RELATIONSHIP BETWEEN ACHEULEAN BIFACE DIMENSIONS AND HAND SIZE
J. Walker & K. Lee

ABSTRACT
This exploratory study sought to establish a possible relationship between the dimensions of Acheulean bifaces and the hand sizes of male and female tool users. Although many studies of biface design have focused on planform and symmetry, no attention has been given to ergonomic relationships between their size and the ability of users to handle them. An analysis of 263 digitised images of ovate bifaces held by the Archaeological Data Service revealed multimodal breadth and weight distributions skewed towards smaller sizes. An exploratory experiment was designed to test the relationship between the dimensions of larger and smaller reproduction ovate flint bifaces, male and female hand sizes, and reported ease of handling. The findings confirm a significant relationship between hand size and ease of handling the larger tool, but not the smaller tool. Females found it more difficult than males to use the larger biface but there was no significant sex-related difference in reported ease of handling the smaller tool. The findings support the possibility that prehistoric flint knappers had the cognitive ability and technical competence to make tools that addressed the ergonomic needs of users.


Keywords: Sexual dimorphism, biface size, ergonomic, hand-axe

INTRODUCTION
The aim of this study was to explore possible relationships between the dimensions of the Acheulean biface and the size of the user’s hand, including the potential influence of sexual dimorphism on the ability to handle this type of tool. The biface heralded a new evolutionary era in terms of technological sophistication, with the ability to produce such a tool seen as indicative of advanced cognitive planning and execution processes (Pope et al. 2007). Machin et al. (2005) recorded general agreement that an important function of the Acheulean hand-axe was that of butchery tool. Analyses of early Acheulian assemblages from Kenya led Gowlett & Crompton (1994) to conclude that biface size was an important determinant of its shape. However, reasons for its morphology have remained a matter of considerable debate and whilst much subsequent attention has focused on explanations for biface form (cf. Wenban-Smith 2004; Machin et al. 2005), much less consideration has been given to reasons for size variations per se.

Emery (2010) undertook a comprehensive review of biface form and identified three key explanations for differences in biface size and shape: the type, size and quality of available raw material (White 1998; Schick & Clark 2003); intensity of resharpening processes (McPherron 1995); and the influence of sociocultural norms (Wenban-Smith 2004). White (1998) found evidence from assemblages in southern Britain that the dimensions of the available material were likely to impose limitations on tool size and shape. However, whilst it is clear that a large tool cannot emerge from a small lump of stone, recent experimental evidence has failed to support the raw material hypothesis as the sole predictor of tool shape or size (Eren et al. 2014). Based on evidence from the archaeological record, Wenban-Smith (2000) and Stout et al. (2005) concluded that ancient hominins were able to produce well-crafted tools by preferentially selecting good quality material. Emery (2010) pointed out that most hand-axes show signs of reductive processes as a result of re-use or resharpening. However, although McPherron (1995; Iovita & McPherron 2011) demonstrated changes in hand-axe length and shape as a result of resharpening, Andrefsky (2009) noted that these processes were not commonly observed when users had ready access to raw materials.
The ability to produce a symmetrical bifacially knapped tool appears to demonstrate enhanced spatial cognition (Wynn 2002). Indeed, Kohn & Mithen (1999, 525) proposed that the level of skill required to produce these tools signalled genetic superiority and they may therefore have been used for male display. The same argument seems equally likely to apply to the ability to produce large sized tools. Whilst these theories all offer plausible explanations for variations in size as well as shape, this paper explores another possible reason for differences in biface size.

When reviewing the dimensions of the biface, Thompson (2012) noted the obvious importance of taking into account variations in the sizes of hands that used them. This, he suggested, might paint a picture of makers intentionally able to manufacture tools to suit the size of the user’s hand. But whilst many studies of butchery practices have demonstrated that biface symmetry improves both tool efficiency (cf. Jones 1980; Schick & Toth 1994) and ease of use (Simao 2002; Machin et al. 2007), none of these studies have taken into account variations in the hand size of the user, possibly because butchery studies have focused almost exclusively on male participants. One experimental study that included both male and female participants failed to identify a relationship between flake tool dimensions and the size of hands necessary to make efficient use of that type of tool (Key & Lycett 2011). However, the grip used to hold a biface is quite unlike that used to hold a flake tool or modern knife. Figure 1 illustrates how the thumb and fingers must be sufficiently long to accommodate the breadth and thickness of biface without damaging the palm. A large number of anthropometric studies, based on different human populations, demonstrate significant sexual dimorphism in human hand size (cf. USARDL 1981; Donelson & Gordon 1995; McLain 2010; Ibeachu et al. 2011), while sexual dimorphism in hominin hand size is well documented in the archaeological literature (cf. van Gelder & Sharpe 2009). Thus it is predicted that males are better able than females to handle bifaces of larger dimensions. Differences in the relative robustness of the male and female musculoskeletal frame (Stock 2006), notably wrist strength (Riggs et al. 2006), indicate that the weight of biface might be an important factor in tool handling. Therefore, the experimental study reported here explored the relationship between biface size and hand size, and compared the ability of males and females to handle bifaces of different sizes.

**Biface size**

In order to base the experiment on biface sizes representative of those found in the archaeological record, data on biface dimensions were obtained from the Archaeological Data Service (ADS) (Marshall et al. 2002). In order to standardise biface typology, selection was limited to classic, deliberately formed, ovate bifaces, classified by McNabb (2007, 329) as E1 (classic biface) and Roe (1981, 154) as group VII (rounded ovates). The following inclusion criteria were applied: hand-axe; flint; ovate, elliptical or discoid; linear edge profile; circumference 100% worked; complete; fresh or lightly abraded. Only those made from flint were included since this was the material used in the biface experiment. In order to ensure uniformity of form and function, those classified as (or observed from images to be) cleaver-shaped, irregular or damaged were excluded. Pointed bifaces were excluded as a distinct planform (Roe 1969), whereas rounded symmetrical shapes were considered to represent a continuum in terms of form and function (cf. McNabb 2007; Iovita & McPherron 2011). This selection process identified a sample of 263 bifaces, the majority of which were from Warren Hill, Suffolk (n = 166), Boxgrove, West Sussex (n = 48) and Corfe Mullen, Dorset, UK (n = 40).
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Figure 2. Biface breadth distributions.

Figure 3. Biface weight distribution (n = 263).

Figure 4. Biface planform distribution.

Mean = 0.71
Median = 0.71
SD = 0.09
Range = 0.47-1.02
n = 254
The analyses presented here focus on breadth and weight as predictors of handling ease (the point of maximum thickness was too variable to provide a valid predictor of handling ease). The breadth distribution appeared bimodal (or possibly a mean with subsidiary mode, Shennan 1997) with a range of 41.8–116.8 mm and modes at 68 mm and 85 mm (Figure 2). The weight range was 42–728 g (median 171 g), skewed towards the lighter end of the distribution and tendency to multimodality (Figure 3). Bifaces from Warren Hill were found to be significantly smaller than those from Boxgrove and Corfe Mullen in terms of weight (Kruskall-Wallis p <0.001) and breadth (Kruskall-Wallis p <0.001). Data for planform across all sites, measured by maximum breadth/maximum length, approximated to the normal distribution (Figure 4). This appears to support continuity of form and function between discoid and ovate bifaces.

EXPERIMENTAL MATERIALS AND METHODS

Reproduction ovate bifaces (Figure 5) were knapped by Karl Lee and Antony Whitlock to approximate to modal values of the larger and smaller distributions in terms of maximum breadth (93 mm and 65 mm) and weight (320 g and 129 g), as indicated in Figures 2 and 3, with maximum thickness of 30 mm and 27 mm respectively. Edges were blunted by light abrasion with a hammer stone to prevent injury. The study tested ease of handling each tool, in the absence of material resistance, whilst engaged in a hand/wrist sweeping movement observed from extensive experience (Lee and Whitlock) to be most efficient and effective when butchering deer carcasses. Several small pilot studies involving up to five anthropology students were conducted to ensure that the type and duration of hand movements were safe and practicable, the instructions clear, adherence consistent, and to confirm the face validity of the measurement scales used.

Participants in the main experiment were twenty male and twenty female university students and staff, aged 18 to 57 years, recruited at a university science outreach event. University ethical approval was obtained and each participant signed informed consent to ensure they had no history of hand/wrist injury or pain that might be exacerbated by repetitive action. Each recorded their handedness (5 left, 35 right), and rated their level of engagement in upper body fitness training (from every day to never) in order to identify potential confounding influences of upper body strength. Dominant hand size measurements (Figure 6) included wrist crease to (straightened) thumb tip (ab) and wrist crease to index finger tip (ac) using spreading callipers, selected as relevant to tool hand hold (Figure 1) and having easily identifiable anchor points. Maximum hand breadth (de), using digital callipers, and wrist circumference (through a), using a tape measure, were included as potential indicators of hand and wrist strength.

The experimental task required participants to follow instructions on a pre-prepared video that demonstrated an up-down hand/wrist movement (Figure 7) whilst holding each tool (one large and one small) in turn for one minute. Speed of movement was standardised, using music delivered via headphones, to a
beat of 106 bpm (each up or down movement to a single beat). The video ensured uniformity of action to deliver a standardised force to the hand and wrist. Arm movements were found during the pilot study to be difficult to control and were therefore restricted by the instruction to anchor the upper arm to the body using the opposite hand, whilst keeping the elbow flexed to 90° (Figure 7). In order to eliminate carry-over effects whereby fatigue from handling the first tool might affect ease of handling the second, half of the female and male participants handled the large biface first and half the small one first. After handling each tool, participants were asked to rate how easy or difficult it would be to continue with the same movement, using a seven-point semantic differential scale from very easy to very difficult. At the end of the two handling sessions, participants were asked to identify which tool they would prefer to use and to add relevant comments. SPSS was used to apply parametric and nonparametric tests of comparison and correlation, as appropriate, to test for sex differences in hand size, relationship between ease of use and hand size, and sex differences in ease of use and tool preference. Where relevant, participants' comments are reported.

RESULTS

Tests of comparison confirmed that female hand sizes were significantly smaller than those of the males on all four hand/wrist dimensions (Table 1). Figure 8 illustrates sex differences in wrist-finger and wrist-thumb dimensions. No confounding sex-related differences in self-reported levels of upper body fitness training were identified (Table 1).

Longer finger and thumb measurements were each associated with increased ease of handling the large biface (Table 2). No such associations were observed with respect to the small biface. Neither hand breadth nor wrist circumference was associated with ease of handling either size of tool.

Table 1. Between-sex comparisons of hand/wrist measurements and self-report of upper body fitness.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sex</th>
<th>Mean</th>
<th>Median</th>
<th>SD</th>
<th>Max</th>
<th>Min</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist to index finger tip distance</td>
<td>Male</td>
<td>18.0</td>
<td>18.2</td>
<td>0.89</td>
<td>19.2</td>
<td>16.2</td>
<td>&lt;.000*</td>
</tr>
<tr>
<td></td>
<td>Fem</td>
<td>16.17</td>
<td>16.1</td>
<td>0.9</td>
<td>18.2</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Wrist to thumb tip distance</td>
<td>Male</td>
<td>13.2</td>
<td>13.15</td>
<td>0.69</td>
<td>14.3</td>
<td>11.6</td>
<td>&lt;.000*</td>
</tr>
<tr>
<td></td>
<td>Fem</td>
<td>11.75</td>
<td>11.7</td>
<td>0.82</td>
<td>13.1</td>
<td>9.8</td>
<td></td>
</tr>
<tr>
<td>Hand breadth</td>
<td>Male</td>
<td>8.46</td>
<td>8.42</td>
<td>0.56</td>
<td>9.39</td>
<td>7.12</td>
<td>&lt;.000*</td>
</tr>
<tr>
<td></td>
<td>Fem</td>
<td>7.5</td>
<td>7.68</td>
<td>0.41</td>
<td>7.97</td>
<td>6.66</td>
<td></td>
</tr>
<tr>
<td>Wrist circumference</td>
<td>Male</td>
<td>16.95</td>
<td>16.7</td>
<td>0.79</td>
<td>18.7</td>
<td>15.9</td>
<td>&lt;.000*</td>
</tr>
<tr>
<td></td>
<td>Fem</td>
<td>15.4</td>
<td>15.1</td>
<td>1.07</td>
<td>17.6</td>
<td>13.8</td>
<td></td>
</tr>
<tr>
<td>Upper body fitness training</td>
<td>Male</td>
<td>3.0</td>
<td>1</td>
<td>5</td>
<td>0.11</td>
<td>ns**</td>
<td></td>
</tr>
<tr>
<td>(1 every day to 5 never)</td>
<td>Fem</td>
<td>4.5</td>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*1-tailed independent t test; **Mann-Whitney U test, 2-tailed.
Females reported the larger tool more difficult to use, but there was no sex-related difference in ease of handling the small tool (Table 3). The distribution of reported ease of handling the large biface approximates to a normal distribution for females, but was positively skewed towards easy for males (Figure 9). Given the lack of resistance required by the task, it seems likely that this was due to a ceiling effect, with the larger biface well within the handling capacity of most of the males. Cross-tabular analysis supported the prediction that males were more likely to express preference for using the large biface and females the small one (1-tailed Fisher exact \( p = 0.017, n = 37 \); three males did not express a preference). Comments confirmed the statistical findings and drew attention to the relevance of tool size to the task in hand: ‘larger axe is best for larger work’ (male); ‘size depends on the task’ (male); ‘long fingers make the large size more comfortable in the hand’ (male with long fingers who was observed to find the small biface difficult to handle); ‘weight was an issue with the larger one’ (female).

Table 2. Spearman’s rank correlations (2-tailed) between hand size measurements and ease of handling the small and large bifaces.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Ease of use small biface</th>
<th>Ease of use large biface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist to index finger tip</td>
<td>r_s=0.033, n=40, ns</td>
<td>r_s=0.39, n=40, p&lt;0.05</td>
</tr>
<tr>
<td>Wrist to thumb tip</td>
<td>r_s=0.04, n=40, ns</td>
<td>r_s=0.44, n=40, p&lt;0.01</td>
</tr>
<tr>
<td>Hand breadth</td>
<td>r_s=0.2, n=36, ns</td>
<td>r_s=0.09, n=36, ns</td>
</tr>
<tr>
<td>Wrist circumference</td>
<td>r_s=0.16, n=40, ns</td>
<td>r_s=0.3, n=40, p=0.06, ns</td>
</tr>
</tbody>
</table>

Table 3: Sex-related comparisons of ease of handling the larger and smaller tools.

<table>
<thead>
<tr>
<th>Tool</th>
<th>Sex</th>
<th>Range*</th>
<th>Median</th>
<th>p**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larger</td>
<td>Male</td>
<td>1–5</td>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1–6</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Smaller</td>
<td>Male</td>
<td>1–6</td>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>1–5</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

* Semantic differential scale: 1 very easy to 7 very difficult ** Mann-Whitney U test, 2-tailed.
DISCUSSION

The findings of the small experimental study indicate that females find it more difficult to handle a larger size of biface. Significant relationships between handling ease and length of finger/thumb tip to wrist (Table 2) support the importance of hand/digit length in relation to biface hold. With the possible exception of men with long fingers, both males and females appear able adjust their grip to accommodate a smaller size of biface and handle smaller tools with relative ease. Hand breadth and wrist circumference were included as possible indicators of hand and wrist strength on the assumption that these might influence weight handling, however no effects were observed. Males expressed a preference for the larger biface, though this may have reflected social response bias through a desire to present a masculine image. The findings nevertheless raise a number of questions discussed here.

Are these experimental findings relevant to ancient Homo? Although the experiment did not involve actual butchery, it did identify significant sex-related differences in tool handling ability. Participants in the present study did not face the physical demands of ancient hunter-gatherers, but archaeological evidence appears to support comparable sex-related differences in hand and wrist sizes. The classic bifaces from Boxgrove, Warren Hill and Corfe Mullen were found at sites dated to around 0.5 My, occupied by *Homo heidelbergensis* (Emery 2010; McNabb et al. 2012). Sexual dimorphism is reported to have been similar or even greater among ancient tool-makers (Plavcan 2001). Neanderthal postcranial dimensions appear no different to those of modern humans (Trinkaus 1980), while sexual dimorphism in *Homo heidelbergensis* may have been even greater than that of modern humans (Rosas et al. 2002). Therefore, there is no reason to doubt the existence of sex-related differences in hand size among ancient stone tool users.

Why are the dimensions of the classic ovate flint bifaces recorded in the ADS database skewed towards smaller sizes? The Warren Hill collection contained more small bifaces when compared to Corfe Mullen and Box Hill. One obvious explanation for this size difference is the limit imposed by the size of raw material available. Flint at Warren Hill and Corfe Mullen is found in fluvial sources and Box Hill in chalk (Roe 1981); all three sites reported to have excellent access to good quality materials (Emery 2010). Thus whilst not excluding raw material size as a limiting factor, these observations leave room for additional explanations. Gowlett (2005) reported a bimodal distribution among Acheulean finds in Africa, with a comparable small modal value. He also observed a similar clustering of small and large bifaces from Beeches Pit, Suffolk, UK, with size differences so pronounced as to suggest differences in function. For example, small tools would have been more easily portable for foraging purposes (Kuhn 1994), whilst larger tools were used to butcher large carcasses (Bello et al. 2009). Findings from the present experimental study indicate that smaller sizes were also likely to suit use by women. Explanations for size variations are, like other aspects of lithic technology, likely to be influenced by assumptions about the division of labour among ancient tool-users (Sassaman 1992). Contemporary ethnographic studies have identified women hunting and preparing small game (Bird 1999), while Arthur (2010) observed that the majority of skilled stone toolmakers and users in the Konso district of Ethiopia are women from the age of 14. Therefore it is reasonable to propose that small tools were made to suit the needs of those with small hands, notable women and possibly children (Lee observed that his six-year-old daughter was quite capable of handling the smaller tool used in the present experimental study). Chamberlain (2000) estimated that children would have comprised up to 36% of a hunter-gatherer population (‘child’ was defined as aged up to 15, the age at which those in traditional societies normally achieve self-sufficiency). It is therefore quite feasible that the preponderance of small bifaces in the archaeological collection reflects tool-making and use by men, women and children for the purposes of foraging and food preparation. Interestingly, the breadth/length ratio of classic ovate bifaces in the ADS collection approximated to the normal distribution, suggestive of chance variation in planform. This observation would suggest that the size of the classic ovate biface was subject to a greater level of selective manipulation than its shape.
What implications might these findings have for our understanding of the relationship between toolmaker and tool user? The findings of this small study appear to indicate that tool users are likely to select a biface that suits their hand size. We cannot know, from information available on the ADS database, if biface tools were likely to have been made by knappers for their own use or for use by others, or both. However, in preparation for the experiment reported here, modern day flint knappers demonstrated the skills to produce bifaces of different sizes to order, at short notice, and there seems no reason to suppose that a skilled ancient knapper would not have been able to do likewise. The production of the Acheulean biface is recognised as requiring a complex series of cognitive and procedural skills (Stout et al. 2014), yet any reference to the ergonomics of biface design is conspicuous by its absence from the literature on lithics. Ergonomics emerged as a field of study from 20th-century military engineering and production imperatives (Waterson 2011). When applied to tool design, it draws on research from such disciplines as biomechanics, anthropometry and engineering to improve tool efficiency and reduce biomechanical stresses to the user's hands, arms and shoulders (Johnson 1993). As an example, Grosman et al. (2011) applied ergonomic principles to show that handgrip places functional constraints on modern day tool size. Charytonowicz (2009) used the term “intuitive ergonomics” to describe the unconscious processes that would have enabled prehistoric hominins to transform their material environment to suit practical needs. The experimental findings reported here appear to lend some support for the idea that, by the time of Homo heidelbergensis occupation in Britain, flint knappers had sufficient intuitive grasp of ergonomic principles to produce bifaces to sizes that suited both task requirements and the needs of users. If verifiable, this would demonstrate a more advanced level of technological sophistication among early Palaeolithic hominins and add a new dimension to our understanding of the evolutionary significance of the Acheulean biface.

CONCLUSIONS

An analysis of classic ovate bifaces demonstrated distributions of breadth and weight skewed towards smaller dimensions. Findings from the exploratory experimental study indicate that ease of handling different sizes of biface is related to hand size, such that women find it difficult to use larger sized tools. Clearly, these findings are based on a small non-random sample of modern day humans and limited to self-reported ease of use in the absence of material resistance. Whilst not excluding other explanations for biface size differences, the experimental findings offer support for the proposition that prehistoric toolmakers were able to tailor the size of bifaces to suit the hand sizes of different user groups, including women and possibly children. A similar study, based on a larger sample size, would help to substantiate these findings, although the inclusion of children in this type of experimental research would pose additional practical and ethical challenges, including biface size selection, recruitment and consent. Further testing of the ergonomic relationships between the hand sizes of males and females, and their ability to use different sized bifaces, needs to reproduce butchery practice using carcass material, similar to the experimental approach used by Machin et al. (2007) to study the effects of variations in biface symmetry. If verified, our findings would cast new light on the production capabilities of ancient flint knappers, and on the roles of prehistoric women as tool users.

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REFERENCES


