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Research Article

What is a 'Giant' Handaxe? Ergonomic Thresholds, Functional Impacts and Acheulean Social Signalling Potential

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Abstract

'Giant' handaxes are a widely recognized but infrequently investigated phenomenon of the Acheulean period. The scale of their distribution and the selective pressures underpinning their production are not well explored. Here, we report new data from a large-scale experimental study that identifies the point at which handaxes become too large to use with a single hand, alongside a review of known Acheulean assemblages displaying 'giant' handaxes. On the understanding that most 'regularly sized' Acheulean handaxes were gripped in one hand, if handaxes require bimanual grips, alternative explanations for their production—beyond unimanual butchery and woodworking tasks—should be sought. Our data identify clear mass, length and thickness thresholds for bimanual gripping. It is revealed that spatially and temporally diverse archaeological sites display 'giant' artefacts that exceed these thresholds. We suggest these atypically large handaxes would most plausibly have been utilitarian tools used for cutting, but in alternative ways to more regularly sized bifaces. This includes when worked materials were secured by another individual or structure, during digging activities, or when used as a stationary cutting 'plane' secured on the ground.

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Introduction

Acheulean handaxes are extremely well known—to such an extent that in popular accounts the artefact becomes an icon, as if all handaxes can be reduced to one single symbol. In fact, form variability in handaxes, both within assemblages and between assemblages, is a fundamental part of the Acheulean pattern. Such variability is recurrently referred to in scaled terms including 'substantial', 'extreme' and 'large' or, conversely, 'diminutive' (e.g. Chauhan 2009; Clark *et al.* 2024; Emery 2010; Muller *et al.* 2022; Wenban-Smith 2004) and plays a major role in driving questions about the design, production and use of these tools by early humans in the middle and late Pleistocene. Explanation for shape variation in these bifacially flaked core-tools most often includes cultural and biological differences between populations, distinct ecological/functional use contexts, variable reduction and resharpening behaviours and raw material factors (Clark *et al.* 2024; García-Medrano *et al.* 2023; Herzlinger *et al.* 2021; Key & Dunmore 2018; Lycett *et al.* 2016; McPherron 2000; Muller *et al.* 2022; Stout *et al.* 2014; Vaughan 2001; White 1998; Wynn & Gowlett 2018). Tool size variation within and between handaxe assemblages can be linked to the same influences (Kempe *et al.* 2012; Key & Lycett 2017b). A combination of these factors likely came together in variable quantities to inform the morphology of these artefacts (Lycett & von Cramon-Taubadel 2015).

Many of these mechanisms would have worked to produce variation around a central tendency, with extreme forms beyond functional, context-dependent thresholds being selected against (Gowlett 2005; Kempe *et al.* 2012; Lycett *et al.* 2016), but with variation in functional pressures still pushing towards scale variations up to a factor of 10 in some variables (e.g. mass). The underlying principle is that most handaxes would have been produced to complete a given (or selection of) task(s), and if their form was detrimental to task performance and/or completion, then its likelihood of reproduction and social transmission would have been reduced. In some specific scenarios this could have resulted in highly specialised forms (e.g. narrow and pointed forms for 'winkling' out a small part from a larger whole: Gowlett 2013), but in the majority of instances—particularly those where tools were produced for multiple tasks—handaxes likely conformed to more generalized ovate-to-pointed plan-view shapes (e.g. Clark *et al.* 2024; García-Medrano *et al.* 2023; Herzlinger *et al.* 2021; Iovita & McPherron 2011; Key 2019). In turn, extreme handaxe forms are comparatively rare in the artefact record, with

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assemblage-level morphological data recurrently adhering to a normal distribution, albeit at times with a long, low-frequency, tailed distribution (Chauhan 2010; Dale *et al.* 2024; Gowlett 2009; 2013; Muller *et al.* 2022; Vaughan 2001).

It is argued here that extreme handaxe morphologies are not defined by the influences that select for central tendencies; rather, they result from exceptional contextual pressures infrequently observed at a population level. Functional, social learning, reduction (resharpening) and raw material factors could sometimes have driven the production of extreme forms. For example, knapping errors leading to a mid-production 'rough-out' breaking in half, or raw material size limitations, could have resulted in handaxes substantially smaller than the ~10 cm length threshold below which cutting performance decreases significantly (Key & Lycett 2017a). Yet not all extreme handaxe forms are proposed to result from these mechanisms; social and aesthetic pressures have repeatedly been put forward as alternative mechanisms.

Aesthetic explanations are plausible for some Acheulean populations (Chase & Dibble 1987; Gowlett 2021; Wynn & Berlant 2019). Most notably those in the mid-to-late Pleistocene who represent the last common ancestor of both *Homo sapiens* and *H. neanderthalensis*; species with evidence for the structured production of non-utilitarian, and arguably aesthetically derived, material culture (Bello 2021; McBrearty & Brooks 2000). Yet, many handaxes that are suggested as being aesthetically derived are assigned based on features with little-to-no impact on their use as a cutting tool (e.g., colouration), or from features that are not technologically exceptional (e.g., presence of a shell inclusion), making alternative hypotheses for their presence difficult to test. Ultimately, aesthetic hypotheses are often unfalsifiable (Chase and Dibble 1987; Flanders & Key 2023; Gowlett 2021).

The potential for extreme handaxe forms to have played roles within Lower Palaeolithic social systems has arguably received greater attention. High levels of plan-view and side-view symmetry in some handaxes, for example, have been suggested to have acted as a social signal within later Acheulean groups (Hodgson 2015; 2017). Kohn and Mithen (1999, 524) famously proposed high symmetry, along with other biface-form 'oddities' and 'additional features', to have played a role in hominin mating behaviours. However, the extent to which highly symmetrical handaxes can be considered extreme or rare is debated (McNabb & Cole 2015; McNabb *et al.* 2018) and it does appear to have been under some form of selective pressure (Lycett 2008). Pope *et al.* (2006) highlighted a potential role for handaxes as visible markers within landscapes, with their recurrent structured form acting as a clear signal of hominin presence and related behaviours. In this context, extreme tool forms would be highly recognizable as a departure from routine signalling. It is impossible to test social hypotheses for species long extinct, but the presence of ochre use and rock art in the Middle Stone Age points to the feasibility of an earlier origin for related behaviours (Kuhn 2014), while differing production emphases between handaxes and cleavers hints at greater social-signalling potential in the former (Herzlinger & Goren-Inbar 2020). The possibility that a capacity for some form of communicative signalling behaviours may be deeply rooted within the hominin clade is also indicated by studies of the genus *Pan* (e.g. Hobaiter & Byrne 2014), including behaviours that involve use of material items (e.g. Badihi *et al.* 2023).

In recent years, the widespread but low-frequency presence of so-called 'giant' handaxes in the Acheulean archaeological record has received particular attention when linking extreme handaxe forms to social signalling (Dale *et al.* 2024; Diez-Martín *et al.* 2019; Ingrey *et al.* 2023; Overmann & Wynn 2019; Wynn 2021). At a fundamental level they are defined as artefacts assumed too large to be applied to, or produced solely for use within, utilitarian contexts (Fig. 1). The reasoning is that if a handaxe cannot be used effectively or efficiently to cut, scrape, pierce or otherwise modify an aspect of the physical environment in which hominins lived, then it is more likely that it had a role within their social environment (Dale *et al.* 2024; Hodgson 2015; Kohn & Mithen 1999; McNabb & Cole 2015). On the other hand, earlier hominins may have displayed some of the greater-than-modern-human upper-limb strength observed in other great apes, and for specific tasks, atypically large tools may have been needed.

Substantial size ranges certainly exist in many Acheulean biface assemblages. Length, for example, often varies by a factor of five (Gowlett 2009), far beyond anything that could be seen as 'copying error' or 'poor standardization'. Variation in mass is even more striking, with a factor of 10 being quite normal in multiple handaxe sets (Crompton & Gowlett 1993). In African handaxes, the issue of size extremes was raised by Mary Leakey's work at Olduvai Gorge (Leakey 1971). In Bed II she distinguished large, well-made handaxes of the Acheulean from 'small and poorly made' handaxes of her Developed Oldowan B. Although Mary Leakey considered these as different industries, perhaps made by separate hominin species, others considered it more likely that palaeogeographic factors affecting access to raw materials explained the different facie (Davis 1980; Stiles 1979a,b). A Wishart's Mode Analysis found probable modes of large and small handaxes side by side within the million-year-old datasets of Kilombe in Kenya (Gowlett 1988). Other examples of both very large and very small handaxes being found together in the same assemblage have been recognized elsewhere on a number of occasions, including in Africa, Europe and Asia (Dale *et al.* 2024; Emery 2010; Gowlett *et al.* 2017; James & Petraglia 2005; Mussi *et al.* 2023; Wang *et al.* 2014).

This size variation inevitably makes an enormous difference in the usability of tools and their capability to do work, but the implications of large and small have only occasionally been tested in functional terms (Key & Lycett 2017b). Key and Lycett (2017a) demonstrated that there is no clear upper size threshold beyond which handaxes become too large to perform a generalized cutting task. Some of the largest replica handaxes in their experiment, which ranged from being very small up to 4.5 kg in mass and 296 mm in length, were inefficient relative to other forms, but there was no clear 'drop off' in performance (unlike the aforementioned lower size-performance threshold) and some were effective tools (Key & Lycett 2017a), demonstrating that even some of the largest handaxes in the archaeological record had potential to be applied to cutting tasks. More recently, Khaksar and Modarres (2024) used large replica handaxes, ranging between 224 and 392 mm in length, to demonstrate

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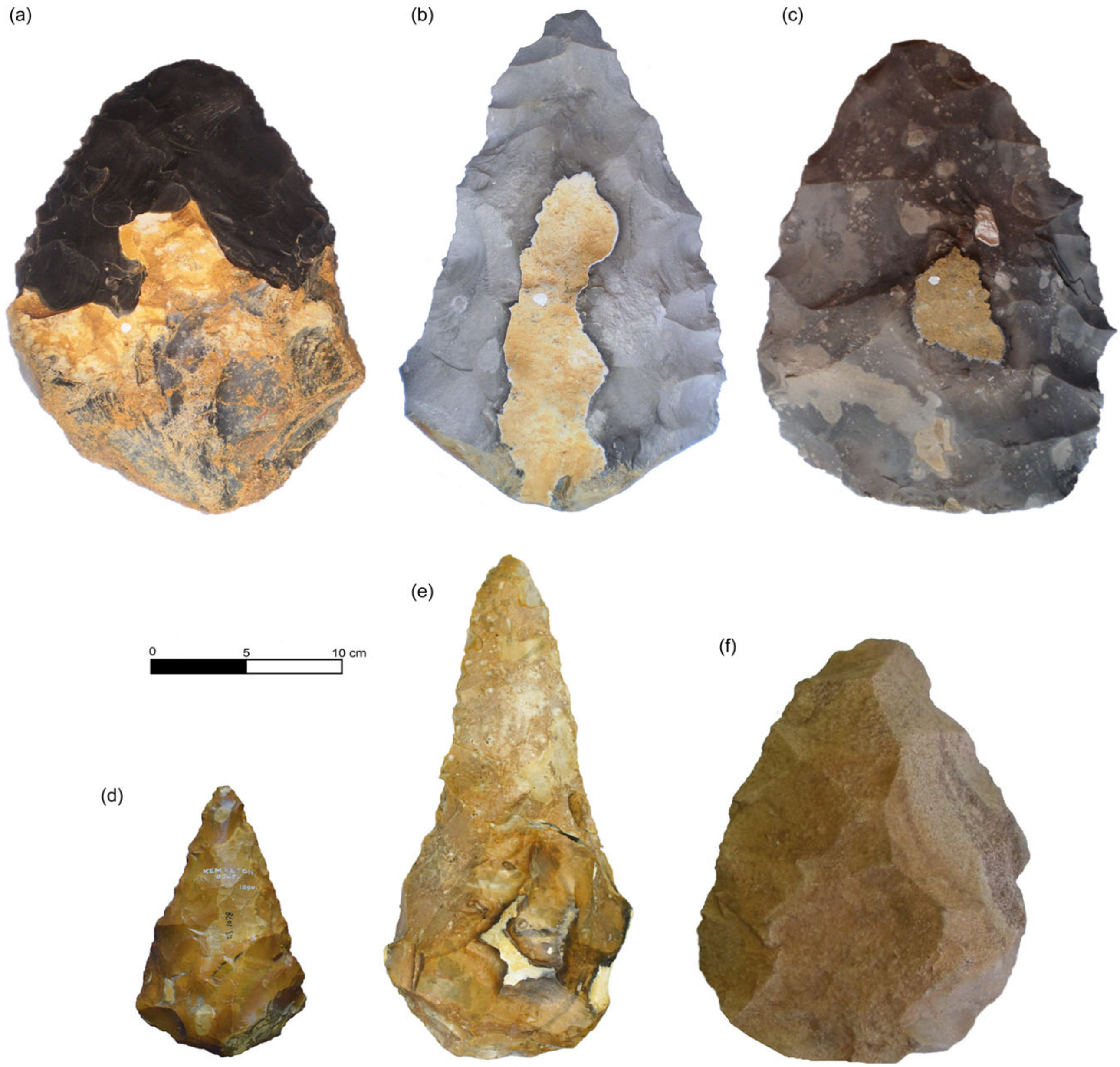

Figure 1. The three longest replica handaxes used in Key and Lycett's (2017a) experiment (a=265 mm, b=296 mm, c=278 mm) alongside a 'regularly' sized (158 mm) British handaxe artefact from Kempston (d), the large (296 mm) Maritime Academy (UK) ficron (e) and a 'giant' (257 mm) biface from Issutugan (Somalia) (f). Scale: 100 mm.

that while these tools can be applied within diverse functional contexts, in most tasks they perform with reduced efficiency relative to smaller, more regularly sized handaxes. This result was replicated by Standley-Barrow (2024) during a laboratory controlled cutting task. Zupancich and Proffitt (2014) demonstrated that giant bifaces could serve as useful cutting tools when stationary and secured in the ground, such that worked objects move across the upper edge of these tools. Together, past work demonstrates that giant handaxes *can* be used as cutting tools, but their relative performance is context dependent and at times reduced relative to smaller alternatives. Binary statements about their inability to cut and modify materials are therefore unsupported (e.g. Hodgson 2015; Overmann & Wynn 2019) and more measured discussion of both cutting and social function possibilities should be preferred (e.g. Dale *et al.* 2024).

While we cannot directly support or refute social hypotheses concerning extinct hominins, we evidently can test alternative hypotheses, including that giant bifaces are effective and efficient cutting tools (including digging: cf. Atkins 2009). Yet to date, this has not brought us closer to reliably identifying whether any giant handaxe artefacts could have been made solely for social signalling purposes. Here, we address this question using binary records of tool-use ergonomics. Our study is based on the recurrent observation that giant handaxes can be difficult to manipulate and manoeuvre with a single hand

(Khaksar & Modarres 2024; Key & Lycett 2017a; Standley-Barrow 2024). Notably, these past experimental studies were performed under controlled laboratory conditions with worked materials secured to a frame or stable platform. However, this would not have been the case with most activities (e.g. butchery) undertaken during the Acheulean, meaning the tool user's non-dominant hand would typically have been required to secure the worked material. It is, therefore, possible to predict that gripping handaxe artefacts with two hands would have been relatively rare. However, some circumstances, such as digging or the chopping of heavier items, may have permitted the use of two hands. In turn, tool forms that required the use of two hands in these experiments may not have been effective hand-held cutting tools when used by a single individual, suggesting similar forms in the Acheulean may potentially have been used for alternative utilitarian purposes, produced for social signalling, or selected for through alternative mechanisms.

Here, we present new data from Key and Lycett's (2017a) experimental study into the functionality of Acheulean handaxes. We identify the duration of time that one or two hands were used to secure each of the 500 handaxes. If a tool was used with two hands for the majority of time, then potentially handaxe artefacts of a similar size were not used by Acheulean individuals as generalized hand-held cutting tools.

Methods

Given that the new data we present were derived from Key and Lycett's (2017a) experimental study, we repeat major methodological details here, alongside new information concerning the collection of ergonomically relevant data: but see Key and Lycett (2017a) for additional data and considerations.

Replica handaxe assemblage

500 replica handaxes were knapped from British flint with the intention of creating an assemblage of tools that could ethically be used in an experimental context (Eren *et al.* 2016) (Fig. 1). The tools were specifically produced to be highly variable in form. Both 'morphologically extreme and archaeologically representative' (Key & Lycett 2017a, 517) handaxes were deliberately created on nodules and large flake spalls using a combination of hard and soft hammer percussion as required. Consideration was given to the necessity of the tools being held in the hand and used in a cutting task, potentially limiting the extreme upper end of the replica tool sizes. Here, we use four univariant metrics that are regularly collected from handaxe artefacts with the intention of defining their size.

'Length' was defined as the maximum straight line measurable on each handaxe when viewed from its superior surface, with the latter being defined as the face of each biface displaying the greatest number of flake scars greater than 1 cm (Lycett *et al.* 2006). 'Width' was defined as the maximum straight-line distance on the superior surface of each handaxe when perpendicular to the tool's line of maximum symmetry. 'Thickness' recorded the maximum dimension of each handaxe at any point perpendicular to its longitudinal and lateral extension (Gowlett 2006). These three variables were recorded in millimetres using digital calipers (Table 1). 'Mass', recorded in grams (g) using digital scales, was used as a record of each handaxe's material volume (i.e. size) as all tools were made from the same raw material (Table 1). As all tools were produced from the same raw material with only minor variation in density due to variable cortical coverage and inclusions, mass can be used adequately to describe differences in tool size. Note that the upper size limits of the replica assemblage conform with many of the largest handaxes observed in the archaeological record (Fig. 2). In addition, we created a broad multivariate record of tool size by entering length, width and thickness data into a principal component analysis (PCA). The resulting principal components (PCs) can be used to examine whether a more generalized measure of handaxe size can differentiate between tools gripped with one or two hands (Table 1).

To investigate further the impact of tool form on bimanual gripping during handaxe use, we examined the role of tool shape and the position of each tool's centre of mass. Shape was recorded at a coarse scale through elongation and refinement ratios, with the former describing the relative thinness of a tool (width divided by length) and the latter representing the thickness of a tool relative to its width (thickness divided by width). Both of these variables appear to have been controlled to varying degrees by Acheulean hominins (Crompton & Gowlett 1993; Wynn & Gowlett 2018). We also investigated tool shape using a dataset of 29 size-adjusted variables, using the geometric mean method of size adjustment (Lycett *et al.* 2006). These 29 variables were recorded using a system of Euclidean distances distributed across the plan-forms and profiles of each artefact, as widely outlined elsewhere (e.g. Courtenay 2023; Pargeter *et al.* 2019; Schillinger *et al.* 2014). The size-adjusted data were subsequently processed through principal component analysis, such that the first and second principal components describe 57.2% and 17.35% of the total shape variation, respectively.

Two proxy variables were used to represent each tool's centre of mass. The first recorded the position of maximum width on each tool expressed as a percentage of the tool's overall length, where 0% equals the very tip of the tool and 100% equals its base. We also recorded the position of maximum thickness on each tool, again expressed as a percentage of maximum length. Centre of mass has been repeatedly linked to handaxe ergonomics and the ease with which distal portions of these tools can be applied to worked materials (Gowlett 2006). Descriptive data for shape and centre of mass variables can be found in Supplementary Table 1.

Participants

Five individuals were recruited to use 100 handaxes each, with tools being randomly assigned to each individual. One-way analysis of variance (ANOVA) confirmed that the masses (F [4, 495] = 1.253, $p = 0.288$) of handaxe groups assigned to each individual were broadly equal. The participants were not aware of the theoretical underpinnings of the experiment. Each was paid a nominal remuneration of GBP £50 for their time. By limiting the number of participants to five, it

Table 1. Descriptive size data for the full handaxe assemblage (n = 500) along with mean data for the tools assigned to each participant (n = 100).

	Length (mm)	Width (mm)	Thickness (mm)	Mass (g)	PC1 (Size)	PC2 (Size)
Minimum (n = 500)	38.8	24.7	7.4	8	−122.71	−52.59
Maximum (n = 500)	296.3	200.3	106.3	4484	181.19	36.88
Mean (n = 500)	135.9	91.9	40.7	577	–	–
Standard Deviation (n = 500)	38.4	26.3	17.3	559	46.4	14.4
Participant One Mean (n = 100)	129.5	88.6	37.5	532.0	−7.851123	−0.02339
Participant Two Mean (n = 100)	139.4	96.0	43.2	603.9	5.652582	1.818537
Participant Three Mean (n = 100)	129.9	87.5	39.5	520.1	−7.50161	0.124773
Participant Four Mean (n = 100)	144.6	97.1	44.4	672.6	10.75503	0.08997
Participant Five Mean (n = 100)	136.2	90.4	39.0	554.7	−1.05484	−2.00989

placed greater emphasis on studying the impact of the variability observed in the handaxe assemblage, which is the focus of the present study.

The size and strength of an individual's hand is known to impact significantly the performance of handaxes during cutting tasks (Key & Lycett 2019). As such, a series of manual biometric traits were recorded from each individual to help understand how any tool-size defined thresholds may be applied within a biologically diverse population. Note both the variety across participants and the relatively great manual strength in some individuals (Table 2). Quite understandably, we were limited to using *Homo sapiens* as participants, yet Acheulean handaxes were used by a variety of hominin species (e.g. Gallotti & Mussi 2017). It is therefore important to highlight that, although there is a dearth of manual fossil evidence for these species, including *H. erectus s.l.*, *H. heidelbergensis s.l.* and *H. antecessor*, what little we do have suggests modern human-*like* manual anatomy and proportions to be present in the hominin lineage from as early as 1.8 to 1.4 million years ago (Marzke 2013). This is broadly consistent with timings for the emergence of the Acheulean, with the two potentially being linked (Key & Lycett 2019).

Table 2. Descriptive biometric data for the five participants who undertook the experiment.

Participant	One	Two	Three	Four	Five
Grip strength (kg)	70	48	55.5	51.5	58
Tip-to-tip pinch strength (kg)	9.4	8.2	7.5	7	6
Pad-to-side pinch strength (kg)	13.7	8.1	12.1	10	11.3
Hand length (mm)	187	193	209	187	194

Experimental cutting task and recording bimanual tool use

Industrially produced materials were used to provide an ethical, replicable functional task that was identical for each handaxe, helping to control for any influence exerted by variables other than tool size (Eren *et al.* 2016). Specifically, corrugated cardboard, neoprene rubber and polypropylene rope were attached to a wooden frame, which was subsequently placed on the floor to simulate more accurately Pleistocene woodworking or butchery activities, which were likely undertaken in a kneeling position. The materials were organized on the frame in such a way that diverse cutting motions were required (e.g. slicing, piercing, sawing), helping to enact multiple ergonomic demands at the hand-tool interface. Further, the materials provided different levels of resistance and required varying precision, further adding to variability in the task (see Key & Lycett 2017a for further information). While such materials were obviously not cut by prehistoric handaxes, cutting through them does require behaviours that nonetheless mimic similar cutting actions that were likely undertaken (e.g. Jones 1980; Machin *et al.* 2007), and therefore appropriately serve to test how tool-size may limit the ability of handaxes to be used with a single hand. Indeed, as with many tasks undertaken by handaxes during the Pleistocene, the most effective way to complete the experimental cutting task was to grip the tool in the dominant hand and secure, create tension in, or otherwise manipulate the cut material with the non-dominant hand.

The participants used their assigned 100 tools across 7–10 days, using 10–15 handaxes a day. Five minutes' rest was enforced between the use of each tool, and the next tool was only used once participants felt comfortable doing so. Previous linear regression confirmed there to be no links between tool-use order and cutting performance (Key & Lycett 2017a), supporting the inference that fatigue did not significantly impact the use of tools used later each day. Fingerless gloves were worn by each participant to help prevent cuts to the palm yet facilitate direct interaction with the tool's surface.

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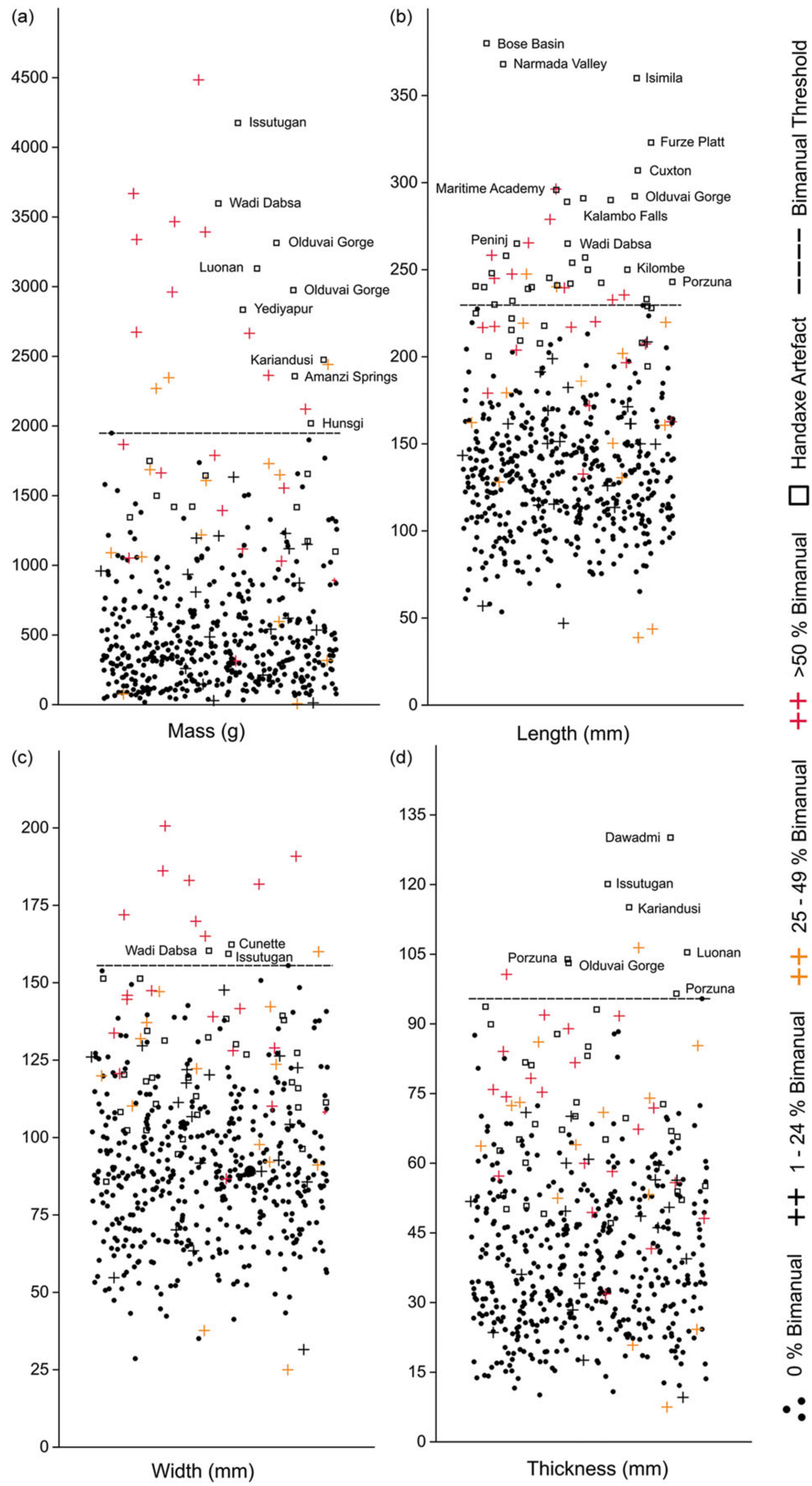

Figure 2. Jitter plots demonstrating the size variability in the experimental handaxe set relative to a series of 'giant' handaxes described in the published literature. The jitter plots of mass, length, width and thickness (a–d, respectively) highlight thresholds above which all replica tools were required to be used with two hands for a period of time.

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Instruction was given for the task to be completed 'in as quick a time as possible and that all cutting actions should be undertaken in a controlled manner' (Key & Lycett 2017a, 527).

As previously reported, the time taken to complete the cutting task was the principal metric under investigation at the point of experimentation (Key & Lycett 2017a). Here, however, we are concerned with the size threshold at which handaxes are required to be gripped with two hands. To collect these new data, we revisited the videos of each handaxe being used and recorded the number of hands securing the tool. We were not concerned with the grips used throughout the task, but instead, which handaxes can be reliably defined as bimanual tools. In turn, we recorded the length of time that either one or two hands were used to secure each tool across all cutting actions (removing time periods when a tool was readjusted or participants paused cutting for any other reason). We then converted these data into a percentage representing the amount of time each tool was secured bimanually.

Statistical analyses

This study is principally concerned with identifying whether size thresholds, beyond which handaxes become bimanual tools, existed in the Acheulean. A series of other morphometric variables are also investigated to determine whether they may play a role in the number of hands used to grip these tools. Jitter plots were used to identify bimanual thresholds for individual variables, with handaxes used with two hands for (1) 1% to 24% of the time, (2) 25% to 49% of the time and (3) ≥50% (i.e. a majority) of the time highlighted separately in each plot. To investigate whether relationships exist between the percentage of time that a tool was used bimanually and the morphometric variables of interest, Spearman's rank-order correlations were undertaken (as percentage data are not continuous) (n = 500). Finally, to identify whether significant differences in form existed between tools used bimanually for any length of time and those that were exclusively secured with a single hand, Mann-Whitney U tests were applied to these two handaxe groupings for all morphometric variables. In all instances $\alpha = 0.05$.

Comparison with archaeological examples

To contextualize any experimentally derived bimanual thresholds against realized hominin behaviour (i.e. 'giant' handaxe artefacts), artefact mass, length, width and thickness data from Acheulean biface assemblages from across Africa and Eurasia were collected. Sites were drawn from the literature or existing data held by the authors (Supplementary Table 2). Maximum values from each site were used, up to a total of three artefacts. Data were collected to investigate maximum handaxe values at a large temporal and spatial breadth and are not representative of an exhaustive review of the literature. Sites investigated include Olduvai Gorge (Tanzania), Kilombe (Kenya), Isimila (Tanzania), Amanzi Springs (South Africa), Issutugan (Somalia), Sidi Abderrahman Cunette (Morocco), Wadi Dabsa (Saudi Arabia), Porzuna (Spain), Furze Platt (UK), Maritime Academy (UK), Bose Basin (China), Luonan (China), Narmada Valley (India), Hunsgi (India) and Chuwoli (South Korea), among others (Fig. 3).

Results

Out of the 500 replica handaxes, 53 were used bimanually for a period of time. Of these, 18 were used with two hands for 1–24% of the time, 16 for 25–49% of the time, while 19 were used bimanually for the majority of the time (i.e. ≥50% of the time taken). Tool size was a clear determining factor, with both extremely large and extremely small handaxes requiring two hands (Fig. 2). Four handaxes at the extreme-diminutive end of the size scale (<100g; n = 38) required two hands, as did 22 of those over 1.5 kgs (n = 38). Correlation analyses returned significant and strong positive correlations for the four size variables, demonstrating that larger tools more often require the use of two hands for greater lengths of time (Fig. 4; Table 3). Conversely, the two size-related PC correlations were not significant, suggesting relationships between handaxe size and bimanual gripping to be more strongly traceable via univariate scaling metrics (Table 3). Elongation, refinement, PC1 (shape), PC2 (shape) and the positions of maximum length and width did not return significant correlations (Table 3), suggesting these attributes have little impact on determining whether handaxes are used bimanually. In turn, tool size alone appears to be driving this ergonomic relationship.

Mann-Whitney U tests confirmed the handaxes requiring bimanual tool use (for any duration) to be significantly greater in size relative to those used exclusively with one hand for mass, length, width and thickness (Table 4). The size principal components again differed in this regard, with no significant differences being noted (Table 4), again suggesting that handaxe length, width and thickness are better determinants of bimanual gripping compared to multivariate records of tool size. The other six variables of interest returned no significant differences between these two groups (Table 4). These data further support the inference that tool size alone is impacting whether handaxes require one or two hands during use.

Figure 2 highlights the size thresholds beyond which handaxes were required to be used with two hands. Those recruiting two hands for 1–24%, 25–49% and ≥50% of the time are highlighted separately as black, yellow and red '+' markers. For handaxe mass, length and width there appear to be clear size thresholds beyond which tools can only be used if two hands are utilized (Fig. 2). These thresholds occur at c. 2 kg (mass), 230 mm (length) and 155 mm (width). Thickness does not appear to display a clear threshold in our experiment, with only two bimanually used tools being present a short distance beyond unimanually gripped tools (Fig. 2). A plot of PC1 (size) against PC2 (size) demonstrates a similar threshold, with almost all tools outside of the 95% ellipses (i.e. the extreme forms) being gripped bimanually (Fig. 5). Thus, despite individual PC data not displaying a significant relationship between bimanual gripping and tool size in the correlation and Mann-Whitney U tests, when PC1 and PC2 are plotted a clear size-dependent pattern emerges. This would suggest that the clustering of the majority of handaxes around the centroid of the plot weakens the visibility of the relationship between

Figure 3. Location of Acheulean sites displaying 'giant' handaxes according to the thresholds identified in this study. Note that this is not an exhaustive list of sites. It is used here to illustrate the diversity of locations where these tools are found. (Image: NASA Visible Earth Project.)

extreme artefact size and two-handed grip use at the level of the entire assemblage in these other analyses.

Comparison with archaeological examples

For all artefact size attributes investigated, it is clear that Acheulean hominins were widely (spatially and temporally) producing handaxes above the bimanual size thresholds identified here (Figs 2a–2d; Fig. 3). A large number of archaeological examples were identified for length, thickness and mass from across Africa, Asia and Europe. Fewer artefacts above the width threshold were identified within the literature. The great majority of tools within many ancient series, such as Kilombe (Kenya) and Porzuna (Spain), fall within the range that are generally used in a single hand, with only a few 'giant' artefacts. Figure 5 shows that there is a large central zone (grey) in which the experiments suggest use would be single-handed.

Taking Kilombe as an exemplar site, it is typical of the African Acheulean in the time range ~1.5–0.5 Ma, but larger mean values for length and weight appear in some assemblages elsewhere. The Olorgesailie (Kenya) catwalk site offers a noteworthy example (Isaac 1977). At Kilombe, Length does not allow easy discrimination between localities, since the means for all areas fall in the range 13–16 cm. Mass, however, shows greater variation from area to area, with an indication that there may be modes at *c.* 300 g, 600 g and >800 g. Such (multivariate) modes cannot be disentangled with total certainty because of the general mixing of bifaces in an assemblage, but may be indicative of varying production emphases through time and space. Wishart's Mode analysis in Kilombe EH isolated a mode with length 163±22 mm (N=80) and one of 108±12 mm (Gowlett 1988). Unfortunately, Wishart's Mode was not incorporated in later versions of Clustan, and data for mass were not available when the original analysis was done. But if all bifaces within the length limits above (at one sd) are selected from the now much larger Kilombe dataset, mean values for available mass data are 560 g (N=164) and 227 g (N=62) respectively—both of these fall squarely within the grey zone of Figure 5, but they could indicate preferences of 'always single handed use' and 'sometimes double handed use'. Some sites display no 'giant' specimens (e.g. Boxgrove, UK), and others, such as Kariandusi (Kenya), employ different production methods (e.g. raw materials—obsidian and lava) for larger and smaller handaxes. The likelihood of an overlap zone, with some specimens used single-handed or double-handed according to context, is a confounding factor in determining bimanual handaxes.

Discussion

'Giant' handaxes are rare in the Acheulean archaeological record, meaning their production requires explanation beyond adherence to population-level utilitarian and ergonomic

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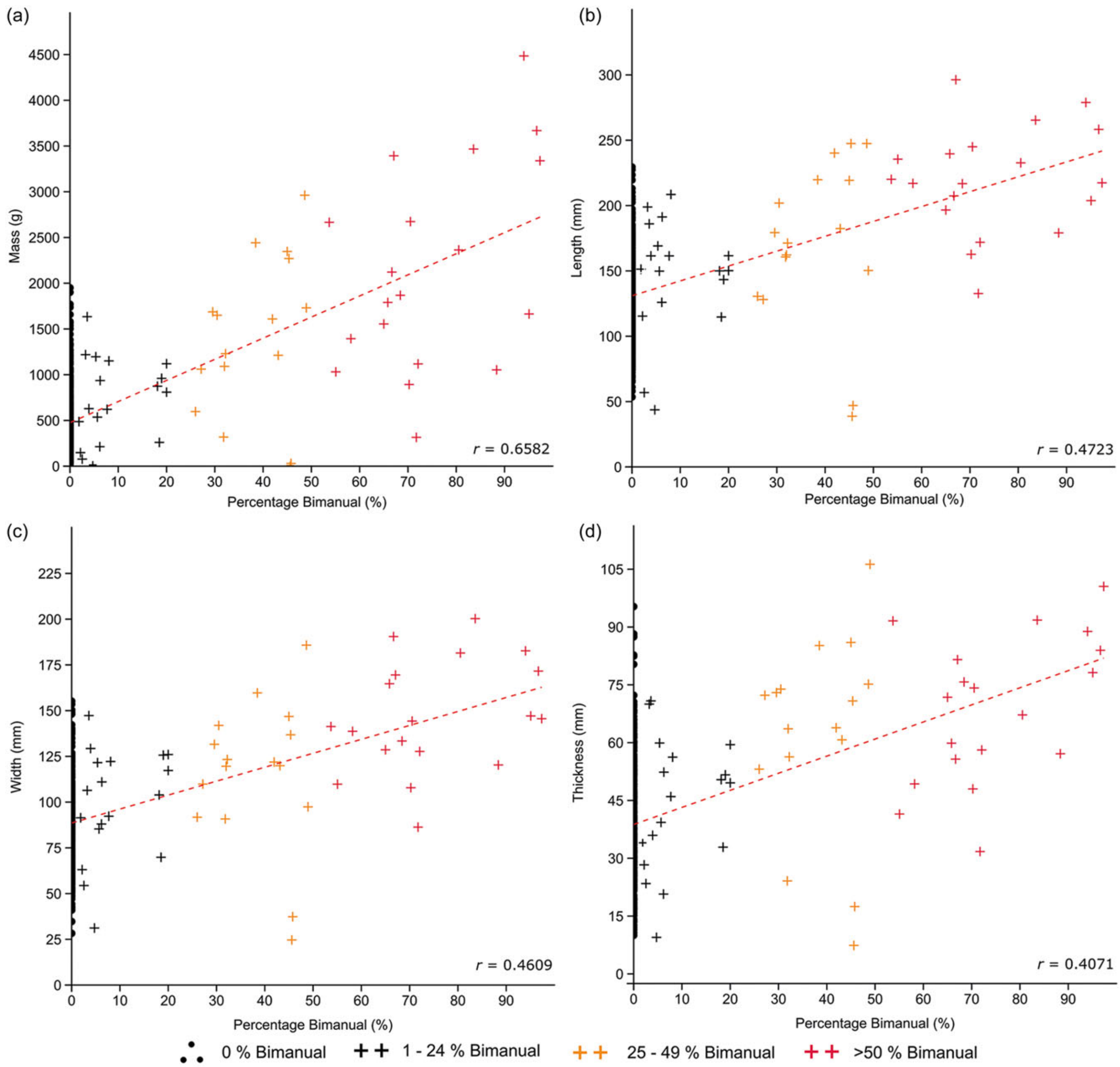

Figure 4. Correlation of the percentage of time that each replica handaxe (n = 500) was used bimanually against the size attributes of mass (g), length (mm), width (mm) and thickness (mm). Results illustrate that the larger the handaxe, the more likely it is to have been gripped with two hands.

selective pressures (Wynn & Gowlett 2018). This does not mean their presence within past landscapes was unusual—a wealth of sites across Africa, Europe and Asia demonstrate their recurrent presence across broad temporal ranges and taxonomic groupings—but even so, individuals infrequently produced such tools relative to smaller biface forms (Fig. 6). Our data highlight two important points relevant to understanding the production of giant handaxes by extinct hominins.

1) There are size thresholds beyond which handaxes become too large to use with a single hand, meaning tools above this point may not have been used in the standard butchery and woodworking settings that are most often associated with Acheulean bifaces (i.e. held in the dominant hand, while the non-dominant secures the worked material). Alternative explanations for their production—be they utilitarian, social or other—must, therefore, be sought.

2) Numerous and diverse Acheulean sites exhibit handaxe artefacts above these thresholds. The alternative selective pressures driving the production of 'giant' handaxes would, therefore, have been present across a broad range of hominin populations, species and ecologies.

Clarifying definition: What are 'giant' handaxes?

'Giant' seems as good a term as any for such artefacts, but applying strict morphological criteria to the definition of these tools is difficult given a lack of anatomical and ergonomic

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Table 3. Spearman's rank-order correlations (α = 0.05) between the ten morphometric variables of interest and the percentage of time that handaxes were used bimanually (n = 500). Significant results are highlighted in **bold**.

	r	r^2	p
Mass	0.6582	0.4332	**<0.0001**
Length	0.4723	0.2231	**<0.0001**
Width	0.4609	0.2124	**<0.0001**
Thickness	0.4071	0.1658	**<0.0001**
Position of Max. Width	0.0179	0.0003	0.6920
Position of Max. Thickness	−0.0009	<0.0001	0.9838
Elongation	0.0002	0.0002	0.7336
Refinement	−0.0153	0.0116	0.1617
PC1 (Size)	−0.0308	0.0009	0.4911
PC2 (Size)	−0.0760	0.0058	0.8945
PC1 (Shape)	−0.0310	0.0010	0.4889
PC2 (Shape)	−0.0877	0.0077	0.4993

Table 4. Mann-Whitney U significance values (α = 0.05) between handaxes that required bimanual tool use (n = 53) and those that were exclusively used with one hand (n = 447) across the ten morphometric variables of interest. Significant results are highlighted in **bold**.

	p
Mass	**<0.0001**
Length	**<0.0001**
Width	**<0.0001**
Thickness	**<0.0001**
Position of Max. Width	0.5507
Position of Max. Thickness	0.5202
Elongation	0.6348
Refinement	0.0122
PC1 (Size)	0.5076
PC2 (Size)	0.1053
PC1 (Shape)	0.5096
PC2 (Shape)	0.1046

knowledge concerning Acheulean groups. Indeed, vital to these and other behavioural interpretations of Acheulean bifaces is knowledge of the manual anatomy of the tool producer/user (Fedato *et al.* 2024; Key & Dunmore 2018; Key & Lycett 2023). The normal distributions observed in Acheulean biface morphologies may even be underpinned by the normal distribution observed in hominin anatomy. Our data may broadly align with *H. erectus* and other hominin species with similar hypothesized or demonstrated manual proportions, strength and dexterity to *H. sapiens* (Marzke 2013), but more diminutive species or those with less derived manual anatomy could have displayed alternative, perhaps smaller, thresholds.

We also acknowledge that some Acheulean individuals were probably stronger than the participants in our study and, therefore, may have been capable of using larger handaxes for generalized cutting tasks with one hand. Indeed, alignment of hand size and grip data with bimanual gripping percentages (Supplementary Figure 1) tentatively suggest a stronger grip results in higher bimanual gripping thresholds. However, it is important to emphasize that individuals exhibiting relatively high manipulative strength were deliberately recruited for the experiment (Key & Lycett 2017a), suggesting our results plausibly have validity for detecting population-level thresholds. Moreover, it is important to note that the archaeological 'giants' identified here (i.e. artefacts above our experimentally determined thresholds) regularly equalled or exceeded the two strongest predictors of bimanual use, mass (2 kg) and length (230 mm) respectively. Accordingly, our experiment identifies generalized thresholds of mass and size by which hominins might potentially have conceived of handaxes as 'giants'. Mass may over-proportionately determine the economic thresholds identified here, given it significantly correlates with length, width and thickness (Pearson *r*; *p*=<.0001 in all instances; *r* = .6597–.8495) and creates the gravitational force muscles must work against, but this simplified model does not account for torque (Key & Lycett 2020) and mass variation along the length or width of a tool.

'Giant' handaxes do not seem to represent distinct metrical modes (nor do, similarly, small ones), rather being the extreme tails of length, thickness and mass spectra that, as noted above, approximate normal distributions. These extreme forms do not represent a fundamental division into single- and double-handed use. Instead, two hands may have been used in varying proportions depending on the task undertaken, the individual using the tool, or any fatiguing accrued. While wider tools do more frequently recruit bimanual grips, few artefacts were identified above our 155 mm threshold, suggesting a steep selective tail to handaxe width. Given the correlations between increasing handaxe size and grip choice (Fig. 4), if an artefact displays multiple size variables approaching, at, or above our thresholds, it suggests the likelihood of bimanual gripping to be magnified. Alternatively, if a tool displays one extreme variable but more regular proportions for other variables, bimanual tool use may be less likely. Quite unexpectedly, our data also reveal some of the smallest handaxes in the replica assemblage to have required two hands during their use. This most likely derives from the need to exert a degree of force while maintaining a secure grip (Key *et al.* 2018; Marzke 1997). Acheulean bifaces of this size (e.g. <6 cm in length) are rare although well attested (Gowlett *et al.* 2017), but are again less likely to have been used during 'standard' handaxe cutting tasks where the non-dominant hand is required to secure the worked material. Alternative explanations for their production may, therefore, be sought, although it is important to note that no clear lower bimanual thresholds are revealed in our data.

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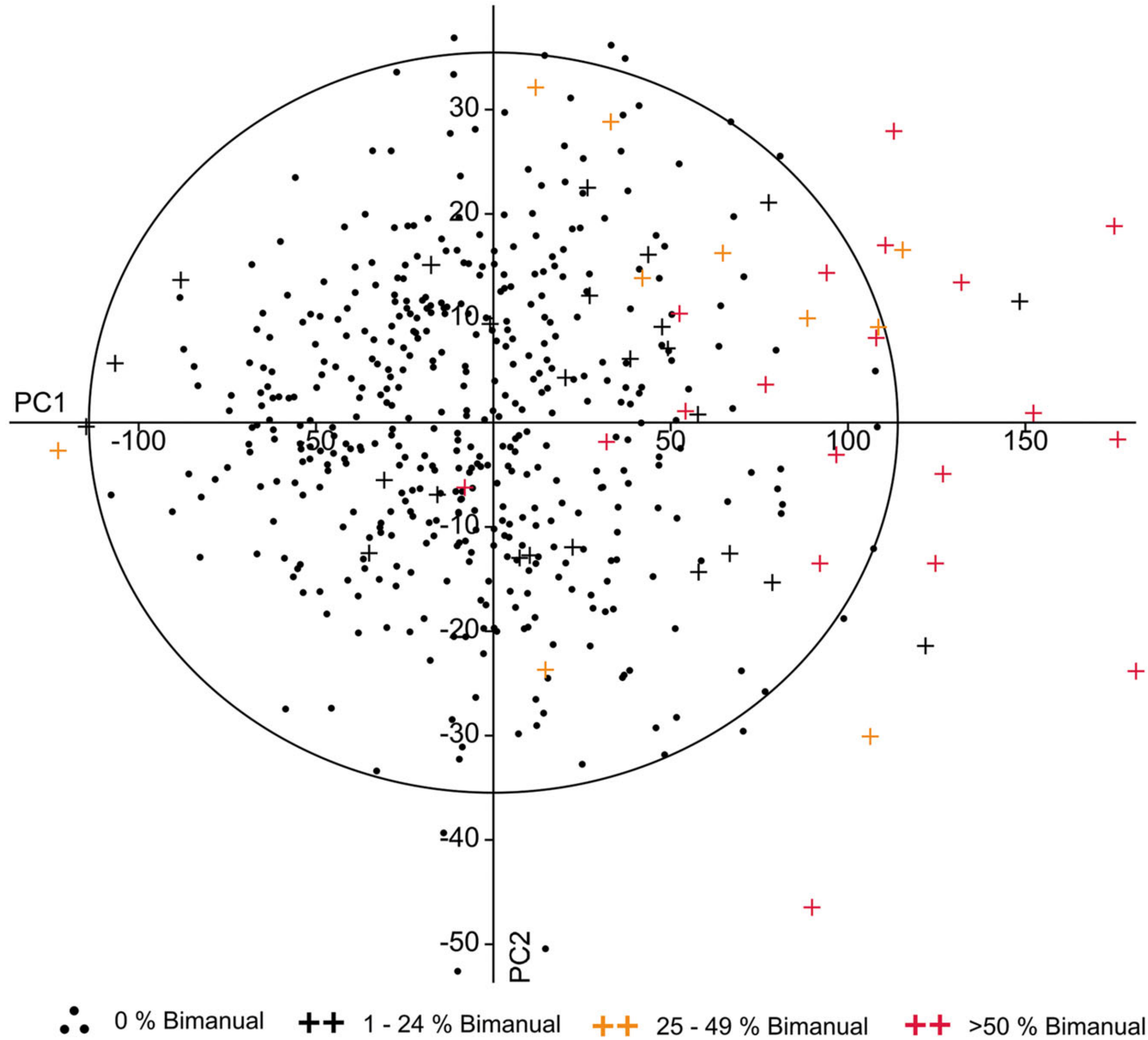

Figure 5. A scatter plot of PC1 (size) against PC2 (size) demonstrates that many of the bimanually used tools (crosses) lay outside the size range exhibited for tools used exclusively with one hand (dots). The circular line highlights the 95% ellipse. PC1 and PC2 explain 87% and 8% of the total variation, respectively. PC1 is most highly loaded by length (0.807), followed by width (0.517) and thickness (0.285). PC2 is loaded towards width (0.628), length (–0.584) and thickness (0.515).

Why were 'giant' handaxes produced?

It is our proposition that the production of handaxes above these bimanual thresholds was due to infrequently observed functional and/or social requirements within hominin groups. This does not preclude smaller bifaces also having had these roles, but our data attest to an increased likelihood of unusually large handaxes being produced for such purposes. In turn, these artefacts may represent distinct modes in terms of the effort required for their manufacture and/or use. We consider a likely role for 'giant' handaxes to have been cutting tools applied within diverse utilitarian contexts, a conclusion not too dissimilar to interpretations of smaller Acheulean bifaces (Key & Lycett 2017b; Kuhn 2020; Shea 2007). The difference lies in *how* these bifaces could have been used.

First, large bifaces could have been used as digging tools, with two hands securing them on each side and thrusting them into soil, sand, or other sediment (Khaksar & Modarres 2024; Phillipson 1997; Posnansky 1959). Tubers, burrowing animals, eusocial insects and other underground resources are present across broad ecological and spatial ranges, possibly explaining why 'giant' handaxes are a widely observed phenomenon. Their low frequencies within assemblages would in turn, however, suggest digging activities to be rare if it was exclusively undertaken with large handaxes, and digging sticks could plausibly be more effective; albeit the latter point requires experimental testing. Additionally, however, and drawing on observations by Zupancich and Proffitt (2014), these artefacts may have been used as stationary cutting tools or 'planes' where

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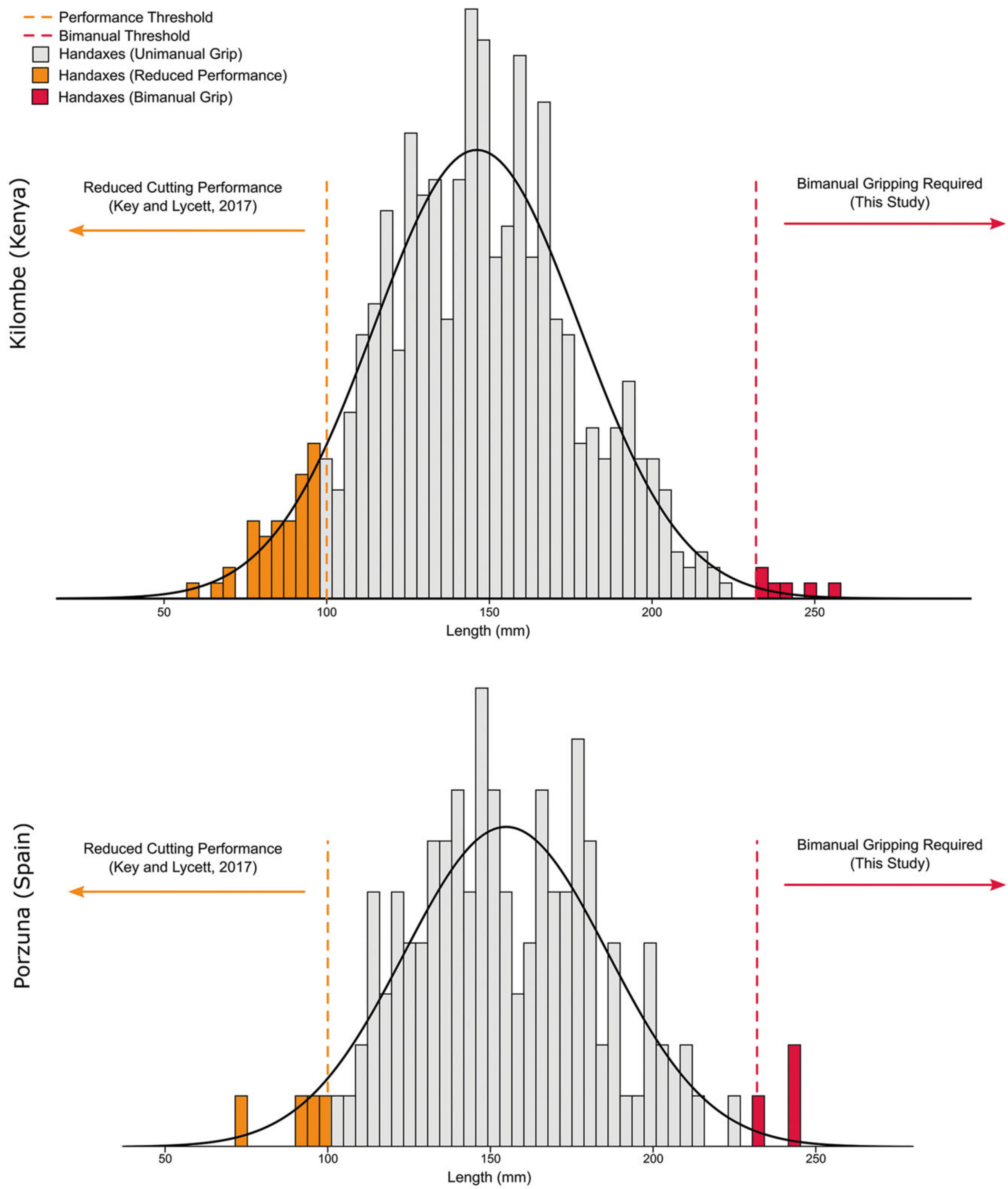

Figure 6. Length (mm) data for handaxes from Kilombe, Kenya (n = 615) (Gowlett *et al.* 2023) and Porzuna, Spain (n = 133) (Arroyo *et al.* 2019). Highlighted in red are artefacts above the size threshold potentially indicating a shift in functional role (e.g., digging, stationary plane) or social signalling. Note that both the performance and bimanual thresholds are task and individual dependent (including age) (see Supplementary Figure 1).

the handaxe was secured into/onto the ground and one sharp edge was positioned superiorly and parallel to the ground, with worked materials (of any type) secured in two hands and drawn across this edge (Foulds *et al.* 2017; Kleindienst & Keller 1976). Such technologies allow for excellent cutting precision with rapid, repetitive movements, given the ability to manoeuvre worked materials easily and apply them with force to an edge. If one edge of a 'giant' biface were secured into the ground and

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between the knees, substantial force could have been applied onto its working edge; potentially more than could be achieved through unimanual handaxe use. The bifacial edges on these tools, which are potentially more durable than unmodified stone edges, may have promoted their use in this way over very large flakes. Further, core-axes, such as those described by J.D. Clark at Kalambo Falls), sometimes lack a sharp edge down the sides, suggesting that they were used in heavy pounding. Finally, for cutting tasks requiring reduced precision, such as modifying large portions of wood (e.g. Barham *et al.* 2023), a very large sharp-edged tool secured with two hands could effectively be used as a chopping or slicing tool, so long as the worked material was secured by another individual or in another way, as previously demonstrated (Eren *et al.* 2024; Gingerich & Stanford 2018; Jones 1980; Key & Lycett 2017a). Indeed, it is noteworthy that in African handaxes the average point of maximum breadth shifts forward in larger specimens, perhaps suggesting forward support by a second hand (Crompton & Gowlett 1993; Gowlett 2006). Handaxes previously assumed to be too large to use (Diez-Martín *et al.* 2019; Hodgson 2017; Overmann & Wynn 2019) may, in fact, have been recurrently, if infrequently, used as cutting tools.

From the viewpoint of parsimony, given that there are multiple, plausible utilitarian task-related explanations for why Acheulean hominins might have been motivated to produce giant handaxes, we might be tempted to favour these over alternative explanations. Given that 'giant' handaxes were produced across broad swathes of time and space, social explanations would also imply shared or similar mechanisms operating across disparate hominin populations and even different species, further complicating this scenario. This alone does not automatically preclude social roles for 'giant' handaxes, either alongside utilitarian functions (e.g. woodworking, digging, butchery) or as the primary factor driving their production, but it does mean this possibility is less parsimonious than utilitarian explanations. Indeed, these artefacts likely do not have a single explanation. It is also worth restating that while social hypotheses for Acheulean bifaces cannot be falsified, data support that Late Acheulean populations displayed complex social behaviours (Gowlett 2021; Overmann & Wynn 2019), and our data highlight that these tools were likely not produced for the routine tasks determining the distributions typically seen in large handaxe assemblages (Fig. 6).

At a minimum, their infrequent production and large size would have signalled a departure from more regular tool production. In a functional context, this could have signalled a specific type of material processing task was being undertaken. For example, if 'giant' handaxes were linked to processing seasonally available plants, the availability of these resources would have been evident as a by-product of the tool's presence. Other social signalling hypotheses outlined above and elsewhere do, therefore, require careful consideration in light of our data. For example, only six handaxes out of 615 from Kilombe, Kenya (Gowlett *et al.* 2023; Key & Gowlett 2022), are above our bimanual threshold for length (Fig. 6), highlighting their scarcity in these past landscapes and the ease with which they would have stood out to other individuals (with a non-biodegradable permanency), increasing their semiotic potential (Pope *et al.* 2006). Indeed, increased size automatically increases the visibility of an artefact on a relative basis (Carr 1995) and there are ethnographic examples where artefact visibility is a trait deliberately exploited and co-opted for communicative purposes, even where the primary function is a utilitarian one (e.g. Lycett 2015; Wobst 1977).

Although the very small and very large handaxes may not stand out as distinct statistical modes, the experimental findings highlight that these specimens require 'special attention'. The small examples require a strong focus of concentration for their manufacture; the large ones require obtaining a suitable size of blank—sometimes needing to be deliberately struck—and their trimming feasibly requires more work and judgement. These aspects draw attention to the possible symbolic component in the manufacture of extremes-of-the-range handaxes. The semiotic ideas mentioned above imply that 'something' is to be signalled. Sexuality, or importance of the individual (power) are two linked possibilities. Interestingly, in the 'sexy handaxe' hypothesis, Kohn and Mithen (1999) do not specify in exact terms what makes an exceptional handaxe, whether a specific size or level of symmetry or finish. Exceptional finish, or selection of material, could sometimes outweigh size as the main vehicle of signalling. Yet the special attention just mentioned can itself be seen as a form of symbolism (possibly as in the preparation of clipped leaves by chimpanzees: Badihi *et al.* 2023). The detailed preparation may be done for a purpose that need not relate to effective physical function, although exceptional tasks remain a possibility. It is possible that the special needs of accommodating exceptional tasks were a driver in the emergence of symbolism focused on artefacts.

An under-discussed issue when considering the phenomenon of giant handaxes is a potential for 'cultural lock-in' whereby culturally instilled and practised, habitual routines of knapping may have been applied even when dealing with atypically large (for handaxes) nodules or boulders for the production of flakes. Hence, even when dealing with a relatively large raw material source, the reliance on deeply instilled know-how and ingrained habits may have caused large 'cores' occasionally to resemble 'handaxes' only incidentally. This possibility may have greater relevance in earlier or cruder Acheulean biface forms, since more heavily shaped tools, such as the Maritime Academy ficron (Fig. 1), reveal increased intention on the part of the tool producer (Clark *et al.* 2024; Flanders & Key 2023; García-Medrano *et al.* 2018). A potential role for such cultural lock-in mechanisms is highlighted in experimental studies involving non-human primates, where they will stick to learned behavioural rules they know will solve a problem presented in a food-reward task, even when that problem is removed from the task (Seed & Byrne 2010, 1034). Anecdotally, we might even recognize instances in our own lives whereby we rely on a habit that—through familiarity—will permit us to 'get the job done' even though it may not be the optimal solution, whether we consciously reflect on this or not. Gould (1980), for example, highlighted how behavioural inertia has prevented abandonment of the QWERTY keyboard that appears on contemporary computers and smartphones, despite the fact that this arrangement of keys is a vestigial relict of mechanical typewriters, not one designed for optimal speed or ease of typing. In some circumstances, such suboptimal solutions can actually be adaptive if they are less costly than switching to unfamiliar alternatives. As we have noted, this is not to say that cultural lock-in can explain (away) all giant handaxes, but it might explain the existence of some. Again, we may be dealing with a phenomenon that does not have a universally applicable explanation.

Conclusion

Our experiment identifies the size and mass threshold beyond which bifaces become too large to use with a single hand; most clearly, tools above *c.* 2 kg in mass and 230 mm in length (although these thresholds would have been dependent on the individual). We also reveal Acheulean hominins recurrently to have produced bifaces above these size thresholds across large swathes of time and space, meaning the selective pressures guiding the production of such large tools influenced the decisions of multiple hominin species in diverse ecologies and climates.

Alternative functional roles and cultural lock-in notwithstanding, it is handaxes above the size thresholds identified here that are most likely to have displayed the greatest potential for social signalling roles within past Acheulean populations. Social roles are, however, hypothesized and although they have possible support in the fine finish of some specimens, it is entirely plausible that most large handaxes were never intentionally used to convey signals to other hominins, or they only did so as a byproduct of their production for other purposes. There is no doubt, however, that handaxes were regularly used as cutting tools (Key & Lycett 2017b; Shea 2007; Wynn & Gowlett 2018). It is completely feasible that 'giant' handaxes were routinely used to cut, split, dig or otherwise modify aspects of a hominin's physical environment.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0959774325100127

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References

Arroyo, A., T. Proffitt & A. Key, 2019. Morphometric and technological analysis of Acheulean large cutting tools from Porzuna (Ciudad Real, Spain) and questions of African affinities. *Journal of Archaeological Science: Reports* 27, 101992.

Atkins, T., 2009. *The Science and Engineering of Cutting*. Amsterdam: Butterworth-Heinemann.

Badihi, G., K.E. Graham, B. Fallon, *et al.*, 2023. Dialects in leaf-clipping and other leaf-modifying gestures between neighbouring communities of East African chimpanzees. *Scientific Reports* 13(1), 147.

Barham, L., G.A.T. Duller, I. Candy, *et al.*, 2023. Evidence for the earliest structural use of wood at least 476,000 years ago. *Nature* 622, 107–11.

Bello, S.M., 2021. Boning up on Neanderthal art. *Nature Ecology and Evolution* 5, 1201–2.

Carr, C., 1995. A unified middle range theory of artifact design, in *Style, Society, and Person: Archaeological and ethnological perspectives*, eds C. Carr & J.E. Neitzel. New York: Plenum Press, 171–258.

Chase, P. & H. Dibble, 1987. Middle Paleolithic symbolism: a review of current evidence and interpretations. *Journal of Anthropological Archaeology* 6, 263–96.

Chauhan, P.R., 2009. The Lower Palaeolithic of the Indian subcontinent. *Evolutionary Anthropology* 18, 62–78.

Chauhan, P. 2010. Metrical varibility between South Asian handaxe assemblages: preliminary observations, in *New Perspectives on Old Stones*, eds S.J. Lycett & P.R. Chauhan. Cham: Springer, 119–66.

Clark, J., C. Shipton, H.-M. Moncel, P.R. Nigst & R.A. Foley, 2024. When is a handaxe a planned-axe? Exploring morphological variability in the Acheulean. *PLoS One* 19(7), e0307081.

Courtenay, L.A. 2023. Exploring the reliability of handaxe morphological analyses in 2D: a simulation-based approach. *Archaeological and Anthropological Sciences* 15, 102.

Crompton, R.H. & J.A.J. Gowlett, 1993. Allometry and multidimensional form in Acheulean bifaces from Kilombe, Kenya. *Journal of Human Evolution* 25, 175–99.

Dale, L., A. Rawlinson, P. Knowles, *et al.*, 2024. Big enough to matter: on the frequency and chronology of giant handaxes in the British Lower Palaeolithic. *Antiquity* 98, 305–22.

Davis, D.D. 1980. Further consideration of the Developed Oldowan at Olduvai Gorge. *Current Anthropology* 21(6), 840–43.

Diez-Martín, F., T. Wynn, P. Sanchez-Yustos, *et al.*, 2019. A faltering origin for the Acheulean? Technological and cognitive implications from FLK West (Olduvai Gorge, Tanzania). *Quaternary International* 526, 49–66.

Emery, K., 2010. A Re-examination of Variability in Handaxe Form in the British Palaeolithic. Unpublished PhD thesis, University College London.

Eren, M.I., S.J. Lycett, R.J. Patten, B. Buchanan, J. Pargeter & M.J. O'Brien, 2016. Test, model, and method validation: the role of experimental stone artifact replication in hypothesis-driven archaeology. *Ethnoarchaeology* 8(2), 103–36.

Eren, M.I., M.R. Bebber, L. Mukusha, *et al.*, 2024. Experimental bison butchery using replica hafted Clovis fluted points and large handheld flakes. *Journal of Archaeological Science: Reports* 55, 104480.

Fedato, A., M. Silva-Gago, M. Terradillos-Bernal, R. Alonso-Alcade & E. Bruner, 2024. The influence of hand dimensions on finger flexion during Lower Paleolithic stone tool use in a comfortable grip. *Quaternary* 7(3), 29.

Flanders, E. & A. Key, 2023. The West Tofts handaxe: a remarkably average, structurally flawed, utilitarian biface. *Journal of Archaeological Science* 160, 105888.

Foulds, F.W.F., A. Shuttleworth, A. Sinclair, *et al.*, 2017. A large handaxe from Wadi Dabsa and early hominin adaptations within the Arabian Peninsula. *Antiquity* 91, 1421–34.

Gallotti, R. & M. Mussi, 2017. Two Acheuleans, two humankinds: from 1.5 to 0.85 Ma at Melka Kunture (Upper Awash, Ethiopian highlands). *Journal of Anthropological Sciences* 95, 137–81.

García-Medrano, P., A. Ollé, N. Ashton & M.B. Roberts, 2018. The mental template in handaxe manufacture: new insights into Acheulean lithic technological behavior at Boxgrove, Sussex, UK. *Journal of Archaeological Method and Theory* 26, 396–422.

García-Medrano, P., M.-H. Moncel, E. Maldonado-Garrido, A. Olle & N. Ashton, 2023. The western European Acheulean: reading variability at a regional scale. *Journal of Human Evolution* 179, 103357.

Gingerich, J.A.M. & D.J. Stanford, 2018. Lessons from Ginsberg: an analysis of elephant butchery tools. *Quaternary International* 466 (Part B), 269–83.

Gould, S.J., 1980. *The Panda's Thumb: More reflections in natural history*. New York: W.W. Norton & Co.

Gowlett, J.A.J., 1988. A case of Developed Oldowan in the Acheulean? *World Archaeology* 20(1), 13–26.

Gowlett J.A.J., 2005. Seeking the Palaeolithic individual in East Africa and Europe during the Lower-Middle Pleistocene, in *The Hominid Individual in Context: Archaeological investigations of Lower and Middle Palaeolithic landscapes, locales and artefacts*, eds C.S. Gamble & M. Porr. London: Routledge, 50–67.

Gowlett, J.A.J., 2006. The elements of design form in Acheulian bifaces: modes, modalities, rules and language, in Axe Age: Acheulian toolmaking from quarry to discard, eds N. Goren-Inbar & G. Sharon. London: Equinox, 203–21.

Gowlett, J.A.J., 2009. Artefacts of apes, humans and others: towards comparative assessment. *Journal of Human Evolution* 57, 401–10.
Gowlett, J.A.J., 2013. Elongation as a factor in artefacts of humans and other animals: an Acheulean example in comparative context. *Philosophical Transactions of the Royal Society B* 368(20130114), 1–11.
Gowlett, J.A.J., 2021. Deep structure in the Acheulean adaptation: technology, sociality and aesthetic emergence. *Adaptive Behavior* 29(2), 197–216.
Gowlett, J.A.J., J.S. Brink, A.I.R. Herries, S. Hoare & S.M. Rucina, 2017. The small and short of it: mini-bifaces and points from Kilombe, Kenya, and their place in the Acheulean, in *Vocation Préhistoire: Hommage à Jean-Marie Le Tensorer*, eds D. Wojtczak, M. Al Najjar, R. Jagher, H. Elsuede & F. Wegmüller. (ERAUL 148.) Liège: Université de Liège, 121–32.
Gowlett, J.A.J., A.I.R. Herries, S. Hoare, S.M. Rucina & I.G. Stanistreet, 2023. Kilombe volcano, in *Handbook of Pleistocene Archaeology of Africa*, eds A. Beyin, D.K. Wright, J. Wilkins & D. Olszewski. Cham: Springer, 577–93.
Herzlinger, G. & N. Goren-Inbar, 2020. Beyond a cutting edge: a morpho-technological analysis of Acheulian handaxes and cleavers from Gesher Benot Ya'aqov, Israel. *Journal of Palaeolithic Archaeology* 3, 33–58.
Herzlinger, G., A. Varanda, M. Deschamps, M. Brenet, C. Lopez-Tascon & N. Goren-Inbar, 2021. Reevaluation of the classification scheme of the Acheulian in the Levant – 50 years later: A morpho-technological analysis of handaxe variability. *PaleoAnthropology* 2021(1), 23–84.
Hobaiter, C. & R.W. Byrne, 2014. The meanings of chimpanzee gestures. *Current Biology* 24(14), 1596–1600.
Hodgson, D., 2015. The symmetry of Acheulean handaxes and cognitive evolution. *Journal of Archaeological Science: Reports* 2, 204–8.
Hodgson, D., 2017. Costly signalling, the arts, archaeology and human behaviour. *World Archaeology* 49(4), 446–65.
Ingrey, L., S.M. Duffy, M. Bates, A. Shaw & M. Pope, 2023. On the discovery of a late Acheulean 'giant' handaxe from the Maritime Academy, Frindsbury, Kent. *Internet Archaeology* 61. doi.10.11141/ia.61.6
Iovita, R. & S.P. McPherron, 2011. The handaxe reloaded: a morphometric reassessment of Acheulian and Middle Paleolithic handaxes. *Journal of Human Evolution* 61(1), 61–74.
Isaac, G.L., 1977. *Olorgesailie: Archeological studies of a Middle Pleistocene lake basin in Kenya*. Chicago (IL): Chicago University Press.
James, H.V.A. & M.D. Petraglia, 2005. Modern human origins and the evolution of behaviour in the later Pleistocene record of south Asia. *Current Anthropology* 46, S3–S27.
Jones, P.R., 1980. Experimental butchery with modern stone tools and its relevance for Palaeolithic archaeology. *World Archaeology* 12(2), 153–65.
Kempe, M., S. Lycett & A. Mesoudi, 2012. An experimental test of the accumulated copying error model of cultural mutation for Acheulean handaxe size. *PLoS One* 7(11), e48333.
Key, A.J.M. 2019. Handaxe shape variation in a relative context. *Comptes Rendus Palevol* 18(5), 555–67.
Key, A.J.M. & C.J. Dunmore, 2018. Manual restriction on Palaeolithic technological behaviours. *PeerJ* 6, e5399.
Key, A. & J.A.J. Gowlett, 2022. Intercomparison of a million-year-old and modern replicated handaxe set. *Lithic Technology* 48(3), 253–69.
Key, A.J.M. & S.J. Lycett, 2017a. Influence of handaxe size and shape on cutting efficiency: a large-scale experiment and morphometric analysis. *Journal of Archaeological Method and Theory* 24, 514–41.
Key, A.J.M. & S.J. Lycett, 2017b. Form and function in the Lower Palaeolithic. *Journal of Anthropological Science* 95, 67–108.
Key, A.J.M. & S.J. Lycett, 2019. Biometric variables predict stone tool functional performance more effectively than tool-form attributes: a case study in handaxe loading capabilities. *Archaeometry* 61(3), 539–55.
Key, A. & S.J. Lycett, 2020. Torque creation and force variation along the cutting edges of Acheulean handaxes: implications for tip thinning, resharpening and tranchet flake removals. *Journal of Archaeological Science* 120, 105189.
Key, A. & S.J. Lycett, 2023. The ergonomics of stone tool production and use, in *The Oxford Handbook of Cognitive Archaeology*, eds T. Wynn, K.L. Overmann & F.L. Coolidge. Oxford: Oxford Academic Press, 771–96.
Key, A., S.R. Merritt & T.L. Kivell, 2018. Hand grip diversity and frequency during the use of Lower Palaeolithic stone cutting-tools. *Journal of Human Evolution* 125, 137–58.
Khaksar, S. & R. Modarres, 2024. How good are giant handaxes in utilitarian functions? An experimental assessment. *Journal of Archaeological Science: Reports* 53, 104301.
Kleindienst, M.R. & C.M. Keller, 1976. Towards a functional analysis of handaxes and cleavers: the evidence from Eastern Africa. *Man* 11, 176–87.
Kohn, M. & S. Mithen, 1999. Handaxes: products of sexual selection. *Antiquity* 73, 518–26.
Kuhn, S.L. 2014. Signalling theory and technologies of communication in the Paleolithic. *Biological Theory* 9, 42–50.
Kuhn, S.L., 2020. *The Evolution of Paleolithic Technologies*. London: Routledge.
Leakey, M.D., 1971. *Olduvai Gorge: Excavations in Beds I and II, 1960–1963*. Cambridge: Cambridge University Press.
Lycett, S.J. 2008. Acheulean variation and selection: does handaxe symmetry fit neutral expectations? *Journal of Archaeological Science* 35(9), 2640–48.
Lycett, S.J., 2015. Differing patterns of material culture intergroup variation on the high plains: quantitative analyses of parfleche characteristics vs. moccasin decoration. *American Antiquity* 80(4), 714–31.
Lycett, S.J., K. Schillinger, M.I. Eren, N. von Cramon-Taubadel & A. Mesoudi, 2016. Factors affecting Acheulean handaxe variation: experimental insights, microevolutionary processes, and macroevolutionary outcomes. *Quaternary International* 411(Part B), 386–401.
Lycett, S.J. & N. von Cramon-Taubadel, 2015. Toward a 'quantitative genetic' approach to lithic variation. *Journal of Archaeological Method and Theory* 22, 646–75.
Lycett, S.J., N. von Cramon-Taubadel & R.A. Foley, 2006. A crossbeam co-ordinate caliper for the morphometric analysis of lithic nuclei: a description, test and empirical examples of application. *Journal of Archaeological Science* 33(6), 847–61.
Machin, A.J., R.T. Hosfield & S.J. Mithen, 2007. Why are some handaxes symmetrical? Testing the influence of handaxe morphology on butchery effectiveness. *Journal of Archaeological Science* 43(6), 883–93.
Marzke, M.W., 1997. Precision grips, hand morphology, and tools. *American Journal of Physcial Anthropology* 102(1), 91–110.
McNabb, J. & J. Cole, 2015. The mirror cracked: symmetry and refinement in the Acheulean handaxe. *Journal of Archaeological Science: Reports* 3, 100–111.
Marzke, M.W., 2013. Tool making, hand morphology and fossil hominins. *Philosphical Transactions of the Royal Society B* 368: 20120414.
McBrearty, S. & A.S. Brooks, 2000. The revolution that wasn't: a new interpretation of the origin of modern human behavior. *Journal of Human Evolution* 39(5), 453–563.
McNabb, J.J. & J. Cole, 2015. The mirror cracked: symmetry and refinement in the Acheulean handaxe. *Journal of Archaeological Science: Reports* 3, 100–111.
McNabb, J., J. Cole & C.S. Hoggard, 2018. From side to side: symmetry in handaxes in the British Lower and Middle Palaeolithic. *Journal of Archaeological Science: Reports* 17, 293–310.
McPherron, S.P., 2000. Handaxes as a measure of the mental capabilities of early hominids. *Journal of Archaeological Science* 27(8), 655–63.
Muller, A., R. Barkai, M. Shemer & L. Grosman, 2022. 3D morphology of handaxes from the late Acheulean Jaljulia: a flexible reduction strategy in the Lower Paleolithic Levant. *Archaeological and Anthropological Sciences* 14, 206.
Mussi, M., E. Mendez-Quintas, D. Barboni, *et al.*, 2023. A surge in obsidian exploitation more than 1.2 million years ago at Simbiro III (Melka Kunture, Upper Awash, Ethiopia). *Nature Ecology and Evolution* 7(3), 337–46.
Overmann, K.A. & T. Wynn, 2019. Materiality and human cognition. *Journal of Archaeological Method and Theory* 26, 457–78.
Pargeter, J., N. Khreisheh & D. Stout, 2019. Understanding stone tool-making skill acquisition: experimental methods and evolutionary implications. *Journal of Human Evolution* 133, 146–66.

Phillipson, L., 1997. Edge modification as an indicator of function and handedness of Acheulian handaxes from Kariandusi, Kenya. *Lithic Technology* 22(2), 171–83.

Pope, M., K. Russel & K. Watson, 2006. Biface form and structured behaviour in the Acheulean. *Lithics* 27, 44–57.

Posnansky, M., 1959. Some functional considerations on the handaxe. *Man* 59, 42–4.

Schillinger, K., A. Mesoudi & S.J. Lycett, 2014. Considering the role of time budgets on copy-error rates in material culture traditions: an experimental assessment. *PLoS One* 9(5), e97157.

Seed, A. & R. Byrne, 2010. Animal tool-use. *Current Biology* 20(23), 1032–9.

Shea, J.J., 2007. Lithic archaeology, or, what stone tools can (and can't) tell us about early hominin diets, in *Evolution of the Human Diet: The known, the unknown, and the unknowable*, ed. P.S. Ungar. Oxford: Oxford University Press, 212–29.

Standley-Barrow, M. 2024. Impossible tools? An experimental re-evaluation of the functionality of the Cuxton giant ficrons. Unpublished undergraduate thesis, University of Cambridge.

Stiles, D. 1979a. Recent archaeological findings in the Sterkfontein site. *Nature* 277, 381–2.

Stiles, D. 1979b. Early Acheulian and Developed Oldowan. *Current Anthropology* 20, 16–129.

Stout, D., J. Apel, J. Commander & M. Roberts, 2014. Late Acheulean technology and cognition at Boxgrove, UK. *Journal of Archaeological Science* 41, 576–90.

Vaughan, C.D., 2001. A million years of style and function: regional and temporal variation in Acheulean handaxes, in *Style and Function: Conceptual issues in evolutionary archaeology*, eds T.D. Hurt & G. Rakita London: Bloomsbury Academic, 141–63.

Wang, W., C.J. Bae, S. Huang, *et al.*, 2014. Middle Pleistocene bifaces from Fengshudau (Bose Basin, Guangxi, China). *Journal of Human Evolution* 69, 110–22.

Wenban-Smith, F., 2004. Handaxe typology and Lower Palaeolithic cultural development: ficrons, cleavers and two giant handaxes from Cuxton. *Lithics* 25, 11–21.

White, M.J., 1998. On the significance of Acheulean biface variability in southern Britain. *Proceedings of the Prehistoric Society* 64, 15–44.

Wobst, H.M., 1977. Stylistic behavior and information exchange, in *For the Director: Essays in honor of James B. Griffin*, ed. C.E. Cleland. (Anthropological Papers 61.) Ann Arbor: Museum of Anthropology, University of Michigan, 317–42.

Wynn, T., 2021. Ergonomic clusters and displaced affordances in early lithic technology. *Adaptive Behavior* 29(2), 181–95.

Wynn, T. & T. Berlant, 2019. The handaxe aesthetic, in *Squeezing Minds from Stones: Cognitive archaeology and the evolution of the human mind*, eds K.A. Overmann & F.L. Coolidge. Oxford: Oxford University Press, 278–303.

Wynn, T. & J. Gowlett, 2018. The handaxe reconsidered. *Evolutionary Anthropology* 27, 21–9.

Zupancich, A. & T. Proffitt, 2014. Macro and microscopic wear analysis of the non-worked lateral edge of a large biface. *Traces in Time* 4, 1–7.

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