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Elongation as a factor in artefacts of humans and other animals: an Acheulean example in comparative context

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Research

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Elongation is a commonly found feature in artefacts made and used by humans and other animals and can be analysed in comparative study. Whether made for use in hand or beak, the artefacts have some common properties of length, breadth, thickness and balance point, and elongation can be studied as a factor relating to construction or use of a long axis. In human artefacts, elongation can be traced through the archaeological record, for example in stone blades of the Upper Palaeolithic (traditionally regarded as more sophisticated than earlier artefacts), and in earlier blades of the Middle Palaeolithic. It is now recognized that elongation extends to earlier Palaeolithic artefacts, being found in the repertoire of both Neanderthals and more archaic humans. Artefacts used by non-human animals, including chimpanzees, capuchin monkeys and New Caledonian crows show selection for diameter and length, and consistent interventions of modification. Both chimpanzees and capuchins trim side branches from stems, and appropriate lengths of stave are selected or cut. In human artefacts, occasional organic finds show elongation back to about 0.5 million years. A record of elongation achieved in stone tools survives to at least 1.75 Ma (million years ago) in the Acheulean tradition. Throughout this tradition, some Acheulean handaxes are highly elongated, usually found with others that are less elongated. Finds from the million-year-old site of Kilombe and Kenya are given as an example. These findings argue that the elongation need not be integral to a design, but that artefacts may be the outcome of adjustments to individual variables. Such individual adjustments are seen in animal artefacts. In the case of a handaxe, the maker must balance the adjustments to achieve a satisfactory outcome in the artefact as a whole. It is argued that the need to make decisions about individual variables within multivariate objects provides an essential continuity across artefacts made by different species.

1. Introduction

Tools made by humans and other animals have certain common features—in particular, tools used in the hand (or beak) usually have dimensions of length, breadth and thickness, a balance point, perhaps a working edge, and can be considered in terms of their mechanical properties. Although these simple characters allow a basic comparative study across species, they are as yet largely unexploited. In general, we know insufficient about the concepts or idea sets that underlie their manufacture, and particularly about the combinations of factors that influence the final product—how much is owing to tradition, how much to individual experience, and how much to the specific task and material.

This paper explores one particular aspect of tools that is often found—elongation. Even simple tools are often extended from fore to aft, and have distinct butt and tip ends. Many of the tools which human beings and chimpanzees make are long and slender. The paper has two aims: (i) to explore the issues on a comparative basis, and (ii) with the assistance of a case study to evaluate what elongation tells us about the way variables are manipulated and adjusted. Although it may seem an arbitrary decision to select elongation for special attention, the imposition or use of a long axis can be seen as a crucial element in simple tool-making. It also occurs repeatedly in artefact adaptations through the course of hominin prehistory. My argument is that elongation can be found in nature or constructed according to need, and that exploring it can help us to see how individual variables are handled in the shaping of multivariable objects.

A definition of elongation is that an object is long in relation to its breadth. Dictionary definitions do not specify how long or narrow, but some psychological frame is given by studies of shape preferences in modern humans. These show that moderately elongated rectangles are preferred to those that tend towards being square or very narrow, but also that there is great individual variability [1]. Other discussions provide a broader context in neural and cognitive terms for the use of such tools in both humans and other animals [2,3]. For the past, archaeological studies provide some insights and measured values. Traditionally, the classic example is the major change of tools found when modern humans replaced Neanderthals across Europe around 40 000 years ago [4]. From the nineteenth century, the contrast between the flake tools of the Mousterian and the blades of the Upper Palaeolithic struck scholars as having a special meaning, bolstered by the artwork and sophisticated stone tools found with the Upper Palaeolithic [4,5]. British scholars such as Burkitt and Clark stressed the blades as marking the change, and Clark emphasized their importance by giving them a new value in his Mode scheme (Mode 4 as opposed to Mode 3 for the preceding flake traditions) [5,6]. It is interesting that continental scholars placed less emphasis on abrupt change: for the French prehistorian Francois Bordes, a Middle Palaeolithic blade could be almost identical to an Upper Palaeolithic blade, and he took the breadth/length (B/L) value 1 : 2 as a measure [7]. Leroi-Gourhan stressed in explicitly evolutionary terms the idea of a continuous development in the length of usable cutting edge that could be unleashed from 1 kg of flint, a value rising from 4 m in the Middle Palaeolithic to 10 m or more in the Upper Palaeolithic [8]. In this trend, he argued that the earlier development of Levallois flakes was the most important development of all, but the most elongate forms described come within the last 40 000 years. Karlin, following Leroi-Gourhan, and working with impressive stone toolkits of the late Magdalenian, classified 1 : 3 as an elongate flake, 1 : 4 as a blade and 1 : 6 as a narrow blade [9].

The Upper Palaeolithic ‘revolution’ still has a major hold on the minds of scholars [10], although it is now well-appreciated that blade tools widely antedate it [11]. Even now, the origins and significance of elongation in the record of stone tools are largely unexplored. Parallels with use of elongated forms by other animals are almost completely unstudied. Yet, the broader context has changed immensely in recent years through primate studies [12–17] and new archaeological finds, so that a new perspective is a necessity. To an increasing extent a comparative perspective is possible, because wooden stems and staves are readily available in nature and regardless of species lend themselves to the manufacture of tools which have qualities of both length and elongation.

Elongate forms seem to be made or used for several reasons. One is to allow further reach, or limb extension, as noted by Köhler in chimpanzees as early as the 1920s [20,21]; related is to allow probing within a hole, and perhaps extraction of substances or creatures which cling to the stem; in projectiles, the shafts of spears may be throwable with more accuracy than rounded objects; in cutting objects, elongation may simply provide a longer working edge, or application of work at a greater distance from the body. The common theme in all these uses—the probable spur for the adaptation—is more effective application of force at distance. In general, the elongate forms allow probing, thrusting (and at least in hominin cases), throwing and cutting so as to gain resources which would otherwise not be available, but without doubt there are other functions not mentioned here.

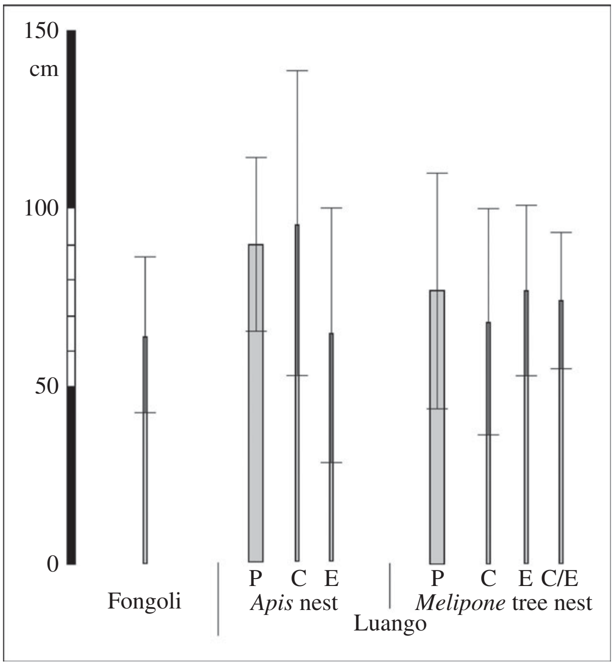

Figure 1. Comparisons of size and elongation in some chimpanzee artefacts involving the use of sticks or stems, showing mean lengths (with s.d.) and mean diameters. From the left, Fongoli probing/thrusting tools [18] and two honey tool sets from Luango [19]. There is an overall similarity in length, but thickness/diameters vary according to function: pounding tools (P) for breaking into bees’ nests are much thicker than collector (C) and enlarger (E) tools.

2. Animal artefacts

Artefacts made by non-human animals give valuable insights into the inferences that we can draw from human artefacts, and vice versa [22–25]. In the case of elongation, a starting point is that most artefacts are made from a single raw material, selected to be oversize and then reduced to the appropriate form. The principle would seem to be that initial selection is followed by the construction of form—sometimes in successive steps. That principle applies to chimpanzee and capuchin artefacts, and to most products of early humans, and has also been observed in activities of New Caledonian crows and other tool-using birds. In each case, there are indications of selection being applied to individual variables. In the case of crows, they have been observed separately to select appropriate diameter of a stick, and to select appropriate length among varied lengths of stick provided [26].

Stems also seem to be selected for qualities of both length and diameter by chimpanzees. An example are sticks from Fongoli in West Africa used for probing for and stabbing

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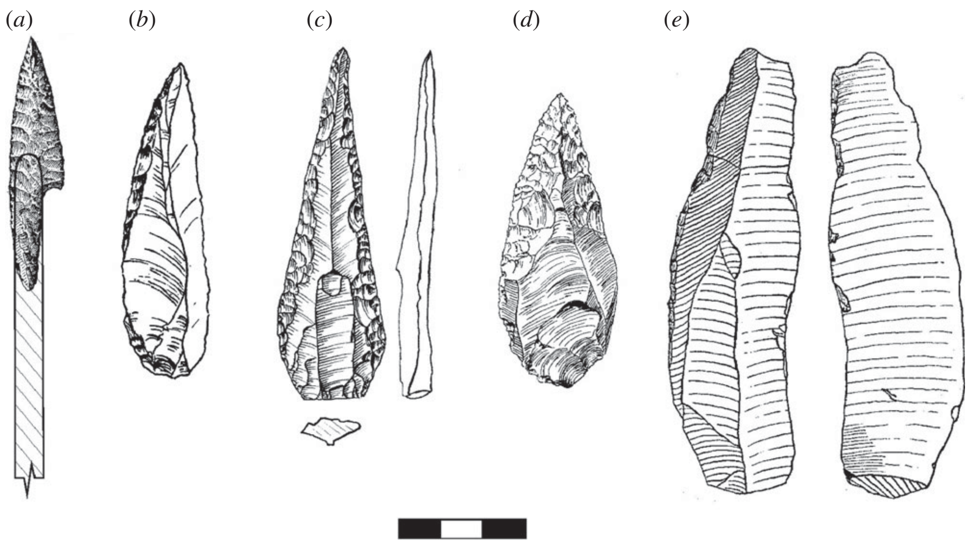

Figure 2. Some examples of elongate stone tools (scale in cm). (*a*) Solutrean point (modified after de Mortillet [42] and Geneste and Plisson [43]). (*b*) Upper Palaeolithic Chatelperron point, after Burkitt [44]. (*c*) Elongate Middle Palaeolithic point of the Hummalian, after J.-M. Le Tensorer [45]. (*d*) Elongate Middle Stone Age point from Kenya (after Leakey [46]). (*e*) Blades from Kapthurin, Kenya (author).

bushbabies [18]. The 'spears' of Fongoli have a mean length of about 60 cm. They range from about 5 to 15 mm in thickness, and have been prepared by clipping at both ends, stripping of side shoots, and in eight cases, stripping of bark from the entire surface. Elsewhere sticks used for ant dipping are also commonly prepared by brushing off side shoots [15]. Detailed descriptions have been given of the preparation and use by chimpanzees of tool sets for breaking open bees' nests and extracting honey in Gabon [19]. Analyses of operational sequences (cf. the archaeological terminology of Leroi-Gourhan [8]) indicate that in a multi-stage process chimpanzees strip side shoots before cutting the tool to its final length. Notably, tools used for pounding into the bees' nests have considerably greater diameter, and hence mass, than those used for extracting. In a number of cases, these different tools have similar mean lengths (figure 1).

Preparation of sticks has been observed in other primate and bird species, including orangutans [27] and woodpecker finches [28,29]. Similar activity has been observed in capuchin monkeys in Brazil on a regular basis [30]. Among around 175 stick artefacts recorded only 13.7% were used without modifications, with cutting, snapping and/or tip thinning occurring in at least three-quarters of cases.

These and other examples [31–34] show the extent of selectivity and deliberate physical interventions in the preparation of stick tools in a way that appears common across species. In their evaluations, authors often use similar language, concurring broadly that the tools are prepared with some anticipation so as to be ready for their task, and also sometimes indicating that the animals are relying on previously acquired knowledge in making their judgements (rather than learning on the observed task). Woodpecker finches, on the other hand, have been observed to learn to strip off side shoots by trial and error [28], and the extent of an animal's awareness of the properties of its tools is the subject of debate [2,29,35,36].

From current evidence, it would be hard to assert that the non-human animals have an overview of all the variables at the same time, or that one is adjusted in relation another. Even so, a generalized completion judgement must be made [23]; otherwise, the maker would go on modifying the tool. Some evidence suggests strongly that the animals may have a general appreciation or internal representation of the object, certainly in the case of monkeys [37], and the ability of macaques to recognize objects after rotation [38,39] must indicate an internal indexing of object characteristics across multiple variables. Frey & Povinelli [40] show that chimpanzees estimate costs of future actions in relation to their appreciation of an artefact's properties. Some knowledge of the whole artefact may be essential to maximizing its benefits in use—cost-effectiveness is likely to be crucial to the success or failure of artefact-using adaptations. What is quite certainly shown across species is a strong selectivity, some appreciation that 'appropriate' quality is required, for example, in length or breadth, and a tendency to work towards a suitable form in the successive steps.

3. Elongation in early human artefacts

The human record gives us the advantage of seeing time depth through more than 2 million years [41]. Wood and bone survive so infrequently that the main focus passes to stone (figures 2 and 3). This imbalance of preservation is unfortunate, because organic materials would certainly offer a major continuity with tools of non-human animals. Three archaeological sites embracing the range 300 000–700 000 years indicate the largely lost potential: Schöningen in Germany, Kalambo Falls in Zambia and Gesher Benot Ya'aqov in Israel [47–50]. Wooden tools preserved, especially the Schöningen spears and staves, and various pointed sticks from Kalambo Falls (figure 4) suggest that similar artefacts were very widely useful.

Although a comparative approach is harder in the case of stone tools, the same basic principles of reduction apply to both the organic and inorganic materials [51,52]. The working techniques are necessarily different. Chewing, cutting and whittling are used for shaping stems and wood; mastery of conchoidal fracture can allow comparable results for stone. The stone tools show that elongation as a particular characteristic goes back a long way in time, and that it makes a useful comparative character.

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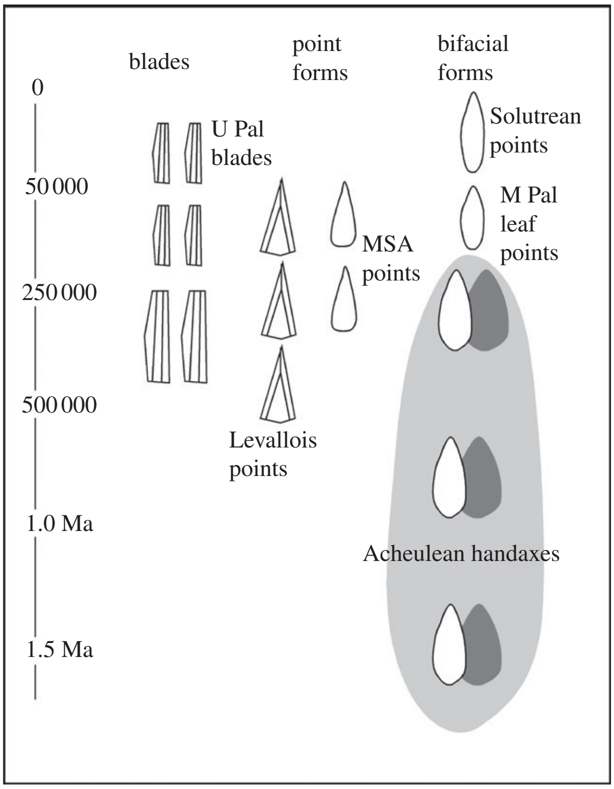

Figure 3. Artefacts in time series: a general representation of elongation in stone artefacts through the past 2 million years. MSA refers to the Middle Stone Age of Africa, time range approximately 40 000–400 000 years ago.

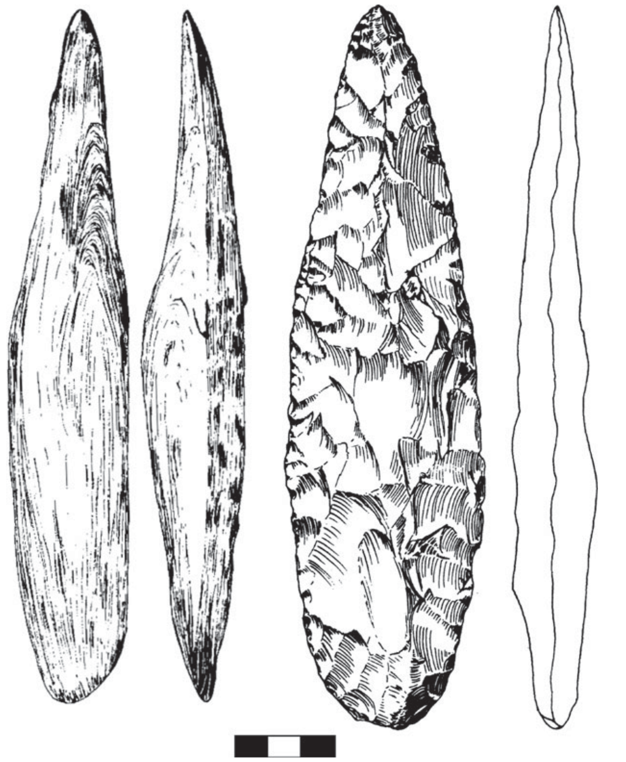

Figure 4. A wooden tool and a Lupemban point from Kalambo Falls, the two showing very similar dimensions (scale in cm) (after Clark [49] courtesy Cambridge University Press).

The blades of the Upper Palaeolithic (approx. 10 000–50 000 years ago) can be highly impressive (figure 2). Their manufacture represents one of the apogees of stone-age toolmaking. The elongation is only one of the skills shown. The best-worked Upper Palaeolithic cores require investment of time and selection, and a 'gearing' of time in which preparation work may take far longer than the final release of end products. Often, it can be seen that function played a role in determining form: thus, bladelets used for projectile tips are among the most elongate [53]. In general, across Upper and Middle Palaeolithic industries, it stands out that the elongation in stone artefacts was desired for more than one purpose. In both projectile points and hand points, it appears to have a strong link with hafting, which obviously entails the cognitive abilities to combine materials, and probably knowledge of glue and/or twine [54,55], the latter clearly a prerequisite for bows [56]. In the case of hand tools, elongation might relate to specific tasks, such as butchery or other cutting with need for a long edge. In the case of projectiles, the need for elongation is fundamental to their effective projection. If stone tips were used on arrows (which can be inferred for part of the Upper Palaeolithic), then their maximum permissible width would be *ca* 10 mm, constrained by the shaft diameter of 8–10 mm [43,57], and length of the stone point would be several times this. The skill of making a tang on an artefact allows the tip of an arrow to be broader than the shaft, and this too occurs, for example in the Aterian in north Africa [58,59]. In the Aterian, similar principles were applied to the making of elongate tips for probably slightly heavier javelins launched by spear-throwers. In projectiles, comparative analyses using ethnographic material and studies of tip cross sections allow distinction of arrows, thrown javelins and heavier spears, studies of arrow shafts, light throwing darts and spears, with approximate widths of 8–10, 10–20 and 30–40 mm, respectively [43,57,60]. In each case, the same principle applies, that the need for penetration, coupled with the constraint on shaft diameter, results in an elongated point.

In this period, some elongate forms also centred on the shaping of leaf points. These were made in many regions and at many times. Best known are the Solutrean points of France and Spain (*ca* 20 000 years ago), made on large blade blanks [61]. Replication studies of these intensely worked bifacial tools demonstrate the complexities of manufacture and show that one challenge for the maker was to maintain the length of the piece while narrowing it from the sides in the final flaking process. The final elongate form was thus obtained from a wider blank. This practice is common in stone working, but it is not certain that it has analogues in simple organic tools, other than in the clearing of side shoots from stems, which is done by chimpanzees, capuchin monkeys, some birds and humans.

The traditions have a far longer conceptual history: leaf points are found in the Middle Palaeolithic in Europe and across Africa [62,63]. They show that elongation was maintained as functionally desirable during successive stages in different technologies.

Before the classic blades of the Upper Palaeolithic, another set of techniques was able to deliver long and narrow blanks for such tools. The name Levallois has long been applied to these in a general way, but recent studies emphasize the great variety derived from so-called prepared cores [64–69]. The common thread is that the maker has to think ahead in the manufacturing process, shaping the stone core with small strikes preparing the way, so that at a certain key moment, the desired flake or blade can be released. In one form, the technique was well suited to making long and narrow convergent points which are almost universally termed Levallois points [69]. These could make good projectile tips, as well as hand-points.

This system is widespread between about 50 000 and at least 300 000 years ago. Similar points are found in Africa, Europe and Asia. Not all the blades were pointed, and it seems clear that they had other uses as cutting edges. Always their manufacture required a high degree of skill. This was certainly not restricted to modern humans and their ancestors. In northern Europe, the blade forms were common around 100 000–120 000 years ago [70]. They occur on occasion twice as long ago [71]. In all European cases, these tools must have been made by Neanderthals or their ancestors.

In the Middle East too, long and slender forms were common at times in the Middle Palaeolithic: Levallois blades form a possible context for the origins of the Upper Palaeolithic blade technique in the Sinai and Levant area. They also occur in the earlier Middle Palaeolithic, for example, the Amudian tradition at Mount Carmel [72], or at Qesem cave in Israel, where systematic production alongside the manufacture of handaxes appears to date back to around 400 000 years ago [73,74]. In the Hummalian tradition in Syria, long points were made on non-Levallois flakes [45]. It is in Africa that we can see the fullest story. Here, Levallois blades were commonly used for producing points through the last 300 000 years in the tradition of the Early–Middle Stone Age. In later times, these were often trimmed into fine bifacially worked points [63]. Again, a notable feature of the production is the variety—a prepared core technique is used in different ways for making handaxes, long blades and Levallois points. The conjunction of these techniques is best seen at Kapthurin near Lake Baringo in East Africa about 300 000 years ago [75,76].

Such variety implies varied uses, possibly involving both hand-held pieces and other tools with hafted projectile tips. The date of first projectile use is the subject of debate. Recent research at Kathu Pan in southern Africa suggests that Levallois points believed to have been used in hafted systems have dates as early as 500 000 years ago [77–79]. Other research suggests that stone projectile tips were introduced more recently, within the last 100 000 years [80–83]. In that case, many of the other elongate pieces would be cutting or scraping tools.

Systematic production of long blades and points appears to fade out beyond around 400 000–500 000 years ago [76–78], but the capability to make elongate forms is found in other guises, some extending further back in time. One example is in the points of the Lupemban, an early Middle Stone Age tradition of central Africa. These are often too long, broad and heavy to have been used as projectile points [49] (figure 3).

4. Elongation in the Acheulean handaxe tradition

The tools named handaxes are extremely well known, but it is much less recognized that they represent almost our only means of driving back the origins of imposed elongation for a further million years. They are the most obvious feature of a tradition which is one of the great phenomena of human prehistory. The Acheulean tradition runs from about 1.75 Ma at the earliest [84,85] to around 0.25 Ma, and sometimes later [86,87], the longest-lasting of all Palaeolithic traditions, widespread across Africa and Eurasia [88].

The characteristic Acheulean handaxes are well-known, but not easy to describe verbally. In plain view, authors often describe a tear-drop shape. In fact, plan shape varies enormously through pointed, ovate and splayed forms. They are stone tools, typically 10–20 cm long, somewhat elongated, and usually have an approximate bilateral symmetry around the long axis. They are often known as bifaces as they have two opposed faces, each of which may be carefully shaped. Trimming flakes are detached from the margin, which marks out a main plane, and is generally bounded by a sharp edge. In general, the bifaces seem to represent large hand tools, with a butt and a tip, and their elongation is moderate rather than extreme. Usually, breadth is about 0.6 of length, and to a remarkable degree, the average falls on the golden section ratio of 0.61 : 1 [89–91].

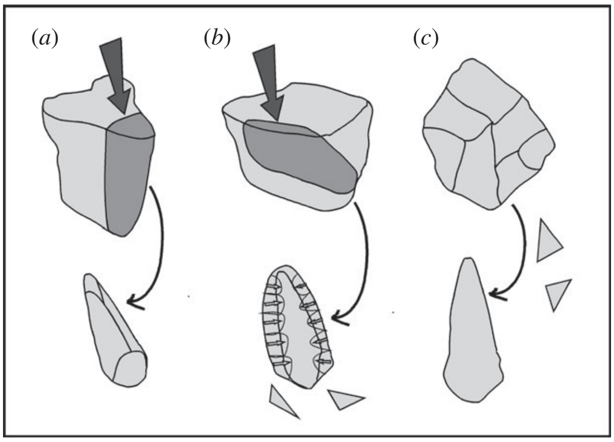

Figure 5. (*a*–*c*) Alternative ways of achieving elongation in bifaces: two variations on the practice of striking large flake blanks, and the idea of working down from a nodule.

Plainly however—and this is their special interest here—some bifaces were made to be much more elongate. The particular value of the information is that this cannot happen by accident: the elongation has to be constructed (figure 5). In one approach, very common in Africa, a large preform or blank is struck by the maker as a single flake, and then trimmed to its final form [92,93]. Sometimes, the maker would set up the core so as to strike the blank long and narrow, and also usually thick. This pick-like form may require very little subsequent trimming (figure 5*a*). Alternatively, a broader flake is struck and then trimmed from the margins to gain the final narrower form (figure 5*b*). In this case, seen, for example, at Kilombe in Kenya, there is an effort to narrow the piece without reducing its length. The other major approach, common in Europe, is to work the piece from a nodule, often on flint. A series of strikes roughs out the handaxe which may then be thinned in a long process. Again, it is not easy for the maker to maintain length, and it cannot be done without a specific intention (figure 5*c*).

The handaxes show us clearly that regularly over an exceptionally long period people were able to make long and narrow objects. Yet, the pattern is puzzling in some respects. Although the elongate specimens cannot be made accidentally, because of the special effort which they require, it appears that, in general, they are not the main design target in a series. Table 1 compiles data from a number of biface sets of different ages (San Isidro/Pinedo (Spain) [94] Kapthurin (Kenya) [75,76,95] Kalambo Falls (Zambia) [49] STIC (Morocco) [96] Kilombe (Kenya) [97] Kariandusi (Kenya) [98] Cornelia (S. Africa) [99] Peninj (Tanzania) [100,101]). It makes plain that, in most cases, the elongated specimens amount to no more than 5–30% of production.

Table 1. Percentage presence of elongate Acheulean bifaces with breadth/length (B/L) ratio 0.50 or less. (Columns: approximate age in millions of years; total sample number; number of specimens with ≤ 0.50; percentage of the elongated specimens; B/L ratio for all bifaces; mean length of all bifaces; mean length of bifaces with B/L ≤ 0.50. Measurements: author, except Kalambo Falls (D. Roe and J. D. Clark); Peninj (I. de la Torre). Principal site sources: San Isidro/Pinedo (Spain) [94] Kapthurin (Kenya) [75,76,95] Kalambo Falls (Zambia) [49] STIC (Morocco) [96] Kilombe (Kenya) [97] Kariandusi (Kenya) [98] Cornelia (S. Africa) [99] Peninj (Tanzania) [100,101].)

	approx. age (Ma)	*N* (all)	*N* with B/L ≤ 0.50	% with B/L ≤ 0.50	B/L all	mean length all	mean length with B/L ≤ 0.50
San Isidro	0.3	45	15	33	0.55 ± 0.07	148	164
Pinedo	0.3	58	4	7	0.61 ± 0.09	118	148
Kapthurin	0.3	35	2	6	0.68 ± 0.11	147	202
Kalambo Falls B4	0.4	25	4	16	0.61 ± 0.10	170	208
Kalambo Falls A6	0.4	47	8	17	0.58 ± 0.07	169	163
STIC	0.7	299	52	17	0.57 ± 0.09	161	178
Kilombe	1.0	627	35	6	0.60 ± 0.07	146	167
Kilombe AS	1.0	21	5	24	0.56 ± 0.07	138	148
Kariandusi	1.0	126	20	16	0.58 ± 0.06	164	186
Cornelia	1.0	12	6	50	0.54 ± 0.06	201	221
Peninj BAY	1.4	18	6	33	0.54 ± 0.09	179	199
Peninj MUG	1.4	77	20	26	0.59 ± 0.09	158	182

Many workers have noted that the assemblages with high mean length are also relatively narrower [102–106]. This allometric shift was studied in detail by Crompton & Gowlett [98] as part of an exercise in studying multivariate allometry. It can be summarized as stating that short specimens are often as broad as 0.75 of length, but that long specimens are often as narrow as 0.50 B/L. This is borne out by the figures of table 1, in which site by site specimens of 0.50 B/L or less average about 15% longer than the accompanying broader specimens (the subset of elongated bifaces is usually 20 mm or more longer than the whole series). It was suggested that the longer bifaces were made narrower to prevent weight scaling up excessively [37].

5. Kilombe as an example

The permutations can be explored with unusual clarity at Kilombe, a million-year-old site in Kenya. Here, it is possible to study more than 600 bifaces from one extended surface, with a rare opportunity to study local microvariation [89,97,98,107]. Kilombe as a whole reflects the ‘normal’ picture of Acheulean variation—not especially elongate, and with B/L a unimodal near-normal distribution (figure 6). At Kilombe, all together, just 35 bifaces of 627 are made to the proportion of 0.50 or narrower. These have an average length of 167 mm, considerably longer than the overall average of 149 mm. In the most elongate, Kilombe biface length is almost 2.5 times breadth (158 × 65 mm). Similar elongation is also reached in a massive specimen from La Caune de l’Arago in southern France, dated to about 0.57 Ma (330 × 140 × 65 mm; B/L 0.42) [108] (figure 7). Scatterplots indicate a continuous gradient from the short broad specimens to the larger elongate ones. This continuity can be taken to suggest that elongation does not emerge from separate design modes or shape preferences, but rather that processes

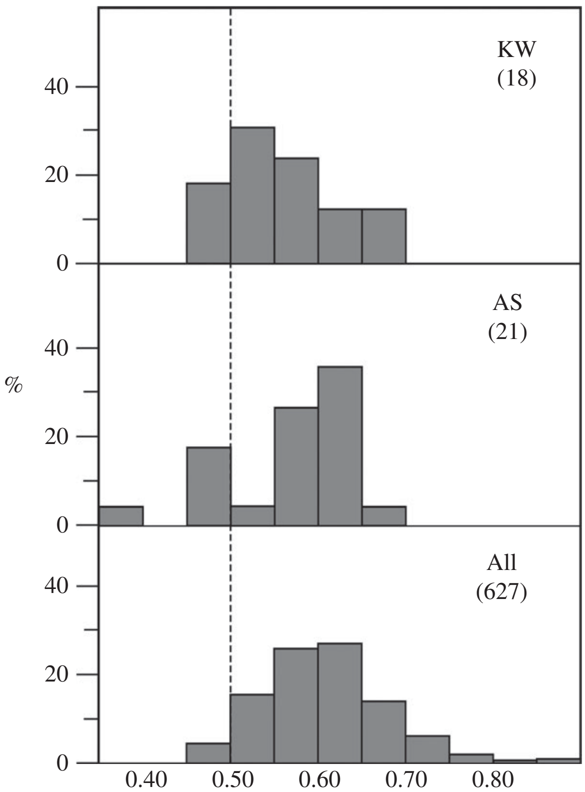

Figure 6. Breadth/length histograms for handaxes from Kilombe, showing how values for two elongate subsets depart from the main series: AS on the main site, and KW at a higher level.

operated which could be applied to a greater or lesser degree to individual specimens depending on needs and circumstances.

Exceptionally, however, one subassemblage of just 21 bifaces AS breaks the pattern. These handaxes were surface finds eroded from the site main horizon very close to the

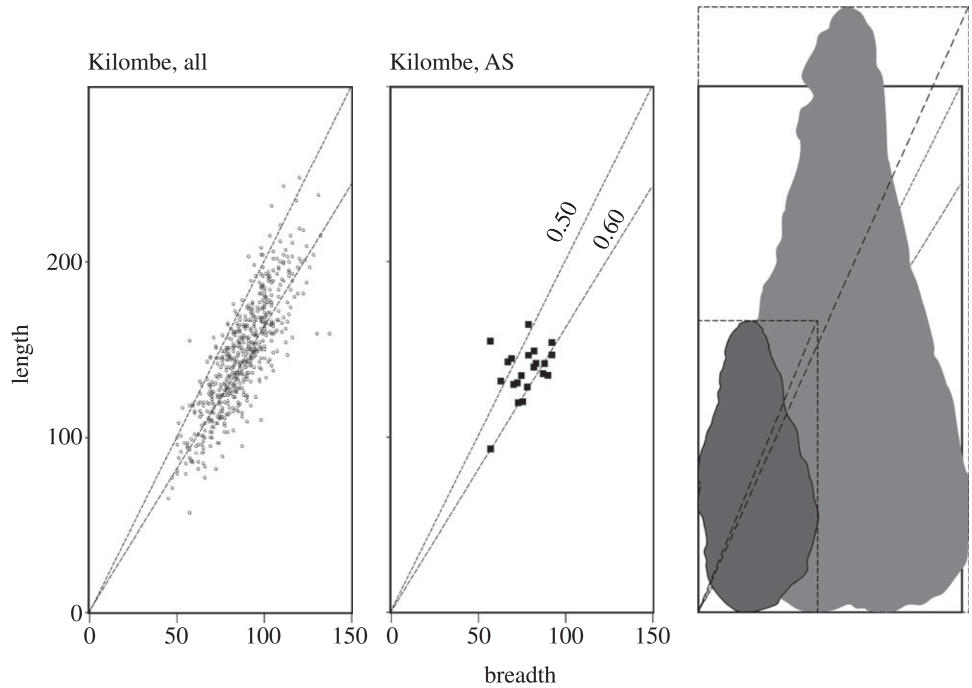

Figure 7. Breadth/length (B/L) proportions in Acheulean bifaces: elongate examples seen in relation to the scatter plot of all finds from Kilombe (scales in mm). Outlines show the most elongated biface from Kilombe (B/L 0.41) and (right) the outline of the grand biface from Arago in SW France, 33 cm long (B/L 0.42) [108].

physical centre of handaxe distribution. They include several of the most elongate bifaces on the whole site (five of 21, compared with 35 of 627: Fisher's exact test $p = 0.01$). Unusually for elongate bifaces, they are not large (figure 7), their length corresponding closely with the mean of the whole site.

This extreme local variation provides the particularly useful information that small groups of specimens do not need to follow the cultural norm for a whole set of bifaces. In the circumstances of archaeological recovery (finding abandoned specimens one million years later rather than seeing actual activity as with chimpanzees), it cannot be determined whether one or two individuals came to make such specimens habitually, contra the norm; or whether the functional needs of a particular situation led to the manufacture of unusually narrow specimens. If it can be seen as a general principle that in Acheulean individual variables are adjustable according to need, as if on a sliding scale, then the latter explanation seems more likely. My suggestion is that narrow and sharp points were required on the particular occasion, perhaps for a task of butchery or plant preparation which involved an unusual degree of 'winkling' out a small part from the larger whole. A few similarly narrow bifaces recur at the higher-level site of KW, about 1 km away, deposited following major volcanic eruptions in the area. They could thus be many thousand years younger than the main site, and indicate that similar conjunctions of demands could arise at other moments in time.

6. Time patterning of elongation in the Acheulean

High proportions of elongated specimens are present both on some late sites (e.g. San Isidro in Spain) and on some other relatively early sites, showing beyond doubt that the elongation could occur in the early Acheulean, well beyond 1 Ma. At Cornelia in South Africa, on a million-year-old site, six of 12 bifaces are at 0.50 or narrower, with an average length of 201 mm, and average B/L of 0.54 [99]. Thicker pick-like specimens are found at various periods, for example, the STIC Casablanca site at about 0.7 Ma [96,109] but also at much earlier dates at Chesowanja and particularly at Peninj in Tanzania [100,101]. Despite their age, such picks are sometimes more elongate than any other bifaces.

Certain repeating features can be seen in the data (the bifaces studied are selected across regions and age, although they cannot be totally representative of the huge Acheulean domain). First, the younger bifaces around 250 000–400 000 years old are not necessarily more elongate. Those from Kapthurin in Kenya and Pinedo in Spain include very low proportions of elongates; other assemblages measured, including Vaal Douglas and Holsdam from South Africa, and Sidi Abderrahman Cunette from North Africa contain no specimens more elongated than 0.50 (data in the electronic supplementary material).

Two recently published occurrences with argon–argon dates have pushed back the beginning of the Acheulean to around 1.75 Ma [84,85]. These are W. Turkana and Konso Gardula in southern Ethiopia. The numbers of bifaces are fairly small, but the photographs and figures indicate proportions that would be representative for the Acheulean at any later date.

It may be emphasized that the restricted proportion of elongate bifaces recurs across regions and across ages, and, in general, it is the longer bifaces that are the narrower. Although the possibility of an active preference for the 0.5 : 1 (or 1 : 2) ratio has been mooted [89], this idea cannot be certain as highly elongate specimens range to a value as narrow as 0.40 : 1 in a continuum. If 0.50 was preferred for long bifaces, then it was in an imprecise way, but it is notable that most bifaces greater than 200 mm in length tend towards this figure. As preferences for proportions are variable in modern humans [1], it is arguably unlikely that earlier humans would have inclined towards a fixed relation, but this idea of strong preference or fixedness in an abstracted design form is one for further consideration.

7. Discussion

An examination of tools across species (in the light of the bifaces which give time depth and large numbers) draws out various common themes. First, the artefacts show a high degree of selection carried on in operational activities. Then, there is evidence of separate attention given to variables such as breadth or diameter and to length. This is found in a range of species. In most cases in the artefacts made by non-humans, it is hard to determine on present evidence whether tool manufacturers make any general overview or review of the 'package' rather than the individual requirements, although this is possible [36]. Preparation of a stick tool often involves action A and action B and Action C (e.g. trim side shoots, break to length, thin tip), and it is possible that these are viewed as co-requirements rather than simply in sequence.

The handaxes do provide evidence of such an overview. Where a long biface flake is struck, to serve as a blank, it was often convenient or desirable for it to meet the requirements of several variables, so as to minimize subsequent trimming. This is evidence that the maker was considering the 'package' that would be required in the final tool. Even so, the side-trimming that is required for finishing the tools is a recurring phenomenon outside the Acheulean—occurring in later human artefacts and also in a sense in the chimpanzee and capuchin artefacts in which side shoots are smoothed off from a stem. In the handaxes, the fact that elongate specimens appear as one tail of a distribution, rather than as a clear mode, reinforces the idea that these forms are made through a particular conjunction of needs rather than as a specific design target. They may combine a particular requirement for a long cutting edge at that moment in time with a heuristic rule that large bifaces must be narrow so as to constrain weight (a significant factor in tools that may weigh more than 2 kg) [98].

That is, the elongate bifaces seem to meet needs of function: otherwise, they would not repay the extra efforts of manufacture, which also involve risks of breakage. Similar considerations operate in later artefacts such as the Solutrean points, or the prime handaxe example at Arago [108], but at some stage, there comes a change: in these specimens, the 'overfinish' is so striking that the investment is often believed to have social or even sexual selection significance [110]. Artefacts can certainly be invested with value at a level of 'symboling' [111]. In terms of cognition, however, it would be hard to say that elongation has some particular significance *per se*, unless it is invested with that meaning as a shared value in a particular community or tradition. The 'scaffold' of long and thin forms is readily available in nature, in wooden stems and bones (for example), but it still has to be harnessed or unleashed. There is, indeed, some evidence that transfer of design forms can occur across materials, as demonstrated in rare bone handaxes from Olduvai and Konso Gardula, as well as later European examples [85,112]. It is equally possible that wooden forms influenced stone production (and vice versa) with migration of ideas between materials: a short wooden stave from Kalambo Falls (figure 4) closely resembles, in general form elongate stone points from the same period.

In stone tools, elongation can nevertheless be seen as a hallmark of cognitive complexity, because it is rarely achievable without high technical skill, and because it tends to be linked with the practice of other advanced tasks. It is useful, then, for our general understanding of hominin evolution to see that the pattern goes back beyond 1 million years, towards the roots of stone-toolmaking, and towards the first presence of *Homo erectus*. By 1.7 Ma, in some sense, a first human revolution had occurred. *Homo* diversified into different descendant species, but the continuities of handaxe production and of other pointed tools suggest that these species never became very different in some basic aspects of visualizing and producing artefacts. The technical processes often involve operations in which the general shape or outcome of the tool is not visible to the maker at the moment of striking a reducing blow, and hence they imply the ability to visualize 'in the mind's eye', to the extent of manipulating orthogonal planes and other technical detail [113–116]. Such continuities and common points that can be seen in the artefacts of early hominins of course cannot be assumed in other species, even those closely related. The point has been made that traditions may come and go without phylogenetic continuity [14]. Again, the value of comparative study can come from the point that the artefacts themselves impose some similarities of adaptations, to which the makers' control systems must respond in somewhat similar ways.

8. Conclusion

Amid burgeoning studies of cultural behaviour in different animals, with much focus on process and transmission, it is important to pay attention to complexities of content in artefacts, as measured by attributes or variables. In an overview of elongation in tool-making and using, it has been argued here that it is helpful to take a comparative approach that draws out common points in the adaptations of humans and other animals. In the effort to integrate time-depth, there is some risk of imbalance as the hominin record is much fuller, but its richness also allows further insights into tool manufacture by other animals. We can look at a past record directly for the most part only from hominin stone tools. They show that apart from its presumed use in stick tools, elongation was worth achieving at least 1.5 Ma in hard rock, and subsequently was favoured at many times through the later record. It was rarely an end in itself, as handaxe figures suggest: it is part of a continuum, with no more than 5–10% of Acheulean bifaces reaching pronounced elongation. The Kilombe AS example gave an extreme case, but similar issues of matching up dimensions one to another seem to appear in almost all tools.

Probably within the last half million years, some handaxes appear to have been given added symbolic value, with elongation being one possible way of demonstrating this. Apart from such cases, elongation shows little sign of being abstracted as an end in itself, but rather seems to be driven to exist in so far as it gives efficiency or cost-effectiveness to specific tasks. Dimensions are tuned by the needs of the task, which provide a constant challenge to notions owing to tradition or past individual experience. Although making comparisons between human and non-human artefacts can seem laboured, as there are major differences in complexity, a useful bridging point seems to come from considering the relationship of single variables to an overall design. It seems reasonable to argue that in some sense there is a 'universal grammar' of what Leroi-Gourhan [8] termed operational behaviour, determined by the hard realities of objects in the world, and thus somewhat independent of the neurological bases of thinking in individual species. An issue for further work is to trace the extent to which the variables in a tool design are handled separately, or to what extent a maker reviews the others as a 'package' when adjusting one. The making of early Acheulean handaxes seems to entail such a general overview, but it remains to be seen how far this occurs in other tools.

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