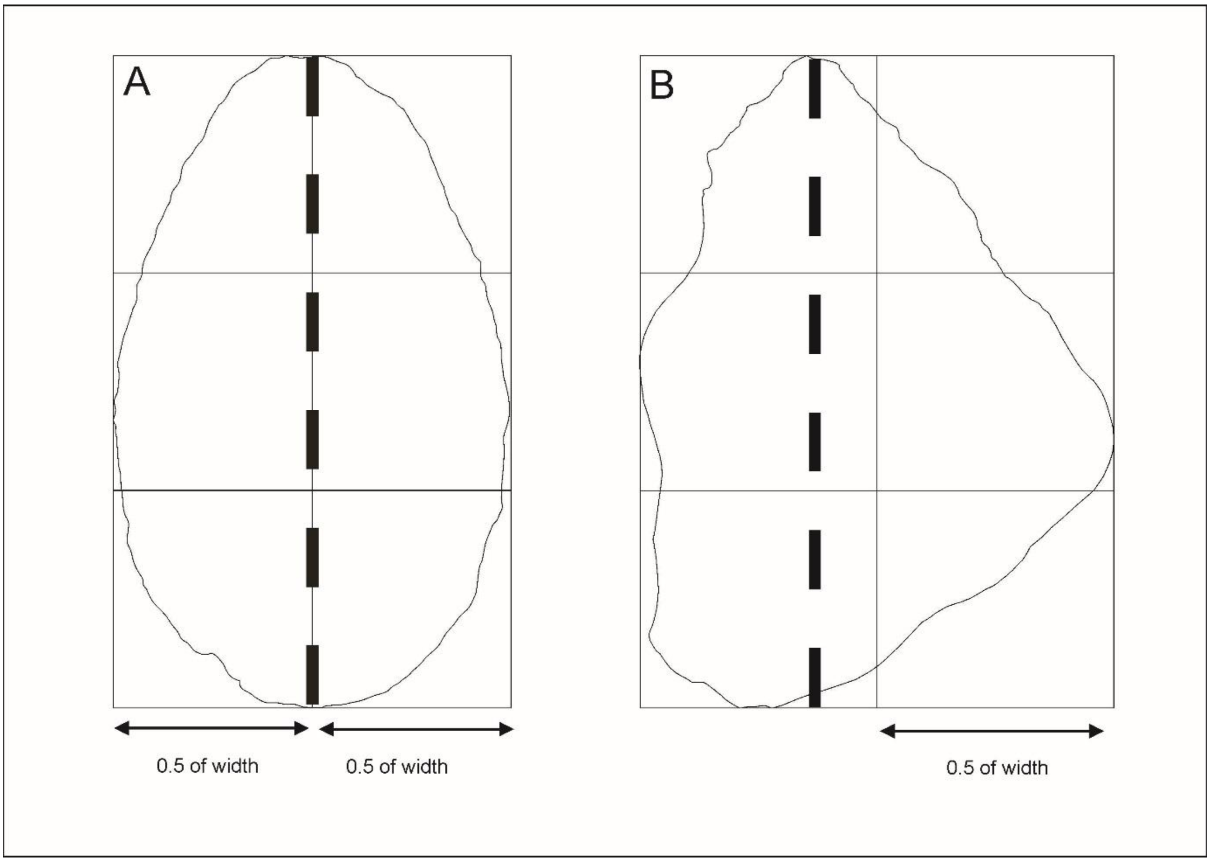

Figure 4. The location of the two mid-lines around which outline mirroring and the calculation of overlap for symmetry analysis occurs. The figure shows two handaxes prior to the mirroring process. The figure is intended to show that some handaxes are more suitable to be analysed by reference to one mid-line and not the other. On the left (4A) is the digitised outline of a Boxgrove handaxe. It shows the position of the natural mid-line. This axis, bisecting the handaxe, is set at half (0.5) of the handaxe's total width. The natural mid-line and the imposed mid-line (see text and below) would be in the same/very similar location on a handaxe that was this symmetrical. The imposed mid-line is shown on the digitised handaxe outline from Cuxton on the right (4B). It has a cutting edge at the tip and on the upper part of the tool. The imposed mid-line bisects the tip and is clearly offset from where the natural mid-line would fall. The base and right hand side of this handaxe are cortical and thick, where as the pointed tip has been carefully fashioned by thinning and shaping. The natural mid-line would bisect the unknapped part of the

nodule on this handaxe while the imposed mid-line bisects that part of the handaxe clearly shaped by the knapper and the tip of the tool.

Figure 4 should be B&W or grayscale and can cover 1 column

The imposed mid-line is of course more difficult to replicate as a methodological factor because of the higher potential for inter-observer error in the axis' placement. Some researchers may not see the need for the two axes, and encourage the use of only one, however we believe the use of both more properly reflects the true character of symmetry present in a handaxe assemblage.

How the handaxe is orientated before any axis or overlap around it is analysed will have a serious impact on how symmetry is perceived. A number of earlier studies on various aspects of handaxes, including evaluations of symmetry, have attempted to deal with this issue (see review of symmetry studies above). Most researchers would agree there is a natural orientation to an LCT. On many, a clear and narrowly fashioned tip shows careful working while the opposite end lacks a cutting edge and/or is only roughly flaked, thick or cortical (Figure 4B and Figure 1 2nd- 4th rows). Others, with more careful working all the way around (Figure 1 top row and Figure 4A), or variations on this (various possibilities in Figure 2 and Figure 1 5th row), almost always still have one end narrowing more clearly than others. It is an assumption of most workers in the discipline that these narrower ends represent 'a tip'. This is sometimes referred to as the typological orientation, and we follow that convention here. This initial orientation, which must happen before the exact placement of any axis can occur, will have important ramifications for overlap once an axis has been applied.

Readers familiar with this issue will quickly grasp that, in practice, the typological orientation is the same as the imposed mid-line when that axis bisects the apex or the mid-point of the taper. We are acutely aware of the replicability issues here and of the need to establish common base lines in methodology that inspire confidence. But we are also aware of the potential problems in applying unrealistic handaxe alignments by software packages in order to ensure absolute replicability. We hope to stimulate discussion on this aspect.

5.0. Materials

For this paper we have taken the British Middle Pleistocene Acheulean record from MIS 13 down to MIS 7. For comparative purposes we have included a Late Pleistocene handaxe rich site from the MIS 4/3 boundary - Lynford. This Neanderthal site currently has the largest sample of handaxes from this period in the UK. Our sample covers 10 sites and several hundred thousand years of

Pleistocene time – see Table 1 and Figure 5. The British Middle Pleistocene was chosen because it currently represents one of the best dated and chrono-stratigraphically well constrained sequences in north-western Europe (Hosfield, 2011, McNabb, 2007). Handaxe assemblages were chosen because of their appropriate size or site character (e.g. *in-situ*, excavated or well collected).

There is also a theoretical model that can potentially explain any evidence of change, or increase in sophistication (i.e. symmetry) in the material culture record of the Acheulean across this time span. It is an assumption of British Lower Palaeolithic studies that at the onset of a glaciation, and as sea level drops reconnecting the UK to the European mainland, hominin communities migrate southward toward continental refugia, where an intermixing of ideas and groups would occur. Otherwise, local extinction was the likely fate of many hominin groups. As temperatures improve with the return of interglacial conditions, hominins reoccupied Britain bringing new practices with them (Ashton and Lewis, 2002; Ashton et al., 2011; Bridgland and White, 2015; White, 2000; White, 2015; White and Schreve, 2000). Within the last two decades the British Middle Pleistocene interglacial record has been refined considerably to the point where we can now isolate stadials and inter-stadials within specific glacial/interglacial climatic histories (Ashton et al., 2008; Bates et al., 2014; Moncel et al., 2015). This creates the potential for identifying changes in material culture behaviour across the full span of an interglacial.

A detailed description of the British Middle Pleistocene context within which our ten chosen sites are set is presented in Supplementary Information 1. Readers not familiar with this background are encouraged to read this first. The photographs used in the methodology were sourced from the Marshall et al. database (Marshall et al. 2002) and from personal archives of JM (Furze Platt & Swanscombe) and JC (Pontnewydd, Lynford, Elveden).

6.0. Methodology

In brief, the method involved importing a digital photograph of a handaxe into CorelDraw16. Its outline was digitised using the bitmap/outline trace/line art function. The image was deleted leaving the digitised outline. All line widths were set to hairline. The outline was then orientated following the discussion of the tip above, and hand calliper measurements for length and width were inputted which scaled the handaxe outline to real-time size in millimetres. The digitised outline was then exported into AutoCAD16, maintaining the scaling, and the surface area of the whole handaxe in millimetres was generated, in AutoCAD16, and added to an MS Excel spread-sheet.

Marine Isotope Stage	Site	Handaxe Sample	Mean overlap and SD for imposed midline in mm	Mean overlap and SD of natural midline in mm	Median overlap for imposed midline in mm	Median overlap for natural midline in mm
13 528-474 kya	Warren Hill	50	393.7 +/- 327.6	260.7 +/- 195.1	268.7	216.7
	Boxgrove	50	821.3 +/- 1017.4	305.2 +/- 128.3	413.5	293.0
11 427-364 kya	Elveden	32	384.9 +/- 405.3	266.3 +/- 144.3	237.0	244.0
	Swanscombe Upper Middle Gravels *Homo* layer	58	313.5 +/- 222.2	308.4 +/- 292.0	270.0	262.7
	Bowman's Lodge	28	369.8 +/- 403.8	249.1 +/- 302.6	223.0	170.6
9 334 – 301 kya	Broom	50	525.0 +/- 450.7	382.8 +/- 214.2	413.0	359.0
	Furze Platt	69	714.8 +/- 531.3	516.9 +/- 250.3	553.1	471.3
7 242 – 186 kya	Pontnewydd	37	464.3 +/- 321.6	327.8 +/- 166.3	389.4	313.0
	Cuxton	50	737.9 +/- 488.2	591.7 +/- 408.8	621.6	457.6
4/3 4 – 3 boundary at c. 57 kya	Lynford	48	445.5 +/- 449.0	277.5 +/- 132.7	344.2	241.3
Total handaxes		472				

Table 1. The handaxe assemblages for the British Middle and Late Pleistocene used in this study. The mean and median overlap for each assemblage was generated by calculating the overlaps for both mid-lines on each individual handaxe and the assemblage value then calculated from these.

Figure 5. Map showing location of British Middle and Late Pleistocene handaxe sites used in analysis.

Figure 5 should be B&W or grayscale and can cover 1 column

In CorelDraw a 2x3 grid was added to a copy of the already digitised and scaled handaxe outline, as in Figure 1, representing right and left segments for tip, middle and base. Edge cutting pattern (Figure 2) was established at this point from the photograph. Ideally, this should be done from the gridded-out photograph with the artefact in front of you.

To calculate the overlap of the two edges on the natural mid-line the outline of the handaxe and the grid was copied, pasted on top of itself, and the copy (outline+grid) mirrored, see Figure 6a. The software automatically recognises the grid's tip middle and basal sub-divisions. The overlap for each of these three segments was 'smart-filled' on one side (the right for consistency). The two whole axe outlines were then deleted leaving the smart filled segments representing the overlap for the handaxe's three segments. These were then exported into AutoCAD16 and the calculation of surface area for the overlap for each segment was made. These were transferred into the Excel spread sheet and a calculation of the total overlap along the natural mid-line for each axe was made by summing the overlap values for the tip middle and base.

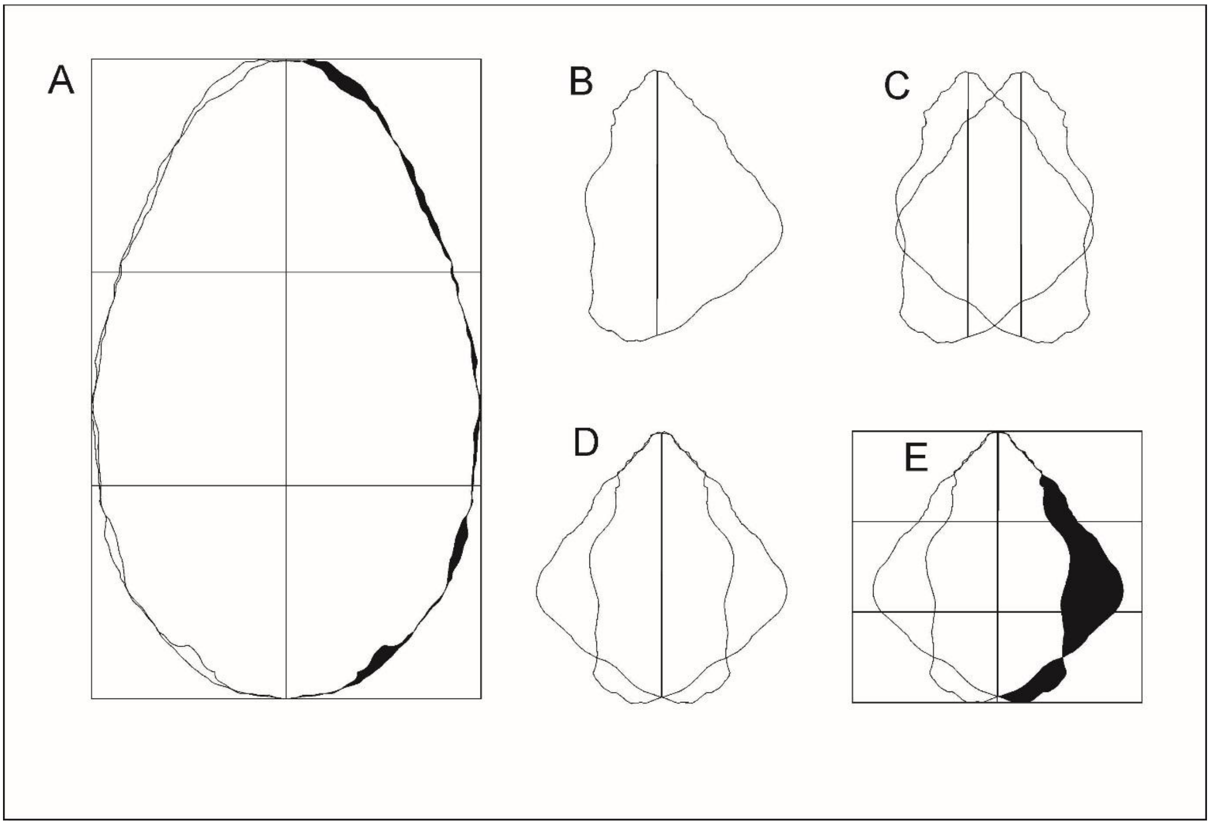

Figure 6. Mirroring and 'smart filling' the handaxe outlines in CorelDraw. Image A on the left is the handaxe from Boxgrove in Figure 4, and images B-E are the Cuxton handaxe also from Figure 4. The dark infilled segments are the overlap after mirroring – whose surface area calculation in millimetres represents the degree of symmetry present on each axe. The smaller the dark infill, the less overlap and the greater the symmetry. The larger the overlap the greater the asymmetry. Figure 6A shows the mirroring for the natural mid-line and Figures 6B-E show the mirroring process for the imposed mid-line. See text for more details

Figure 6 should be B&W or grayscale and can cover 1 column

The overlap calculation for the imposed grid line is slightly different. Firstly the position of the imposed mid-line is fixed. This involves imposing the 2x3 grid over the digitised handaxe outline and positioning the centre line of the grid exactly over the position the imposed mid-line would occupy. Then a straight line is drawn at that position to represent the mid-line itself and the grid deleted. This all ensures the imposed mid-line is absolutely vertical, Figure 6b. Then, the handaxe outline and imposed mid-line axis are copied, pasted and mirrored as above, Figure 6c. The two mid-lines are then brought into alignment, Figure 6d. One mid-line can be easily dragged and dropped onto the other in CoreDraw using the 'snap to' setting for the two outlines and using the topmost node at the tip as a reference point to ensure identical positioning. The grid is redrawn ensuring its mid-line sits directly over the two imposed mid-lines. The overlap for tip middle and base is then easily smart filled, Figure 6e, and exported into AutoCAD16 for surface area calculation as above. The results were then transferred to the Excel spread sheet as above.

7.0. Results

Figure 7 presents the overlap data for the 10 British sites in Table 1. Initial analysis of the data showed there were a large number of significant outliers in the distributions for each site (assessed via boxplots – not presented) and consequently the figure presents the median as the most appropriate measure of central tendency. The median for each site was generated by firstly dividing the total surface area of each handaxe by the total surface area of its edge overlap (tip+middle+base), thus scaling the overlap ratio for size. The median for each site was then generated from the individual scaled handaxe ratios for each assemblage. All original surface area measures were in millimetres. The higher the ratio the smaller the overlap and so the greater the degree of symmetry.

Two conclusions can be drawn from Figure 7. Firstly, the sites with the most symmetry all cluster in the top right of the distribution. Boxgrove shows the highest symmetry of all 10 assemblages, followed by Warren Hill, Bowman's Lodge, Lynford, Broom and Elveden. This group with higher symmetry are not related to particular interglacials, as all are represented with the exception of MIS 7. A middle range of symmetry values are represented by Swanscombe and Pontnewydd, and once again there is no age specific relationship. This pattern continues in the bottom left hand corner of the diagram where two of the three assemblages dominated by cutting edges at the tip or upper part of the handaxe

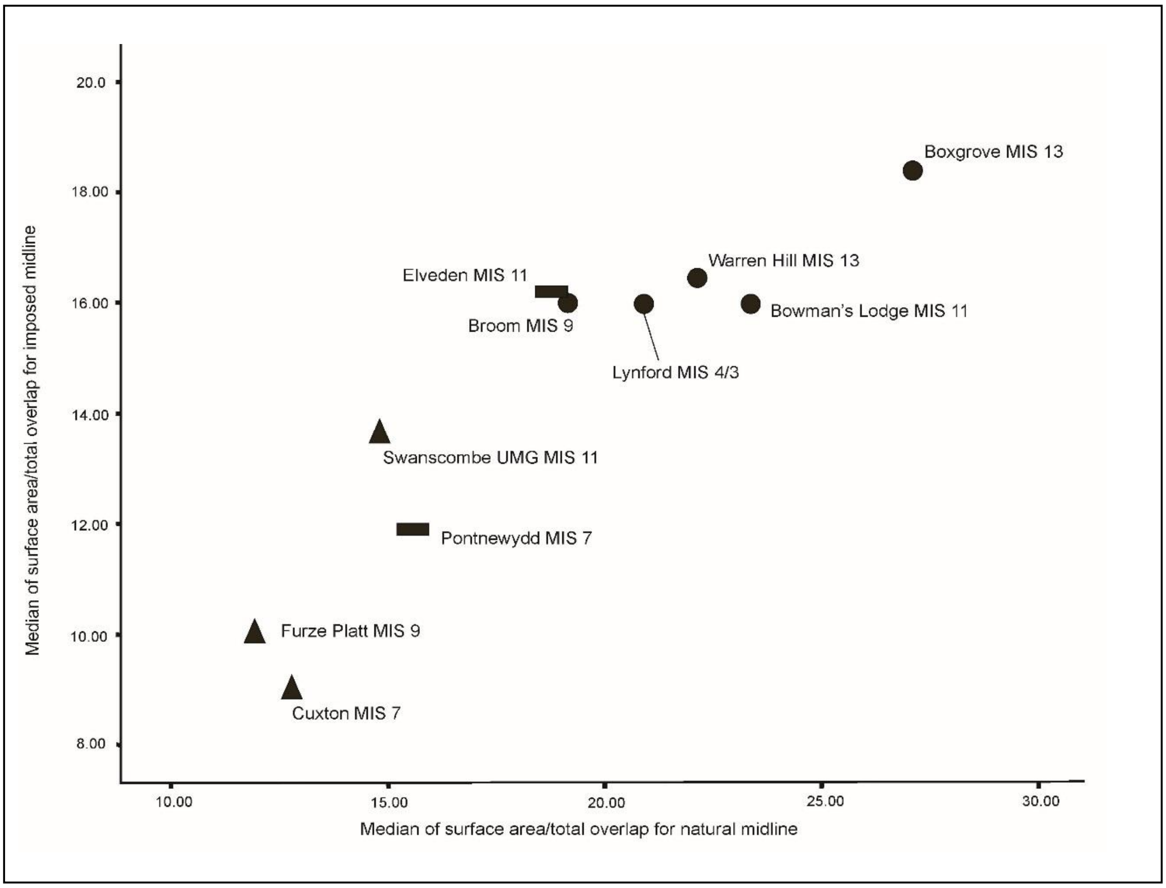

Figure 7. Quantification of the degree of bi-lateral symmetry present in handaxes from 10 sites covering the British Middle and Later Pleistocene. Measure of central tendency used here is the median. Data plotted against the natural and the imposed mid-lines. Circles indicate assemblages of handaxes dominated by a cutting edge all the way around (group 1, Figure 3). Triangles indicate assemblages of handaxes dominated by a cutting edge at the tip/upper part of the handaxe (group 3, Figure 3). Rectangle indicates handaxes with different patterns (groups 2 and 4, Figure 3).

Figure 7 should be B&W or grayscale and could cover 1 column

(group 3 assemblages, Figure 3) show the lowest values and therefore express the highest asymmetry in the dataset.

Secondly, there appears to be a strong link between the sites dominated by handaxes with a cutting edge all the way around (group 1, Figure 3) and higher symmetry values (top right of Figure 7). This raises the distinct possibility that the way a handaxe is made, in this case the extent and location of cutting edge, can influence how symmetrical it is. In order to test this, the data for the assemblages in each group were combined which increased the available sample size, and plotted against the two mid-lines. These data are shown in Figure 8. On both mid-lines the handaxes from sites dominated by those with a cutting edge all the way around have higher ratios and therefore show the most symmetry, while the group 3 assemblages have the lowest ratios and show the most asymmetry. Elveden (group 2) plots with group 1 as it does in Figure 7, and Pontnewydd (group 4) lies closer to group 3. Figure 8 supports the interpretation that handaxe edge working pattern may exert an influence on the degree of symmetry present. It will be recalled that here we are not discussing shape – so an equivalence with the typological ovate or cordiform handaxe should not be assumed.

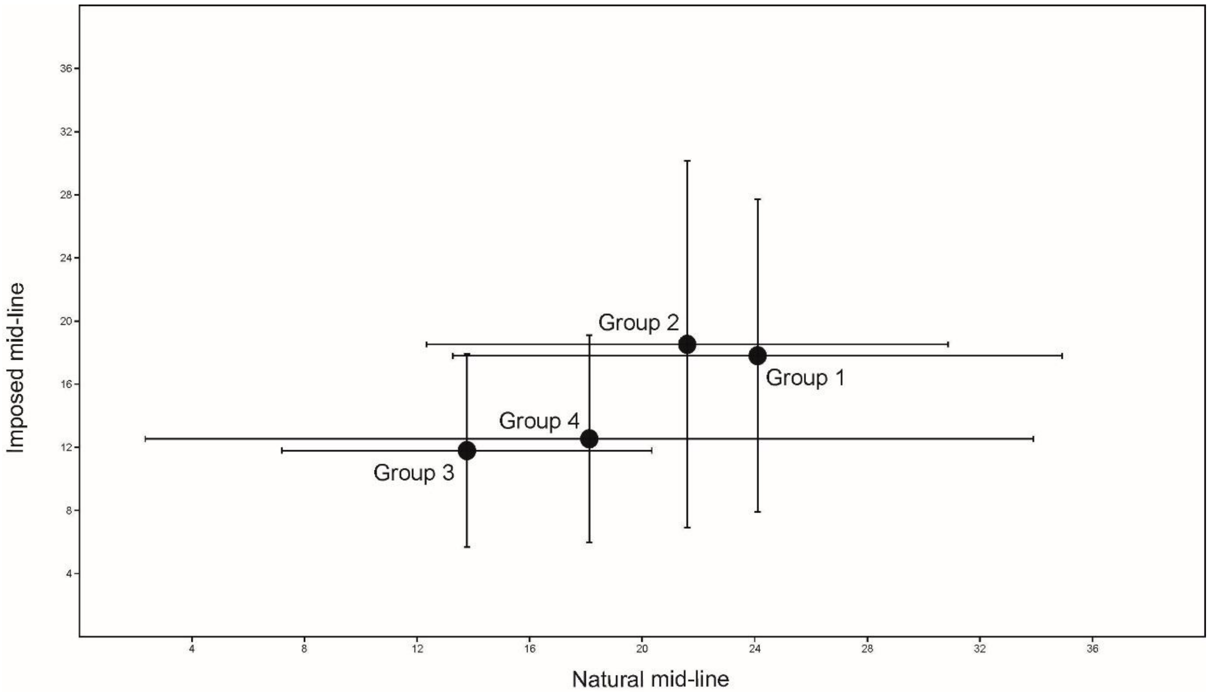

Figure 8. Quantification of the degree of bi-lateral symmetry present in handaxes when plotted by assemblage grouping, see Figure 3, against the natural and the imposed mid-lines. The measure of central tendency used here is the mean because following this approach sample sizes are bigger. Group 1 = Boxgrove, Warren Hill, Bowman's Lodge, Broom, Lynford, N=226 handaxes. Group 2 = Elveden, N=32 handaxes. Group 3 = Cuxton, Swanscombe UMG Homo layer, Furze Platt, N=177 handaxes. Scales are ratios from total surface area of handaxe/total surface area of overlap.

Figure 8 should be B&W or grayscale and can cover 1 column

From Figures 7 and 8, building on the sample sizes in Table 1, it is clear that the group 1 assemblages, dominated by cutting edge pattern 1, show the highest levels of symmetry on both mid-lines. The natural mid-line shows higher values than the imposed, as might be expected given its suitability for handaxes with a cutting edge all around. But at the lower and more asymmetric end of the distributions the values for both mid-lines become more similar, presumably reflecting the greater appropriateness of the imposed mid-line for the group 3 assemblages.

The results demonstrated an unexpected advantage to using the two mid-lines. This concerned the ability to compare the data from both for statistical equivalence. This took the form of a Kruskal-Wallis test, conducted in SPSS 22, comparing all the assemblage values on the imposed mid-line with each other, and subsequently all those on the natural mid-line with each other. Statistically significant differences between the assemblages were present on each mid-line (imposed: $N = 472$, *test statistic* = 64.655, $df = 9$, $p = < 0.0001$); (natural: $N = 472$, *test statistic* = 132.774, $df = 9$, $p = < 0.0001$). Pair-wise Mann-Whitney U tests explored the relationship between individual assemblages within each mid-line to assess where these differences lay. The results are presented in Table 2. The unexpected advantage was our confidence in identifying a genuine difference between two assemblages when a statistically significant difference was present on *both* of the midlines. While a number of assemblages show statistically valid differences between each other on the natural mid-line only, Furze Platt and Cuxton show consistent differences with the five assemblages in group 1 on both mid-lines.

	Warren Hill	Boxgrove	Bowman's Lodge	Broom	Lynford	Elveden	Pontnewydd	Cuxton	Furze Platt	Swanscombe UMG
Warren Hill							**N**	**I** **N**	**I** **N**	**N**
Boxgrove							**N**	**I** **N**	**I** **N**	**N**
Bowman's Lodge								**I** **N**	**I** **N**	**N**
Broom								**I** **N**	**I** **N**	**N**
Lynford								**I** **N**	**I** **N**	**N**
Elveden								**I** **N**	**I** **N**	
Pontnewydd										
Cuxton										
Furze Platt										
Swanscombe UMG										

Table 2. The table shows the relationship between assemblages dominated by group 1 handaxes (Warren Hill, Boxgrove, Bowman's Lodge, Broom, Lynford) with a cutting edge all around the edge, and group 3 (Swanscombe, Furze Platt, Cuxton) with a cutting edge confined to the tip or upper part of the handaxe. The relationship is based on statistically significant differences between individual assemblages. A Kruskal-Wallis test comparing all assemblages with each other on the imposed mid-line identified that differences were present between assemblages (see text for details) and a Mann-Whitney pairwise test identified which assemblages differed; statistical differences are indicated in the table but individual values are not presented. The tests were then repeated for the natural mid-line. The data being tested were the size adjusted overlap distributions (handaxe surface area/overlap surface area) for each assemblage. In the table the differences between individual sites are noted by the presence of an upper case letter - imposed (I) and natural (N), depending on which mid-line the statistically significant difference occurred on. For example Pontnewydd and Warren Hill were statistically different from each other on the natural mid-line, but Cuxton and Warren Hill showed statistically significant differences on both. Here we take a statistically significant difference on *both* mid-lines to indicate a genuine difference between sites. Empty cells indicate no statistically significant difference was present. Significance was indicated when p =< 0.05

In addition, our methodology allows for a comparison between the tip, middle and basal sections of the handaxes from the various assemblages to asses whether symmetry is 'applied' differently across the different assemblages. Figure 9 presents the median data and Table 3 gives the results of statistical testing for similarity in overlap between the different assemblages. Initially a PCA was attempted on the ratios for all individual assemblages for tips middles and bases but the resultant plot was a single data cloud with no structure to it at all. The presentation in Figure 9 and Table 3 shows what relationships are present more clearly.

	Warren Hill	Boxgrove	Bowman's Lodge	Broom	Lynford	Elveden	Pontnewydd			Cuxton			Furze Platt			Swanscombe UMG		
Warren Hill										**N**	**N**	**I** **N**	**N**	**N**	**I** **N**		**N**	**N**
Boxgrove								**N**	**N**	**N**	**I** **N**	**I** **N**	**N**	**I** **N**	**I** **N**		**N**	**N**
Bowman's Lodge											**N**	**I** **N**			**I** **N**			**N**
Broom											**I** **N**	**I** **N**		**I** **N**	**N**		**N**	**N**
Lynford									**N**		**N**	**I** **N**		**N**	**N**		**N**	**N**
Elveden											**I**	**I** **N**		**I**				
Pontnewydd																		
Cuxton																		
Furze Platt																**I**		
Swanscombe UMG																		

Table 3. This table follows the pattern of Table 2 but focuses on the similarities and differences between assemblages in terms of their tips, middles and basal segments. Empty cells indicate no statistically significant differences. Where a difference is present the cell has been divided into three representing the tip in the left sub-division, the middle in the central sub-division and the base in the right sub-division of the cell. The mid-line around which a statistically significant difference was demonstrated is indicated by a capital letter - imposed (I) and natural (N). A difference on both mid-lines is taken to be a real difference between assemblages. A Kruskal-Wallis test established whether there was a difference between assemblages for each mid-line (see text for details), and Mann-Whitney pairwise tests indicated which assemblages were different (individual values not presented). Significance was indicated when $p = < 0.05$.

Tips. Two groups are picked out by the median data in Figure 9a. The sites in group 1 with a cutting edge all around show more attention to producing symmetrical tips than those in group 3. However, the division is not absolutely clear cut as Swanscombe and Elveden (groups 3 and 2 respectively) are both located in the more symmetrical part of the diagram, while Pontnewydd (group 4) is in the more asymmetrical part. It is possible there is a temporal pattern here, or one where knappers in particular assemblages are showing a greater preference for more symmetrical tips. Larger samples and more sites are required to test this. The statistical testing (Table 3) shows no difference between the tips within the cutting edge all round group, nor between those assemblages within group 3 (although Swanscombe and Furze Platt are statistically different on the imposed axis). The tip data for Swanscombe in Table 3 shows no other differences, mapping nicely onto its position amongst the more symmetrical handaxe tips on Figure 9a. Cuxton and Furze Platt show some differences with some of the assemblages in group 1, but this is persistently on the natural axis. In summary the tip data shows one group of handaxes with more symmetry and one with less. There are differences between the two groups, but not within them, so symmetry would appear to be applied in a uniform way, within each group. No clear cut temporal pattern is evident.

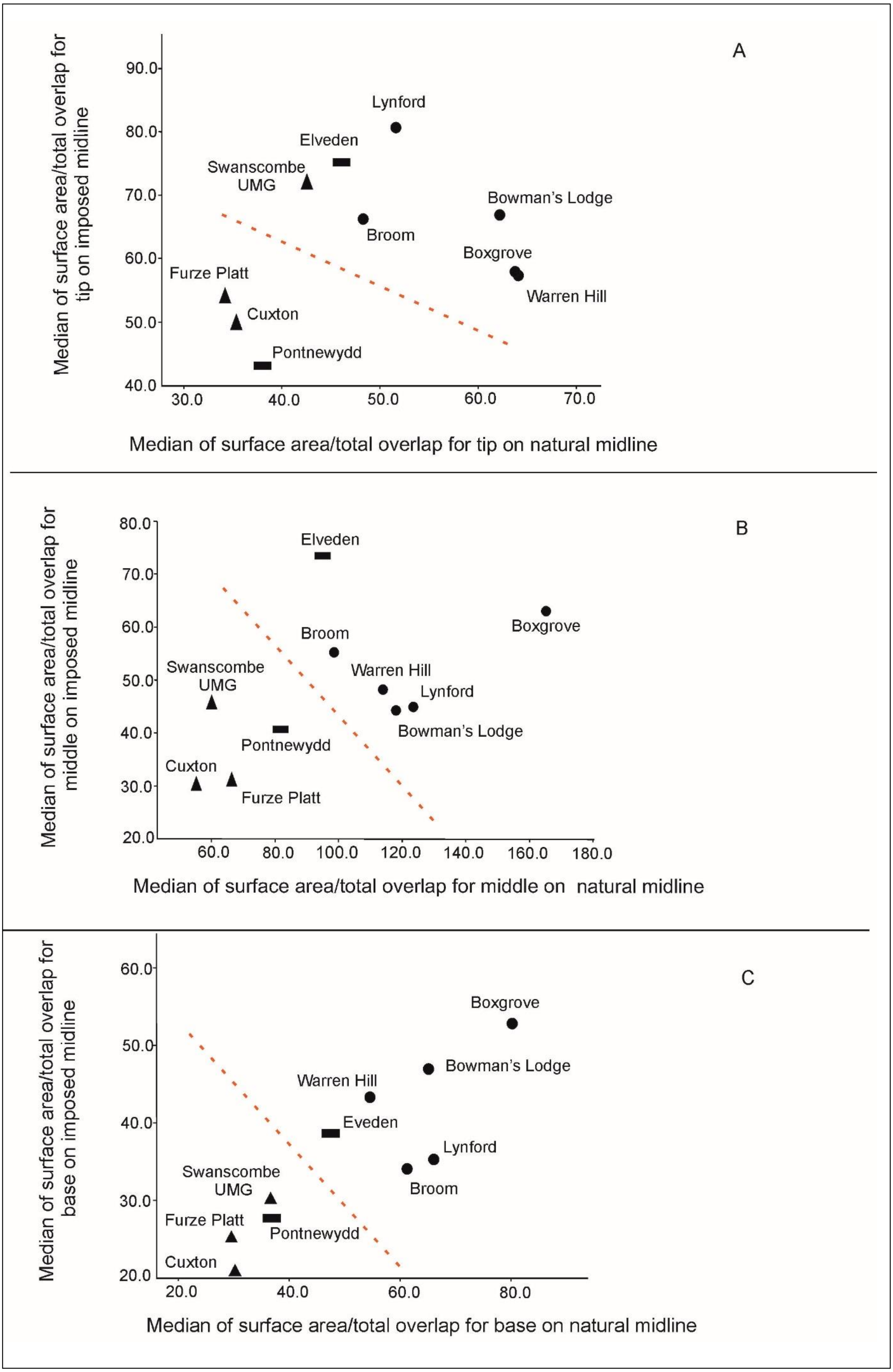
A
Median of surface area/total overlap for tip on imposed midline
Median of surface area/total overlap for tip on natural midline
Lynford
Elveden
Swanscombe UMG
Bowman's Lodge
Broom
Boxgrove
Furze Platt
Warren Hill
Cuxton
Pontnewydd
B
Median of surface area/total overlap for middle on imposed midline
Median of surface area/total overlap for middle on natural midline
Elveden
Boxgrove
Broom
Swanscombe UMG
Warren Hill
Lynford
Bowman's Lodge
Pontnewydd
Cuxton
Furze Platt
C
Median of surface area/total overlap for base on imposed midline
Median of surface area/total overlap for base on natural midline
Boxgrove
Bowman's Lodge
Warren Hill
Eveden
Lynford
Broom
Swanscombe UMG
Furze Platt
Pontnewydd
Cuxton

Figure 9. Measures of central tendency (median) comparing the symmetry present in the tips, middles and basal segments of handaxes by reference to the imposed and the natural mid-lines.

Figure 9 should be B&W or grayscale and cover 2 columns

Middles. The data for these are shown on Figure 9b. Once again there is a bipartite division, although Swanscombe now plots out with the other handaxes in group 3. The natural mid-line shows a somewhat greater separation between the two groups of handaxe working than was evident in the tip data, probably reflecting the greater degree of working in the middle sections in group 1 assemblages, and so the potential for greater symmetry. Swanscombe Furze Platt and Cuxton all show statistically significant differences with a number of other sites, Table 3. Unlike the tip data, there are now statistically valid differences between assemblages on both mid-lines. Furze Platt shows a clear difference in symmetry with Boxgrove and Broom, as does Cuxton. In summary the data for the middle segments of handaxes continues to show a bipartite division with assemblages in group 3 showing greater asymmetry. Application of symmetry through knapping in middle sections appears consistent within each group, but differs between the groups. No temporal pattern is present here either.

Bases. The statistical testing shown in Table 3, and pattern in Figure 9c, shows that most of the major differences between the two groups of handaxes being discussed here are focused in this segment. This is hardly surprising. Furze Platt and Cuxton (and Swanscombe) will have a much higher incidence of handaxes with cortical and thick partially flaked butts. Furze Platt and especially Cuxton show this with marked differences between them and the group 1 assemblages clear on both mid-lines. Again no distinct temporal pattern is present.

8.0. Discussion.

This paper has two main aims. The first is to explore the research question – is symmetry consistently applied to handaxes in the British Acheulean from MIS 13 – MIS 7, and in the Mousterian of Acheulean Tradition site at Lynford? The second is to flag some issues in the study of handaxe symmetry which we believe should be highlighted in the hope that they will stimulate further discussion amongst researchers of this topic.

Beginning with the first. On the basis of the data presented here the answer to our research question is in the negative, symmetry is not *consistently* applied in the

British Acheulean record. It will be recalled that in the broad sweep of the Acheulean's duration our data set covers the latter part of its time span, after 0.5 mya, the period that Wynn and Coolidge (Wynn and Coolidge, 2016) suggested saw the increase in exact mirror imaging of edges *and* cross-sections (which clearly does occur – just not consistently). No persistent increase in symmetry is evident in our data across the four interglacials and +300 ky duration of the British Acheulean and beyond. Boxgrove and Warren Hill (MIS 13 and presumably *Homo heidelbergensis*) show broadly comparable distributions of handaxe symmetry to that in Lynford (MIS 4/3 and *Homo neanderthalensis*). Between the two extremes the data shows variability.

Furthermore, the location and extent of edge working on a handaxe may influence the degree of symmetry present – those with a cutting edge all around are more naturally prone to greater symmetry.

All the assemblages in our data set show a continuum of symmetry from quite asymmetric handaxes to ones that show high degrees of bi-lateral symmetry. If we take just the data from the imposed mid-line, which we have suggested was the axis around which hominins actually evaluated a visual appreciation of symmetry, this intra-assemblage range can be seen in the boxplots in Figure 10a. One point to consider is that artefact taphonomy (condition/history) and site formation processes would affect the patterns in such representations, however, apart from a proportion of the Warren Hill material (see Supplementary Information 1) the handaxes in our sample are all in a fresh to lightly rolled condition. So the range of symmetries in the boxplots should be a fair reflection of the intra-assemblage variation originally present in each assemblage. Boxgrove, Broom and arguably Lynford represent the least disturbed assemblages, the context of their depositional histories have been recently investigated (Boismier et al., 2012; Hosfield and Green, 2013; Roberts and Parfitt, 1999). The continuum of variability from asymmetric to symmetric is clearly present in these assemblages as well as the other sites.

On an intra-site basis the variability within handaxe symmetry is highlighted in the selected cumulative percentage curves in Figure 10b. The more asymmetric handaxes are on the left of the horizontal scale and the figure presents the distributions for the two MIS 13 sites in the cutting edge all around category. Notice how Boxgrove has a few more markedly asymmetric examples than Warren Hill (steeper left hand curve) but then more or less 'plateaus' after a ratio of about 7.2, after which it shows a consistent climb towards the most symmetric examples. The positioning of the Boxgrove line, to the right of Warren Hill shows it has a higher frequency of more symmetrical examples than its East Anglian counterpart. In terms of symmetry we are almost dealing with two sub-groups at Boxgrove.

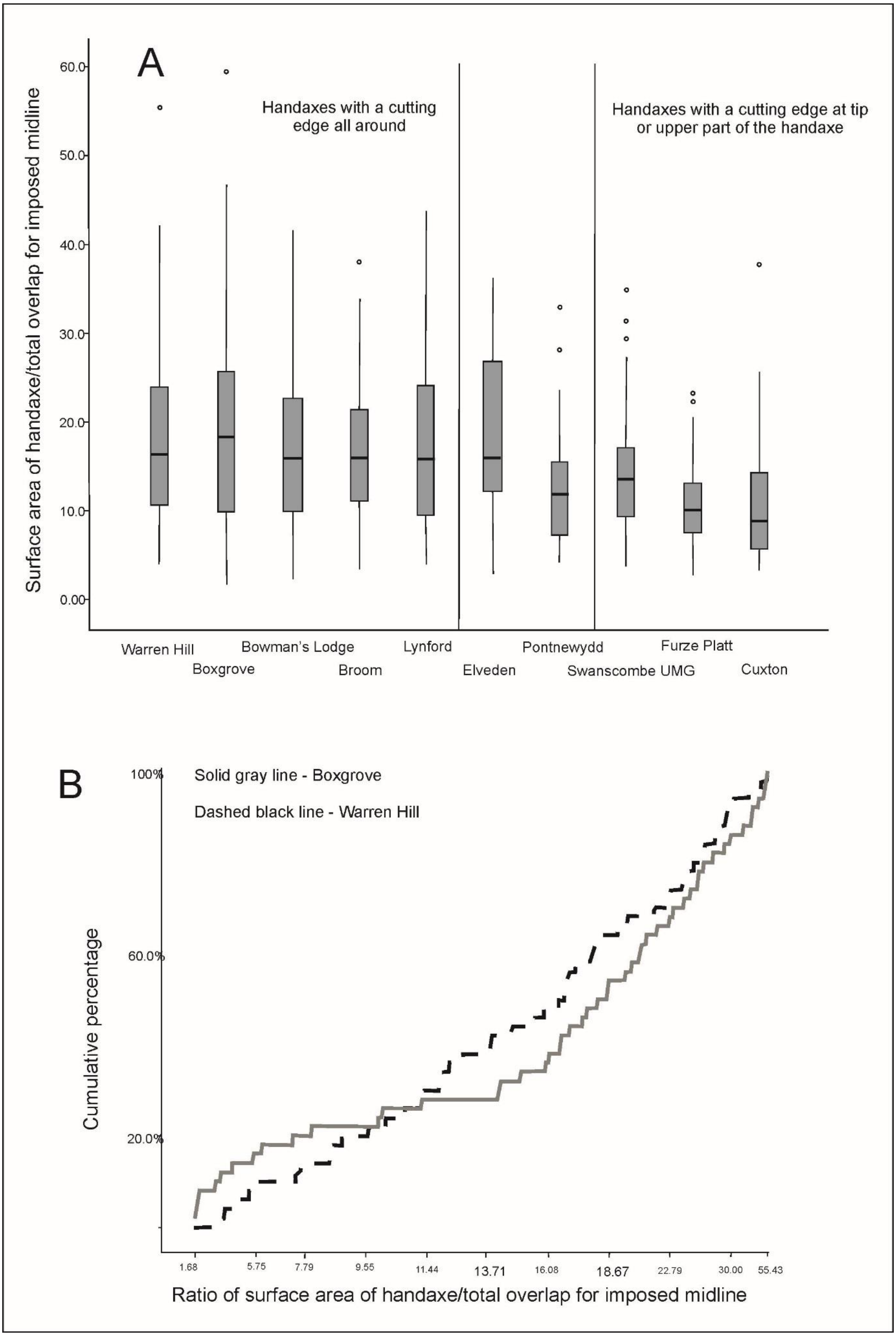
A
Surface area of handaxe/total overlap for imposed midline
60.0
50.0
40.0
30.0
20.0
10.0
0.00
Handaxes with a cutting
edge all around
Handaxes with a cutting edge at tip
or upper part of the handaxe
Warren Hill
Boxgrove
Bowman's Lodge
Broom
Lynford
Elveden
Pontnewydd
Swanscombe UMG
Furze Platt
Cuxton
B
100%
60.0%
20.0%
Cumulative percentage
Solid gray line - Boxgrove
Dashed black line - Warren Hill
1.68
5.75
7.79
9.55
11.44
13.71
16.08
18.67
22.79
30.00
55.43
Ratio of surface area of handaxe/total overlap for imposed midline

Figure 10. Comparing the distribution of symmetry within individual assemblages and between them by reference to the imposed mid-line only. Figure 10A shows boxplots arranged by cutting edge group (Figure 3); group 1 on the left and group 3 on the right. The sites are arranged from oldest to youngest, within each group, starting with the oldest on the left. Groups 2 (Elveden) and 4 (Pontnewydd) are in the middle of the diagram. Figure 10B compares the pattern of the distribution of symmetry in the two oldest sites in the data set, both of which are dominated by handaxes with cutting edges all the way around.

Figure 10 should be B&W or grayscale and cover 2 columns

Warren Hill however shows a single unbroken slope from its most asymmetric to its most symmetric examples. Both figures show that these individual continua are also variable on an inter-assemblage basis. The most asymmetric handaxes at Warren Hill and Lynford, (on the lower tail of the boxplots) are not as asymmetric as Boxgrove's (but only on one or two examples). On the flip side Boxgrove as an assemblage has more symmetrical examples (longer upper tail). The cutting edge all round group show higher symmetry than the cutting edge at the tip/upper part handaxes do, as noted above.

So symmetry is not *consistently applied* by Middle Pleistocene hominins to their handaxes on an intra- or inter-assemblage basis. Yet symmetry is *consistently present* as the upper tails of the distributions in Figure 10a show.

How should these patterns be interpreted?

On the one hand it could be argued that symmetry is an emergent property of manufacture – almost an epi-phenomenon, as Hayden and Villeneuve suggested, in their case as a bi-product of re-sharpening and the need for thinning flakes for cutting (Hayden and Villeneuve, 2009). Although Hayden's re-sharpening interpretation is not supported here, an argument could be constructed that symmetry automatically emerges from the application of a socially learnt bauplan (Ashton and McNabb, 1994; Lycett and Gowlett, 2008), the shared group understanding of what a butchery and carcass processing knife ought to be.

Take for example the Boxgrove bauplan, a bifacially thinned and shaped hand-held cutting tool, with a cutting edge all round, worked by extensive and invasive soft hammer working. More often than not it was finished with a tranchet, and with a narrower tip than base. A knapper would be hard pushed not to produce an artefact with a continuous convex edge which is lenticular in cross section across the width and down the long axis. The same could easily be imagined for Bowman's Lodge and Broom. Conversely, at Cuxton or Furze Platt, where the tips and upper parts of handaxes were carefully fashioned, an elongated and pointed tip bifacially thinned and shaped, is more likely to be relatively symmetrical as a function of manufacture and the original narrowness of the nodule at that end (Ashton and McNabb, 1994).

Symmetry in these scenarios is passive, and would map onto those studies that show increased symmetry does not confer measurable functional advantages (Machin, et al., 2007). However, Iovita and colleagues (Iovita et al., 2017) have recently argued that symmetry is anything but passive, rather it is a deliberately imposed feature on handaxes from Brinay la Noire on the Cher river, in the middle reaches of the Loire basin. Those from the lower level, stratum B, are c. 700 kya and represent the earliest securely contextualised and dated Acheulean handaxes yet found in western Europe. Higher, in stratum C, handaxes date to c.450 kya. The higher handaxes show an increase in symmetry over those lower down, but only slightly so. Symmetry at the site is achieved independently of raw material constraints, reduction technique, or stage of manufacture. The authors then compare their results to Boxgrove and find comparable levels of symmetry between all three assemblages (it would be fascinating to know in which handaxe category the French sites would fit).

The broad comparability in symmetry between the three assemblages discussed by Iovita et al. maps onto that found in our sample for group 1 handaxes. Iovita and colleagues raise the possibility that persistent handaxe symmetry only emerges in the handaxe record once hominins first enter Europe, which would raise Wynn's threshold (Wynn and Coolidge, 2016) from c. 500 kya to at least c. 700 kya. In which case symmetry may reflect the bauplan of earlier hominin migrants (Bridgland and White, 2015). One new and important factor is raised by Iovita et al. (2017). Where and when in its life cycle, and at what kind of site a handaxe is discarded or lost influences the modern interpreter's view of symmetry, because it may vary with different locations in the landscape. This is a factor that future studies must address.

A compromise position may be suggested. Whether culturally inclined to make handaxes whose shape and/or manufacturing technique automatically enhanced symmetry, or not, by 0.5 mya, the hominins who occupied and re-occupied southern Britain had achieved the limit of their creative potential in terms of bilateral and three-dimensional symmetry. It remains to be fully tested whether or not handaxes with a cutting edge all around may have been more common in the earlier British Acheulean (White, 2015), while those with cutting edges on the tip or upper part, became more frequent later on in MIS 9/7 (Bridgland and White, 2015, Wenban-Smith, 2004), but each of these basic bauplans or conceptual templates placed limits on the degree of bilateral symmetry (and shape variation) possible. Yet, working within those limits the UK Acheulean knappers and the Mousterian of Acheulean tradition at Lynford, realised to greater or lesser extent the full potential range of variability available to them.

We suggest that focusing on site specific (c.f. Iovita et al.) intra- and inter-assemblage variability in handaxe symmetry would allow for a more nuanced appreciation of the meaning and role of symmetry at individual Acheulean sites.

The second aim of the paper was to explore methodological issues. One of the advantages of the method presented here is its simplicity, - mirroring an outline and then producing a value for surface area, in millimetres, that can be converted into a size scaled ratio[1]. It does not require complicated mathematics or the constructing of virtual models of varying appropriateness to approximate the handaxes' outlines. As such its results are robust – they are easily replicable and easily falsifiable (a clear understanding of the orientation of the handaxe and placement of the mid-line being key in this regard).

The use of two mid-lines, Figures 7-9, shows that some handaxes may be more appropriately described by one and not the other. The pros and cons of both have been discussed above. It is likely that the hominins themselves used the imposed mid-line and assessed symmetry around it by eye (McNabb, et al., 2004). The natural midline, on the other hand has greater scientific rigour and clearly applies to handaxes with a cutting edge all the way around. An unexpected consequence of using both mid-lines in analysis was the greater confidence in identifying real differences between individual assemblages. It would be good to explore this through further debate and larger samples.

Positioning the mid-line precisely and the orientation of the handaxe are of primary importance and we are sensitive to criticisms of the typological orientation that has been followed here. In fairness to our method, we have followed accepted conventions of orientating and displaying handaxes. Nevertheless, consistency and replicability are genuine concerns, but appropriateness of orientation should also be included in deliberations. Broader discussion on these points would be very instructive. We as yet have no resolution to the problem, and for the moment believe that evaluations in relation to both mid-lines following a typological orientation have a role to play.

In broader discussion, Shannon McPherron (pers. comm.) raised the issue of what was the appropriate measure for assessing symmetry. Was it assemblage average (i.e. the whole distribution) or assemblage best (the presence of the most symmetrical handaxes). This is a reflection of an older and broader debate. In the culture-historical approaches of the first half of the last century (McNabb, 1996; Trigger, 1989) the *fossil directeur* approach focused on assemblage best. After the collapse of culture history, post-second world war, the whole assemblage approach was pioneered by Bordes (Bordes, 1961) and expanded on by others (Isaac, 1977; Roe, 1964, 1968). Recently the assemblage best approach has been revived as British archaeologists have tried to link specific handaxe types with the changes in the bio-tidal ebb-and-flow of hominin populations over the English Channel across the Middle Pleistocene.

Which approach is adopted is closely linked to the research question posed and we should be wary of setting them up as mutually exclusive variables as, in some cases, both may provide a perspective on a handaxe assemblage. For example, and paraphrasing McPherron (pers. comm.), were our research question to be 'does symmetry increase over time?' the assemblage average and distribution would likely be more appropriate; on the other hand if the question concerned specific aspects such as increasing motor control or the actual ability to impose symmetry itself, then assemblage best may well be most appropriate (also Wynn 2002). Our research question is more properly addressed though a whole assemblage approach as the two graphs in Figure 10 show. A significant point here is that if we were focusing on assemblage best then assemblage group makes a difference since the best-of-the best may be better in one group than in another. To re-contextualise the question, should we judge an assemblage by the few gifted knappers present, or by the results of all the knappers who contributed to that group's survival? Once more engendering debate on this issue would be profitable to researchers interested in handaxe symmetry. If nothing else our methodology shows that both are present in handaxe assemblages.

9.0. Conclusions

Quantifying the presence and amount of symmetry present on handaxes has become easier as digital technology has become more sophisticated and more widely available. On the other hand, digitisation allows for the proliferation of competing methodologies as becomes clear from our review of symmetry studies. The method suggested here is simple and effective, but we do not wish to suggest it is superior to others, merely that it provides a relatively simple approach to looking at an important question. Some colleagues may argue we are just throwing 'new tech' at an old problem because we can. We would dispute this. New technology provides new ways of exploring old questions afresh and as such can provide important new insights. At the end of the day it is the research questions that are the most important aspect of what we do.

Arising from our results three new research questions could be posed:-

- Is symmetry deliberate despite the potential influence of handaxe type, and methodologically how would we demonstrate that?
- What does intra-assemblage variability mean, not only from the perspective of the Acheulean knappers but how we as researchers approach it?
- What does inter-assemblage variability imply for hominin cognitive evolution and why is symmetry not consistently applied in the later (British) Acheulean?

If nothing else, new approaches can focus the spotlight on aspects of a topic that more traditional methods do not highlight, and our research into the topic of this paper has brought that home to us. In thinking about this paper, and its results there are a number of issues raised that could generate useful debate.

One such is the need for more sites with clear chronostratigraphic sequences that contain large assemblages of Acheulean handaxes that are securely dated. Such sites and assemblages would then allow researchers to meaningfully compare the behavioural signatures through time, as well as realistically assess characteristics like the imposition of shape and form. Such sites are hard to come by in the archaeological record, but we should still prioritise trying to discover them. In addition continued attempts at re-dating older sites will allow them to contribute to modern debates. Many of these sites were significant in establishing the current perspective on the British Acheulean. In addition, researchers should make the data available to others through timely publications and open-access databases. Such repositories (of which Marshall et al. 2002 is an excellent example) would allow the investigation of the three questions posed above.

For us, there is not a one size fits all interpretation to the question of symmetry in the Acheulean. Rather, the inter- and intra-assemblage complexities we are starting to recognise probably mirror small, fractured, highly mobile and dispersed hominin groups that move around landscapes which provide different affordances and present different challenges. Many of these groups may go extinct or be replaced by different groups of hominins - sometimes of the same species (but of a different cultural tradition), or at other times by social groups from a different hominin species altogether. What we see today (particularly in the British Palaeolithic context) is the result of the many different groups producing artefacts within the same landscapes, but spread over many thousands of years lumped together in large assemblages. Consequently, the assemblages are not contiguous but palimpsestual in their make-up. This is not a new observation, but what the patterns of handaxe making in our results suggest to us is that we do need to pay closer attention to the physical context and time depth of assemblages and not interpret them as blanket degrees of sameness. This is implicit in Iovita et al.'s (2017) position. Engaging with the methodological difficulties (and potentials) of palimpsests would be a major step forward in bringing large bodies of (currently difficult to deal with) data into the frame. If we can start to tackle assemblages from this perspective we should also be able to get a better understanding of hominin social group structures, interactions, speciation events, and movements across the landscape as well as potential cognitive developments. The resolution of the record in terms of vertical/chronological understandings is good, and getting better all the time, but with a few exceptions (e.g. Boxgrove, the Ebbsfleet Elephant site and potentially the new investigations at Barnham) our understanding of the contemporaneity and time depth of sites within landscapes remains poor. To really understand diachronic change in symmetry we need a good grasp of the vertical and the horizontal.

One way to overcome these difficulties is through greater collaboration and collegiate discussion of the Acheulean. This already exists within many distinct research groups (some of these are large and well established), but perhaps it is time for us to pool together in order to understand the complex phenomenon of the Acheulean handaxe.

Notes.

1. We are exploring various options that allow the calculation of area within CorelDraw16 itself which would greatly simplify the method.

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