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Why are some handaxes symmetrical? Testing the influence of handaxe morphology on butchery effectiveness

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Abstract

The morphology of Acheulean handaxes continues to be a subject of debate amongst Lower Palaeolithic archaeologists, with some arguing that many handaxes are over-engineered for a subsistence function alone. This study aims to provide an empirical foundation for these debates by testing the relationship between a range of morphological variables, including symmetry, and the effectiveness of handaxes for butchery. Sixty handaxes were used to butcher 30 fallow deer by both a professional and a non-professional butcher. Regression analysis on the resultant data set indicates that while frontal symmetry may explain a small amount of variance in the effectiveness of handaxes for butchery, a large percentage of variance remains unexplained by symmetry or any of the other morphological variables under consideration.

Keywords: Experimental archaeology; Handaxes; Butchery; Function; Symmetry

1. Introduction

Acheulean handaxes are the most enigmatic artefacts from the Lower Palaeolithic and have been the source of widespread debate since their antiquity was first established over 150 years ago (Wynn, 1995). Although commonly described as heavy duty butchery tools, many handaxes intuitively appear to be over-engineered for this purpose alone. Much of the debate has focused on the issue of symmetry and form, which appears to have been intentionally imposed on many handaxes during manufacture. This has been explained as a means to increase the efficiency of the handaxe as a butchery tool (Mitchell, 1996; Simao, 2002), as a by-product of raw material type and the bifacial knapping method (McPherron, 2000; White, 1998), as a form of sexual display (Kohn and Mithen, 1999), as a marker within the landscape (Gamble, 1999; Pope and Roberts, 2005), and as an indication of an aesthetic sense in Early and Middle Pleistocene hominins (Edwards, 2001; Pelegrin, 1993).

This paper seeks to make a contribution to this debate by establishing the relationship between the degree of symmetry exhibited by a handaxe and its effectiveness as a butchery tool. If a positive relationship exists, support can be given to those who argue that handaxes were primarily, or perhaps solely, subsistence tools. If no such relationship exists, then support will be given to those who argue that social, sexual or aesthetic factors may have been important influences on handaxe morphology. Previous experiments have addressed this topic (e.g. Jones, 1980; Mitchell, 1996; Schick and Toth, 1993), but these have always been on the basis of small scale butchery (one or two carcasses) and reliant on the subjective assessment of the butcher (often an archaeologist with limited experience of butchery techniques). Here we provide results from a substantial programme of butchery undertaken in experimentally controlled conditions, with two butchers and employing a statistical analysis of the data.

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2. Methodology

The experiments were designed to test the following hypothesis:

Symmetry increases the effectiveness of a handaxe as a butchery tool.

'Effectiveness' can be measured in various ways. One might, for instance, wish to prioritise time and hence be concerned with the speed of a butchery event. Alternatively, one might be concerned with the quality of the butchery process, although this is intrinsically difficult to quantify. We used both measures, recording the time taken for a series of butchery events relating to each carcass and asking our butchers to score the effectiveness of each handaxe as a butchery tool on seven ordinal scales relating to different measures of butchery quality and tool use.

Two people were employed to undertake the butchery, the aim being to test whether the results from one butcher can be replicated, and to increase the robusticity of any significant results obtained by the scoring of the handaxes' utility, which inevitably has a subjective element. Butcher 1 (B1) was a professional game butcher, David John, from the Covered Market in Oxford; B2 was a Palaeolithic archaeologist, Matt Pope, who has extensive knowledge of lithic technology and some, untutored, experience of using stone tools for butchery. As such, we were able to contrast the professionally taught technique of B1 with someone who had limited experience of butchery, but knowledge of stone tools and the archaeological debates surrounding their interpretation. We were aware that B2's experience of studying lithics may have led him to have pre-conceived ideas as to how a handaxe might be used, something which will not have affected B1.

The experimental assemblage consisted of 60 ovate and cordiform handaxes of varying degrees of frontal (FS) and side (SS) symmetry (Fig. 1). These had been randomly selected from a pool of 104 flint handaxes manufactured by John Lord. Using raw material sourced from the Lynford gravels, Norfolk, John was directed to produce an assemblage of handaxes which, in his opinion, were all capable of butchery (i.e. had a length of cutting edge) but exhibited variability in frontal and side symmetry. Thirty of these 60 handaxes (H1–H30) were randomly assigned to B1, and 30 (H31–H60) were randomly assigned to B2 (Charts 1–4).

Having been assigned a unique identifier, the breadth, length and weight of each handaxe was measured, prior to being digitally photographed in plan and profile. The resultant images were processed by software designed for the Acheulean Biface Database (Marshall et al., 2002). This generated a range of morphological measurements including frontal (FS) and side (SS) symmetry using the Continuous Symmetry

Fig. 1. The experimental assemblage (the outlier H2 is the second handaxe from the left in the top row).

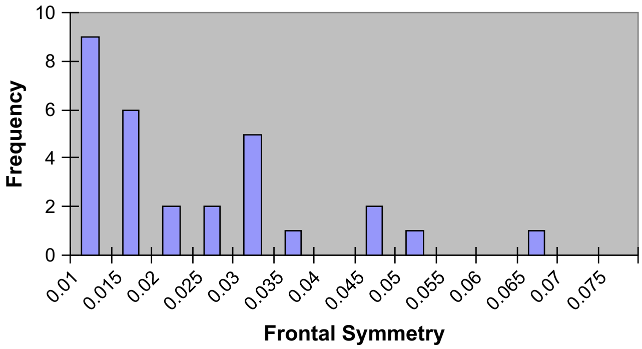

Chart 1. Histogram of frontal symmetry (FS) values for B1's experimental handaxe assemblage (Kolmogorov–Smirnov normal distribution test: $p = 0.568$).

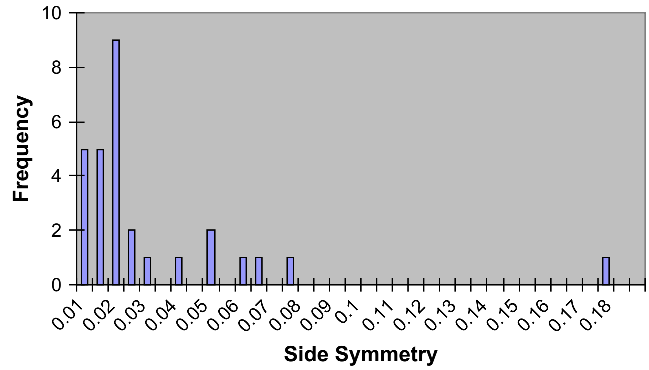

Chart 3. Histogram of side symmetry (SS) values for B1's experimental handaxe assemblage (Kolmogorov–Smirnov normal distribution test: $p = 0.031$).

Measure (CSM) (Saragusti et al., 1998). In this measure, zero represents absolute symmetry and increasing values indicate increasing distances away from absolute symmetry. Descriptive statistics for the two assemblages are provided in Table 1. While both assemblages are considerably more symmetrical than those utilised by Saragusti et al. (1998) in their original study of handaxe symmetry, the ranges exhibited here are comparable to those found at Boxgrove, Warren Hill and Montagu Cave, three of the complete assemblages analysed by Marshall et al for the Acheulean Biface Database (Marshall et al., 2002).

Thirty wild shot fallow deer were used during the course of the experiment and collected as required from a supplier on the morning of the experiments. To minimise the impact of the specific nature of each carcass on the experimental results, the ages and weights of the carcasses were restricted to animals less than 2 years old and between 50–60 lbs.

The experiments were carried out over the course of five half day sessions per butcher, using six handaxes and three deer per session, during September 2005. B1 carried out his sessions on three consecutive Mondays (two whole days and then one half day), whereas B2 completed his sessions over two and a half consecutive days. Each butcher was asked to butcher half a deer with each handaxe: this involved removing the skin and flesh from one fore limb and one hind limb. Initially, the butchers were allowed to butcher the hind and fore limbs in whichever order they wished but following the first session, when it became clear that some of the handaxes were blunting between the first and second limb, the butchers were asked to butcher the hind limb first followed by the fore limb. This allowed for the comparison of hind or fore limb data separately, should this be required, and for the impact of blunting to be controlled. It was unclear whether the blunting was due to physical deterioration of the cutting edge or ‘‘fatting’’ – the accumulation of flesh, hair and grease on the artefact. This change in methodology only affected five handaxes from B1's first session.

Due to the differing backgrounds of the two butchers, they were not asked to carry out exactly the same butchery processes as it was felt that the pressure of learning or memorising a new technique may complicate results. In place of this they were simply asked to be internally consistent in terms of the methods they personally employed with each handaxe so that the data compiled for each of their 30 handaxes could be compared. The processes carried out by the two butchers are detailed in Tables 2 and 3. The main differences were as follows:

- the nature of skin removal – B1 tended to cut less skin to aid skin removal.

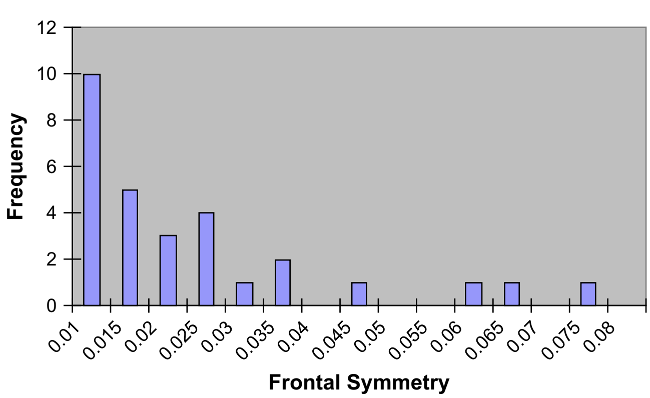

Chart 2. Histogram of frontal symmetry (FS) values for B2's experimental handaxe assemblage (Kolmogorov–Smirnov normal distribution test: $p = 0.191$).

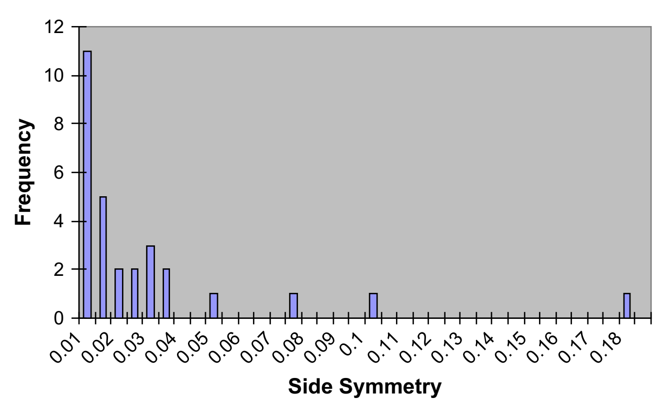

Chart 4. Histogram of side symmetry (SS) values for B2's experimental handaxe assemblage (Kolmogorov–Smirnov normal distribution test: $p = 0.007$).

Table 1
Descriptive statistics for the experimental assemblages

Handaxe attribute	Minimum value		Maximum value		Range		Mean		Standard Deviation	
	B1	B2	B1	B2	B1	B2	B1	B2	B1	B2
Frontal symmmetry	0.0017	0.0019	0.0614	0.0741	0.0597	0.0722	0.0199	0.0200	0.0148	0.0183
Side symmetry	0.0014	0.0032	0.1724	0.1762	0.1710	0.1730	0.0272	0.0260	0.0326	0.0349
Length (mm)	105.00	103.00	130.00	130.00	25.000	27.000	119.00	114.87	6.8531	7.6327
Breadth (mm)	77.000	71.000	111.00	108.00	34.000	37.000	88.933	88.833	8.1998	10.083
Weight (g)	239.00	191.00	600.00	509.00	361.00	318.00	367.80	321.50	89.065	80.586
Thickness (mm)	26.000	22.000	69.000	52.000	43.000	30.000	39.333	35.500	10.532	8.0462
Elongation	0.6308	0.5726	0.8810	0.9217	0.2502	0.3492	0.7483	0.7744	0.0651	0.0804
Thinning	0.2989	0.2525	0.8415	0.7324	0.5426	0.4799	0.4459	0.4052	0.1286	0.1109
Percentage circumference worked (%)	47.200	53.100	100.00	100.00	52.800	46.900	89.283	92.073	16.619	15.100

- the order in which the Achilles tendon was cut.
- the method of removing flesh from bones – in terms of the hind limb B1 removed the flesh in one block, while B2 removed it in several separate muscle blocks. On the fore limb B1 did not remove any meat from the bone, preferring to leave it attached to the scapula and humerus while removing the radius and ulna, while B2 again removed it in several blocks from the radius and ulna.
- the severing of the elbow joint – B1 severed this joint to remove the radius and ulna while B2 did not.

2.1. Data collection

2.1.1. Video logging

The butchery sessions were videoed resulting in nearly 18 h of footage. This was logged by a single observer using the categories detailed in Table 4 resulting in one time log per handaxe. Using the video timer the start and end times of each period of activity were noted, the duration of those periods calculated and the number of episodes counted (one episode being a period of that activity without pause). The butchers had been asked to think aloud so that their thought processes and views on the handaxes during use could be noted to form a verbatim record. Following the completion of each log, the time for each individual butchery process – time to cut skin (t_s), time to cut flesh (t_f), time to cut skin from flesh (t_d), time to cut joint (t_j) and time to cut ligament (t_l) – was calculated by adding all the relevant periods together and ultimately the total time to butcher (t) was calculated by summing the timings for each process ($t = t_s + t_f + t_d + t_j + t_l$).

2.1.2. Subjective scoring

The butchers were asked to score the handaxes on seven, five point ordinal scales as detailed in Table 5. Initially, this scoring occurred once for each handaxe. When it soon became clear that the majority of handaxes were blunting, and hence their performance deteriorating, between the hind and fore limb it was decided to score each handaxe twice, once after the hind limb and once after the fore limb to prevent the overall score being unduly influenced by the performance on the fore limb and to enable the possibility of analysing the degree of blunting by comparing these two sets of scores for one handaxe. This change in methodology only affected data collected from the 12 handaxes in B1's first session.

2.2. Data analysis

2.2.1. Selection of variables

The dependent variables selected to represent effectiveness for butchery were the total time to butcher, the time to carry out each individual butchery process and the seven subjective scoring categories. The independent variables were FS and SS. However, as Charts 1–4 make clear the distributions of these independent variables exhibit a marked right skew for both experimental assemblages, and violate the normal assumption that values can be between + and – infinity. Therefore, FS and SS were transformed using log 10 (log FS and log SS) to improve the symmetry of the distributions (e.g. Chart 5) and to eliminate the problem that negative values are not present in the original range of symmetry values. These transformations also allowed the use of parametric tests in the statistical analysis. In addition to the two symmetry variables,

Table 2
Order of butchery processes carried out by B1

Carcass area	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8
Hind limb	Cut skin/cut skin from flesh	Cut Achilles tendon	Cut hip joint	Cutting skin from flesh	Cut flesh (to sever hind limb from body)	Remove hind limb from body	Cut flesh/cut smaller ligaments (to remove muscle blocks in one piece)	Remove femur/tibia + fibula from meat block
Fore limb	Cut skin from flesh (at cut edge)/cut skin	Cut flesh (to sever fore limb from body)	Cut skin from flesh	Remove fore limb from body	Cut flesh/cut ligaments	Cut elbow joint	Remove ulna + radius	

Table 3
Order of butchery processes carried out by B2

Carcass area	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12	Stage 13
Hind limb	Cut skin	Cut skin from flesh	Cut flesh	Cut hip joint	Cut flesh	Cut skin from flesh	Cut flesh (to sever hind limb from body)	Remove hind limb from body	Cut flesh	Cut Achilles tendon	Remove muscle blocks	Cut flesh/cut ligaments (to remove individual muscle blocks)	Remove femur/tibia + fibula
Fore limb	Cut skin from flesh (at cut edge) /cut skin	Cut flesh (to severe fore limb from body)	Cut skin from flesh	Cut skin	Cut skin from flesh	Remove fore limb from body	Cut flesh/cut ligament (to remove muscle blocks separately from ulna + radius)						

Table 4
Activity categories for video logging

Period of activity	Definition
Butchery stages	
Cutting skin	Cutting through the hide
Cutting skin from flesh	Cutting the seams between the hide and the flesh
Cutting flesh	Cutting flesh and gristle
Cutting joint	Cutting between jointed bones
Cutting ligament	Cutting ligaments and tendons
Handaxe movements	
Rotate handaxe	*Either* flip the handaxe over to use the other lateral edge *or* use another area of the handaxe edge on the same side, e.g. moving from the point to the butt. A distinction was made between handaxe rotations which occurred in the hand and those which occurred after the handaxe had been put down for a period of time.
Clean handaxe	Cleaning the handaxe
Movements of/on deer	
Applying pressure to joint	Applying pressure to a joint
Pulling skin/flesh/ligament	Pulling skin from flesh, pulling flesh or pulling ligaments by hand
Shifting carcass	Moving the deer or sections of the deer
Other	
Pausing	To answer question, think, realign self, indicate areas on handaxe etc

the use of the ABD software in combination with some hand measurements afforded the opportunity to explore the impact of seven other morphological variables upon butchery effectiveness: weight, length, breadth, thickness, elongation, thinning and percentage circumference worked. Summary statistics for these variables are included in Table 1. While this paper concentrates upon reporting the results of the analysis of the relationship between butchery effectiveness and symmetry, a brief summary of the impact of these other variables upon effectiveness will be reported in Sections 3 and 4.

2.2.2. The impact of increasing skill

It is inevitable that during an intensive period of butchery, the skill of an initially relatively inexperienced individual might increase, reducing the time required to butcher carcasses irrespective of the morphology of the handaxe being used. While this was unlikely to be a significant factor for B1, owing to his extensive prior butchery experience (with and without stone tools), the verbatim comments of B2, combined with an apparent increase in speed noted during the experiment, suggested that he had improved his butchery skills during the course of the experiment. This is confirmed by plotting the individual total butchery time for each handaxe (t) against the cumulative butchery time, the latter measure acting as a proxy for experience (Chart 6). The same chart for B1 confirms that increasing skill with experience was less of a problem in his case although its influence as a confounding factor cannot be completely ruled out (Chart 7). To control for the factor

Table 5
Seven scales for subjective scoring of the handaxes

	1	2	3	4	5
Overall usefulness as a butchery tool	Not at all useful		Adequate		Perfect/ideal
Usefulness for cutting skin	Not at all useful		Adequate		Perfect/ideal
Usefulness for cutting flesh	Not at all useful		Adequate		Perfect/ideal
Usefulness for cutting ligaments	Not at all useful		Adequate		Perfect/ideal
Overall effectiveness of cutting edge	Not at all effective as a cutting edge		Adequate		Perfect cutting edge
Weight distribution	Not at all ideal		Okay		Perfect weight distribution
Overall ease of use	Very difficult to use		Okay to use		Very easy and comfortable to use

of increasing skill, we transformed total butchery time (t) to total butchery time adjusted for skill (t_1) using the following formula:

$$t_1 = t - \left(t_p - t_e\right)$$

where t_p is the predicted butchery time for that handaxe and te is the predicted butchery time for the last handaxe (i.e. handaxe 30), the predicted times being calculated from the linear regression of cumulative butchery time against individual butchery time. The total butchery times for each handaxe were transformed, with the two experimental assemblages (assigned to B1 and B2, respectively) being modelled separately. This resulted in Charts 8 and 9, which illustrate cumulative total butchery time against individual butchery time (adjusted for skill) (t_1). The small r^2 values for these graphs indicate that the skill factor has been adequately controlled for. These transformations were also carried out for the individual butchery process times — t_s, t_f, t_d, t_j and t_l — and the transformed data sets were used as the dependent variables in the regression analysis.

2.2.3. Statistical analysis

Single linear regression (least squares fit) analyses were carried out to test the relationships between the independent symmetry variables and a range of the dependent time variables. A multiple regression analysis was used to assess the influence of the symmetry and morphological independent variables upon the time dependent variables. Kendall's Tau-b was selected to analyse the results of the butchers' subjective scorings of the handaxes. All analyses were carried out using SPSS (Version 12.0.1).

3. Results

3.1. Single linear regression: time and symmetry

Single linear regression analysis was carried out using the independent variables log FS and log SS, respectively with, in turn, total time to butcher (t_1) and the time for each individual butchery process (t_{1s}, t_{1f}, t_{1d}, t_{1j} and t_{1l}), separately for each butcher. The regression of individual processes against log FS and log SS was carried out to test whether greater symmetry increased the handaxe's effectiveness for certain processes alone rather than for the entire butchery process. However, none of the regressions were significant when $p = 0.05$ (Table 6).

When graphing the data it became clear that one handaxe, H2 in B1's assemblage, stood out as having a comparatively

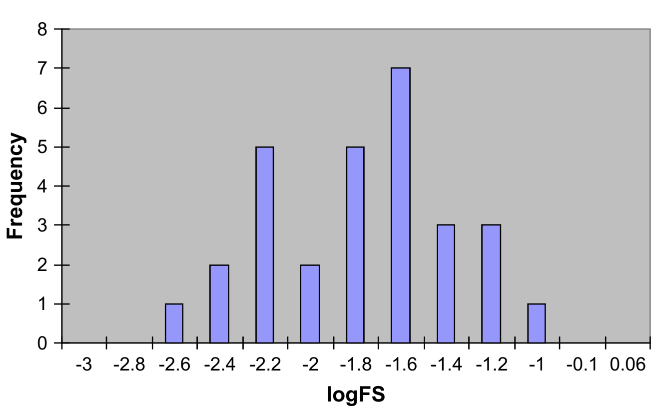

Chart 5. Histogram of the logged frontal symmetry data for B2's experimental handaxe assemblage (Kolmogorov–Smirnov normal distribution test: $p = 0.809$).

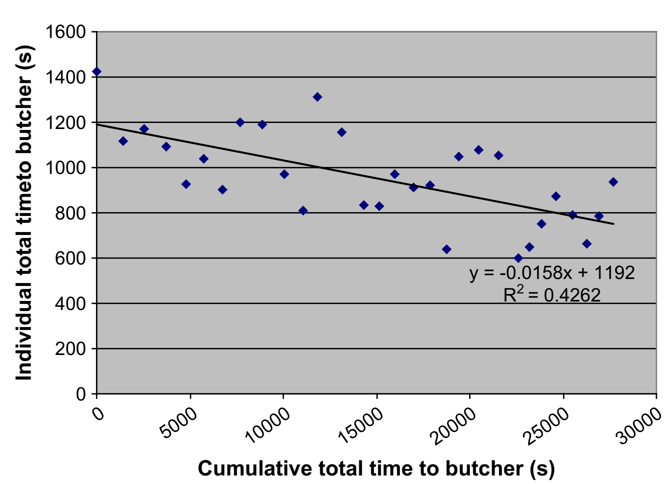

Chart 6. Cumulative total time to butcher plotted against individual total time to butcher for B2, including the linear regression trend line.

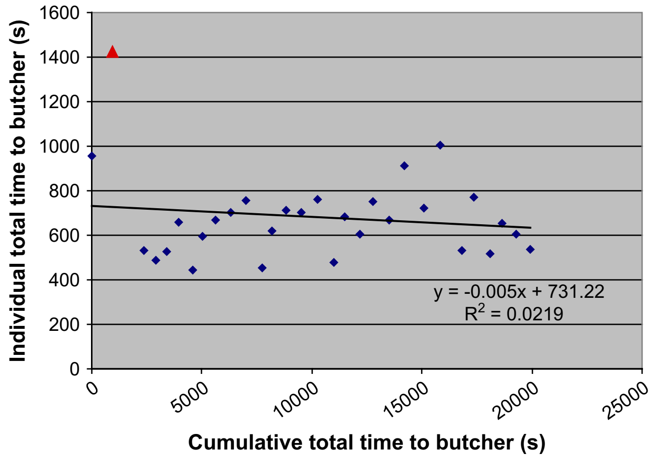

Chart 7. Cumulative total time to butcher plotted against individual total time to butcher for B1, including the linear regression trend line. The outlier H2 is identified by the red triangle.

high t_1 value (Chart 7) and hence forms an outlier to the data set which may unduly influence the results. H2 does not exhibit any striking morphological characteristics which separate it from the other handaxes, indeed the fact that it is relatively refined with a fully knapped circumference may make it subjectively more functional than some that do not bear these traits (Fig. 2). Further, the carcass used to test H2 does not appear to have been unusually tough to butcher as the same carcass was utilised to test handaxe H3. While using handaxe H2, however, butcher B1 appears to have had relative difficulty with cutting the skin, an assertion which is supported by a relatively high t_{1s} time, and that, while fully knapped, the cutting edge is not very sharp. Therefore, the most likely explanation for H2's outlier status is that it was not suitable for the cutting of skin, leading to a high overall butchery time.

The regression analysis was repeated using B1's data set with H2 removed (Table 7). When $p = 0.01$ there is a moderate, but significant relationship between log FS and t_{1s} ($p = 0.000$, $r = 0.606$, $r^2 = 0.367$). When $p = 0.05$ there is a moderate, but significant relationship between log FS and

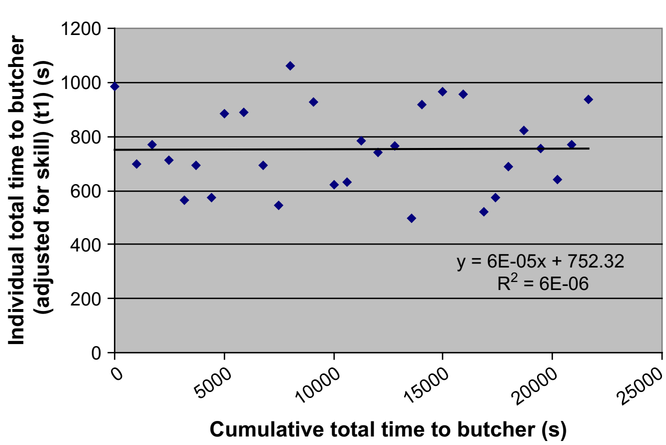

Chart 8. Cumulative total time to butcher plotted against individual total time to butcher (adjusted for skill) (t_1) for B2, including linear regression trend line.

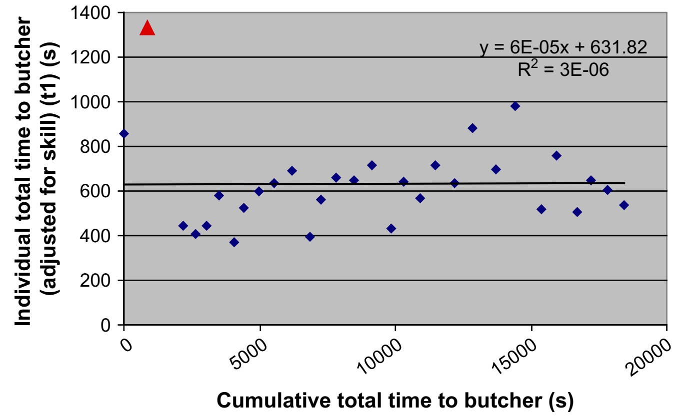

Chart 9. Cumulative total time to butcher plotted against individual total time to butcher (adjusted for skill) (t_1) for B1, including linear regression trend line. The outlier H2 is identified by the red triangle.

t_1 ($p = 0.013$, $r = 0.458$, $r^2 = 0.210$) and a weak, but significant relationship between log FS and t_{1f} ($p = 0.034$, $r = 0.395$, $r^2 = 0.156$).

3.2. Single linear regression: hind time and symmetry

Comments made by both butchers during the course of the experiments suggested that the handaxes became less effective during use. This became particularly evident when attempting to cut the skin and the ligaments on the second limb. A constraint of the experimental methodology was that only one handaxe was made available for the butchery of each half carcass, with no allowance for resharpening; archaeological evidence suggests that handaxes were regularly retouched to refresh a dulled edge (Hallos, 2005; McPherron, 2003; Roberts and Parfitt, 1999; Singer et al., 1993). In case the presence of blunting was skewing any relationship between symmetry and effectiveness for butchery the hind limb time data were analysed separately – the hind limb being the first limb butchered in 25 cases for B1 and 30 cases for B2. As with the other timing data, skill was removed as a factor for all the hind limb

Table 6
Results of the regression of the time variables against the logged symmetry variables

Independent variable	Dependent variable	B1		B2	
		r^2	p	r^2	p
log FS	t_1	0.107	0.078	0.020	0.461
log SS	t_1	0.001	0.897	0.068	0.164
log FS	t_{1s}	0.086	0.115	0.013	0.554
log SS	t_{1s}	0.001	0.893	0.019	0.466
log FS	t_{1f}	0.118	0.063	0.001	0.842
log SS	t_{1f}	0.002	0.834	0.061	0.187
log FS	t_{1d}	0.022	0.430	0.029	0.368
log SS	t_{1d}	0.016	0.501	0.092	0.103
log FS	t_{1j}	0.065	0.173	0.100	0.089
log SS	t_{1j}	0.000	0.967	0.034	0.332
log FS	t_{1l}	0.074	0.146	0.011	0.582
log SS	t_{1l}	0.012	0.565	0.031	0.351

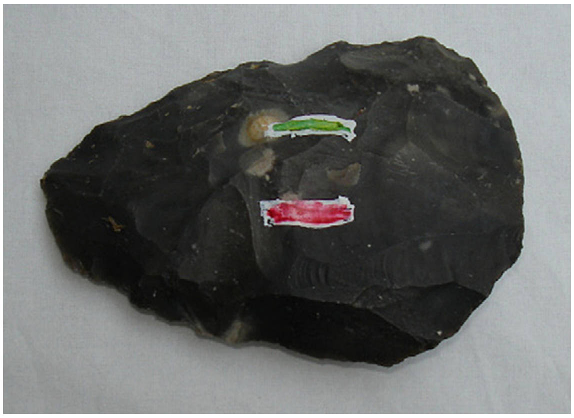

Fig. 2. Frontal view of handaxe H2 from B1's experimental assemblage.

time data. This analysis resulted in a moderate, but significant relationship between log FS and $t_{1d(hind)}$ when $p = 0.05$ for B1 ($p = 0.035$, $r = 0.422$, $r^2 = 0.178$) (Table 8).

This regression analysis was then repeated using B1's data set without H2. When $p = 0.01$, moderate but significant relationships exist between log FS and $t_{1(hind)}$ ($p = 0.007$, $r = 0.534$, $r^2 = 0.285$) and $t_{1s(hind)}$ ($p = 0.002$, $r = 0.606$, $r^2 = 0.368$). When $p = 0.05$, moderate but significant relationships exist between log FS and both $t_{1f(hind)}$ ($p = 0.043$, $r = 0.416$, $r^2 = 0.173$) and $t_{1d(hind)}$ ($p = 0.040$, $r = 0.421$, $r^2 = 0.177$) (Table 7).

3.3. Multiple linear regression: time and independent variables

Following completion of the single linear regression analysis, a multiple linear regression analysis of the time data was undertaken to investigate whether a more sophisticated statistical approach would yield any further significant patterns. This required a larger data set and consequently, those from the two butchers were combined ($n = 60$). A multiple linear regression was carried out using t_1 as the dependent variable and log FS, log SS, weight, length, breadth, thickness, elongation, thinning, percentage of the circumference worked and butcher as the independent variables. Only the independent variable of butcher was significant and this explained 8.9% of the variation in butchery time ($p = 0.012$). When the outlier, H2, was removed, log FS was also significant, and, in combination with butcher, explained 22.6% of the variation in butchery time ($p = 0.030$, $p = 0.001$, respectively).

Table 7
Results of the regression of the time variables for the hind and fore limb and hind limb only against the logged symmetry variables for B1's data set without H2

Independent variable	Dependent variable	r^2	p	Independent variable	Dependent variable	r^2	p
log FS	t_1	0.210	*0.013*	log FS	$t_{1(hind)}$	0.285	*0.007*
log SS	t_1	0.000	0.914	log SS	$t_{1(hind)}$	0.018	0.532
log FS	t_{1s}	0.367	*0.000*	log FS	$t_{1s(hind)}$	0.368	*0.002*
log SS	t_{1s}	0.003	0.795	log SS	$t_{1s(hind)}$	0.008	0.671
log FS	t_{1f}	0.156	*0.034*	log FS	$t_{1f(hind)}$	0.173	*0.043*
log SS	t_{1f}	0.006	0.698	log SS	$t_{1f(hind)}$	0.059	0.255
log FS	t_{1d}	0.023	0.429	log FS	$t_{1d(hind)}$	0.177	*0.040*
log SS	t_{1d}	0.015	0.528	log SS	$t_{1d(hind)}$	0.003	0.816
log FS	t1j	0.078	0.142	log FS	$t_{1j(hind)}$	0.055	0.270
log SS	t_{1j}	0.001	0.873	log SS	$t_{1j(hind)}$	0.046	0.313
log FS	t_{1l}	0.077	0.146	log FS	$t_{1l(hind)}$	0.029	0.426
log SS	t_{1l}	0.014	0.539	log SS	$t_{1(hind)}$	0.006	0.727

Significant relationships are italicised ($r^2 = r$ square; $p =$ significance).

Table 8
Results of the regression of the time variables for the hind limb against the logged symmetry variables

Independent variable	Dependent variable	B1		B2	
		r^2	p	r^2	p
log FS	$t_{1(hind)}$	0.155	0.052	0.020	0.460
log SS	$t_{1(hind)}$	0.007	0.690	0.053	0.222
log FS	$t_{1s(hind)}$	0.097	0.130	0.007	0.657
log SS	$t_{1s(hind)}$	0.001	0.908	0.128	0.052
log FS	$t_{1f(hind)}$	0.138	0.068	0.001	0.859
log SS	$t_{1f(hind)}$	0.045	0.311	0.072	0.151
log FS	$t_{1d(hind)}$	0.178	*0.035*	0.021	0.446
log SS	$t_{1d(hind)}$	0.002	0.822	0.008	0.641
log FS	$t_{1j(hind)}$	0.054	0.264	0.100	0.089
log SS	$t_{1j(hind)}$	0.047	0.299	0.034	0.332
log FS	$t_{1l(hind)}$	0.021	0.487	0.033	0.334
log SS	$t_{1l(hind)}$	0.007	0.697	0.093	0.101

Significant relationships are italicised ($r^2 = r$ square; $p =$ significance).

3.4. Kendall's Tau-b: subjective data and symmetry

In addition to the time data, other measures of handaxe effectiveness were recorded during the experiments, requiring each butcher to score each handaxe using seven, five point ordinal scales (Table 5). These scales reflect the handaxe's overall usefulness for a series of butchery processes, aspects of the handaxe's morphology (i.e. weight and cutting edge) and a measure of ease of use (relating to comfort in the hand and ergonomics, for example). With regard to the hypothesis (stated above), the key relationship to consider is that between the ordinal scale scores and the degree of frontal symmetry (FS) and side symmetry (SS) exhibited by each handaxe. This required the transformation of the symmetry data from interval to ordinal scale data to enable its comparison with ordinal scale variables using a rank correlation test. To do so the handaxes were ranked in order of increasing frontal (FS) and then side symmetry (SS).

Having categorised the handaxes, resulting in one ranking for frontal symmetry and one for side, the relationships between the ordinal scoring data and the symmetry ranks were analysed using Kendall's Tau-b. For B1 this constituted the scoring data from 18 handaxes, as a result of the methodological change which occurred after the first two sessions (see above), and 30 handaxes for B2.

When considering the results of this analysis the most striking are those for B2, which suggest that significant relationships exist between frontal symmetry and various measures of usefulness. When $p = 0.01$, significant relationships exist between log FS and, for the fore limb, overall usefulness for butchering ($p = 0.009$, $r = -0.324$) and cutting flesh ($p = 0.001$ and $r = -0.360$). When $p = 0.05$, significant relationships exist between log FS and, for the hind limb, overall usefulness for butchery ($p = 0.044$, $r = -0.266$), quality of the cutting edge ($p = 0.037$, $r = -0.274$), and usefulness for cutting flesh ($p = 0.028$, $r = -0.303$) and ligaments ($p = 0.049$, $r = -0.299$). For the shoulder, a significant relationship exists at the $p = 0.05$ level for log FS and the quality of the cutting edge ($p = 0.015$, $r = -0.318$) (Table 9). These results do allow the null hypothesis of no relationship between symmetry and effectiveness to be rejected in some cases – the negative correlations indicate that as asymmetry increases usefulness decreases – but it is important to note that the strength of the significant relationships is at best weak, not all results are significant and none of the results for B2 are replicated by B1. Likewise, the two significant relationships present in B1's results are not replicated by B2. One possible reason for this lack of replicability is that the less skilled butcher may be placing greater emphasis on the assumed advantages of symmetry than the more skilled butcher; it must also be borne in mind that B2's subjective opinion may be biased by his knowledge of the considerable literature relating to handaxe form and function.

4. Discussion and conclusions

The experiments and statistical analyses of the results reported here provide some support for the hypothesis that increasing frontal symmetry increases the effectiveness of handaxes as butchery tools. This is indicated on the basis of three tests: (1) the results for B1's data set without H2, which indicates a moderate but significant relationship between log FS and t_1, t_{1s}, t_{1f} (for both limbs and the hind limb alone) and t_{1d} (for the hind limb data alone); (2) the results of the multiple regression, showing that when combined with the butcher variable log FS explains 22.6% of the variance in t_1; and (3) the results of the Kendall Tau-b test on B2's subjective scorings all suggest that frontal symmetry may have some role to play in handaxe effectiveness.

These statistically significant results for frontal symmetry are not particularly strong however, and have mitigating factors. The statistically significant result from B1's data set only arose following the removal of H2 from the analysis on the basis of it being an outlier, but the justification for doing so is contentious. With regard to the multiple regression, this shows that a large amount of variation in butchery time, nearly 78%, cannot be explained by any of the variables regarding handaxe morphology. When considering B2's subjective scorings of handaxe effectiveness, while significant relationships do exist, these are all weak and for the most part only significant at the 5% level. Moreover, a concern remains that B2's archaeological knowledge may have led to a biasing in his subjective scoring towards a preference for symmetry. Finally, while B1's objective results and B2's subjective results provide support for the hypothesis neither are replicated by the other butcher. This leads us to conclude, on the basis of the data available here that at the very most frontal symmetry has a small role to play in handaxe effectiveness. The small amount of impact that it does have could be due to something as straightforward as the slight gain in efficiency associated with the reduced amount of time it takes to locate a good handhold on a symmetrical handaxe following rotation. Alternatively, or in addition to this, the lack of replication of results might suggest that symmetry plays a small role in effectiveness only if the nature of the butchery method adopted by the individual renders symmetry advantageous.

There were no statistically significant results indicating that side symmetry is effective for butchery. However, the verbatim record for B2 refers several times to the importance of the symmetry of the cutting edge: for instance, ''*...the angle I'm finding really hard because its kind of asymmetrical...I haven't got a perfectly symmetrical cutting edge so the edge*

Table 9
Results of Kendall's Tau-b analysis of the subjective data

Scoring category	B1				B2			
	log FS		log SS		log FS		log SS	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Ease of use	0.301	0.126	−0.041	0.839	−0.191	0.164	−0.133	0.359
Weight	0.314	0.111	−0.110	0.535	−0.117	0.465	−0.247	0.092
Hind								
Overall usefulness	0.277	0.175	−0.112	0.551	−0.266	*0.044*	−0.145	0.349
Cutting edge	0.244	0.205	−0.183	0.277	−0.274	*0.037*	−0.118	0.403
Usefulness for skinning	0.388	*0.005*	−0.038	0.831	−0.064	0.673	−0.085	0.595
Usefulness for flesh	0.222	0.231	−0.238	0.181	−0.303	*0.028*	−0.056	0.715
Usefulness for ligaments	0.291	0.104	−0.052	0.736	−0.299	*0.049*	−0.197	0.197
Shoulder								
Overall usefulness	0.287	0.130	0.034	0.857	−0.324	*0.009*	−0.143	0.269
Cutting edge	0.236	0.220	−0.101	0.637	−0.318	*0.015*	−0.035	0.815
Usefulness for skinning	0.130	0.542	−0.284	0.094	−0.098	0.523	−0.098	0.512
Usefulness for flesh	0.211	0.319	−0.227	0.195	−0.360	*0.001*	−0.106	0.455
Usefulness for ligaments	0.346	*0.023*	−0.105	0.510	−0.220	0.087	−0.073	0.607

Significant relationships are italicised (r = correlation coefficient; p = significance).

symmetry is playing a role here''. While references to the importance of aspects of side symmetry were only made by one butcher, and his conclusions were not supported by the statistical analysis, it may be worth pursuing this issue further as these comments referred to the symmetry of the edge rather than to the overall side symmetry of the handaxe which is the attribute measured by the Acheulean Biface Database software (Marshall et al., 2002). This potential functional utility for the symmetry of the cutting edge is perhaps unsurprising as it measures an aspect of handaxe morphology, which is critical to butchery. The verbatim records have highlighted the important role that aspects of the cutting edge – degree of refinement, angle, degree of curve, degree of symmetry – play in the effectiveness of the handaxe for butchery and it could be posited that such aspects may contribute to the 77.4% of variance in time which remains unexplained. Unfortunately, it was not within the scope of this study to carry out further, more detailed analyses of the morphology of the cutting edge and test these in relation to effectiveness, although the experiments have generated the relevant data to test this in a future study.

In addition to the more complex variables of the cutting edge another key variable that requires attention, but was absent in terms of measurement from this study, is that of effort. The most accurate measure of the relationship between time and symmetry would require the butchers to apply a consistent degree of effort throughout the experiment. It is clear from the verbatim records, in which references to tiredness, brute force, power and pressure are repeatedly made that this was not the case. Furthermore, the fact that B1 was able to rest between sessions, while B2 could not (see above) may have meant that tiredness impacted upon the butchers to different extents. The verbatim record already makes clear that there is a link between the need for less effort and aspects of the handaxe's morphology, for example, a thinned piece with a tranchet finished tip, but it would be desirable to analyse this further on an objective basis. The closest proxy to effort we have within this analysis is the subjective measure of ease of use. However, the results of the Kendall's Tau-b analysis do not indicate a significant relationship between this measure and symmetry.

In addition to symmetry, seven other morphological variables were introduced into the regression analysis to assess their impact upon effectiveness. The results were non-replicable between butchers, with significant relationships existing within B1's data set between both t_1 and t_{1d} and the logged data for breadth and elongation but not for B2's, even though B2 expressed a preference for elongation in the verbatim record. Further, while B1's data set, with and without H2, produced some significant results when carrying out single linear regressions with the morphological variables, a multiple regression did not reproduce these results.

In conclusion, the statistical analysis of the quantitative and ordinal data suggests that there may be some influence of frontal symmetry upon handaxe effectiveness. However, this conclusion carries with it several qualifications relating to replicability, the exclusion of outliers and the strength of the observed relationships. While this study is a first attempt to analyse the butchery effectiveness of handaxes on a large-scale, quantitative basis, and the use of only one medium sized species, one raw material and two butchers limits the data set in certain respects, we suggest that in light of the analysis results, factors other than functional considerations for animal butchery are playing a key role in the decisions by hominin stone knappers to impose high degrees of symmetry on some of their handaxes. We hope that reporting these results and conclusions will stimulate others to carry out large-scale butchery experiments with the aim of replicating or challenging our findings.

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