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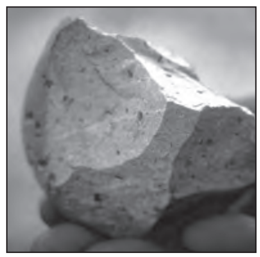
NUMBER 1

THE OLDOWAN:
Case Studies Into the Earliest Stone Age

Edited by Nicholas Toth and Kathy Schick



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COVER PHOTOS

Front, clockwise from upper left:

1) *Excavation at Ain Hanech, Algeria (courtesy of Mohamed Sahnouni).*
2) *Kanzi, a bonobo ('pygmy chimpanzee') flakes a chopper-core by hard-hammer percussion (courtesy Great Ape Trust).*
3) *Experimental Oldowan flaking (Kathy Schick and Nicholas Toth).*
4) *Scanning electron micrograph of prehistoric cut-marks from a stone tool on a mammal limb shaft fragment (Kathy Schick and Nicholas Toth).*
5) *Kinesiological data from Oldowan flaking (courtesy of Jesus Dapena).*
6) *Positron emission tomography of brain activity during Oldowan flaking (courtesy of Dietrich Stout).*
7) *Experimental processing of elephant carcass with Oldowan flakes (the animal died of natural causes). (Kathy Schick and Nicholas Toth).*
8) *Reconstructed cranium of Australopithecus garhi. (A. garhi, BOU-VP-12/130, Bouri, cranial parts, cranium reconstruction; original housed in National Museum of Ethiopia, Addis Ababa. ©1999 David L. Brill).*
9) *A 2.6 million-year-old trachyte bifacial chopper from site EG 10, Gona, Ethiopia (courtesy of Sileshi Semaw).*

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Photographs of the Stone Age Institute. Aerial photograph courtesy of Bill Oliver.

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CHAPTER 6

A Comparative Study of the Stone Tool-Making Skills of *Pan*, *Australopithecus*, and *Homo sapiens*

By Nicholas Toth, Kathy Schick, and Sileshi Semaw

Abstract

An experimental program was designed to compare and contrast the stone tool-making skills of modern African apes (bonobos or *Pan paniscus*), of prehistoric tool-making hominins from the earliest known Palaeolithic sites at Gona, Ethiopia (sites EG 10 and EG 12) dating to approximately 2.6 million years ago (possibly *Australopithecus garhi*), and of modern humans or *Homo sapiens*. All three species used the same range of raw materials, unmodified water-rounded cobbles of volcanic rock from the 2.6 Ma river conglomerates in the Gona study area. A detailed attribute analysis of the three samples was conducted, examining flaking patterns and artifact products and, from these products, inferring relative levels of stone tool-making skill in the three species.

Results of this comparative analysis indicate that, in the majority of artifact attributes that appear to be linked with skill, the Gona hominin tool-makers grouped either with the modern human sample or were intermediate between the bonobos and modern humans. This indicates that the biomechanical and cognitive skills required for efficient stone tool-making were already present at Gona by 2.6 Ma. Although some of the individual stone artifacts generated by the bonobos [with cranial capacities and probable EQ (encephalization quotient) values similar to estimates for prehistoric hominins contemporary with the Gona sites] would clearly be recognized as artifactual by palaeolithic archaeologists, the label "Pre-Oldowan" might be more appropriate for the overall assemblage of artifacts they produce. The level of flaking skill seen in the bonobo assemblage may represent an earlier stage of lithic technology not yet discovered in the prehistoric record. Or, alternatively, if the Gona sites indeed represent the earliest phases of stone tool-making with no precursors to be found, it may be that by the time of the Gona sites early hominins were already "pre-adapted" to more skilled flaking of stone.

This study also highlights interesting aspects of the stone tool-making behaviors of the early tool-makers at Gona by 2.6 Ma: 1) the Gona hominins were selective in choosing raw materials, sometimes selecting excellent quality raw materials from the river gravels available within the Gona region; 2) the Gona hominins conducted earlier stages of the reduction of cobbles off-site, prior to the transport of cores to the floodplain sites; and 3) the Gona hominins likely transported numerous larger, more usable flakes away from the floodplain sites. This suggests a higher level of early tool-making complexity, and presumably subsistence complexity, than many prehistorians have appreciated.

Introduction

The evolution of technology has occurred in tandem with human biological evolution during at least the past 2.6 million years. This unique co-evolution ultimately has led to the modern human condition, and it is likely that major cognitive and biomechanical changes occurred during this time through selection for more efficient tool-related activities. Different stages or grades of human evolution tend to be associated with different levels of technology, with a general trend of increasing technological complexity and sophistication through time.

A persistent challenge in paleoanthropology is how to determine levels of cognitive and biomechanical skill based upon the archaeological record, which consists primarily of flaked stone artifacts and, sometimes, associated faunal remains. It would be interesting to be able to observe and compare different levels of flaked stone technology between prehistoric hominins and extant apes and humans. Unfortunately, Early Stone Age hominins are extinct, and modern apes are not known to flake stone intentionally in the wild. However, the lasting products of early tool-making persists in the form of stone artifacts at early archaeological sites at Gona in Ethiopia, and, beginning in 1990, captive bonobos have been producing flaked stone artifacts in an experimental setting (Toth *et al*., 1993; Schick *et al*., 1999). This provides a unique opportunity to conduct a three-way comparison of tool-making patterns evident in the earliest known tool-makers, in stone tool-making apes, and in modern human knappers, in order to investigate technological patterns and abilities evident in each group.

This study, part of a long-term investigation of stone tool-making and tool-using abilities in captive African apes, is an attempt to approach this problem through rigorous comparisons of the artifacts produced by the earliest stone tool-makers and those produced by bonobos and modern humans in controlled experiments. In this study, the bonobos and modern humans used volcanic cobbles from the same river gravels that had served as the source of raw materials for the early Gona stone tool-makers. Thus, all three samples, the prehistoric tool-makers and the two groups of experimental tool-makers, were effectively using the same raw material source.

This study provides a valuable three-species comparison (probably in three different genera) of stone tool-making and spanning a time period of 2.6 million years. This makes it possible to make detailed comparisons of the stone technologies of the earliest known stone tool-makers, those produced by modern humans, and those made by modern apes. Inferences can then be made regarding discrete attributes, and combinations of attributes, that emerge as sensitive indicators of relative levels of skill. Further insights can thereby be gained regarding behavioral implications of the early archaeological sites at Gona, as well as regarding ape stone tool-making abilities and a possible evolutionary 'substrate' for the development of technological skills in human evolution.

The Comparative Samples

In effect, then, this study is a comparison of technological skill between three species over some 2.6 million years, with good control over raw materials. These three different samples whose artifacts will be compared and contrasted are: 1) an experimental sample produced by African apes who are practiced in stone tool manufacture (bonobos); 2) an archaeological sample produced by early hominins (at Gona, Ethiopia); and 3) an experimental sample produced by modern humans who are experienced stone tool-makers.

African Apes

The African ape sample consisted of two bonobos ("pygmy chimpanzees"), Kanzi and his half-sister Panbanisha, both born and raised in captivity with daily human contact. At the time of these experiments Kanzi was twenty years old and Panbanisha fifteen (Figures 1 through 12). Kanzi had been knapping stone for ten years by this time and Panbanisha for four years. The average cranial capacity of *Pan* about is 380 cc, and the Homocentric EQ (a human-centered encephalization quotient, or ratio of brain size to body size, in which human EQ=1.0) is 0.38 (Holloway, 2000). The bonobos have learned to flake stone to produce large, usable flakes as cutting tools (cutting through a rope or membrane to access a food resource). They were encouraged to reduce cobbles as far as possible with a stone hammer to produce a range of

Figure 1

1. *Portrait of Kanzi.*

Figure 2

2. *Portrait of Panbanisha.*

Figure 3

3. *Kanzi flaking a cobble core.*

Figure 4

4. *Kanzi flaking another cobble core.*

Figure 5

5. *Kanzi using a flake to cut through rope to access a food resource.*

flakes and fragments from which they could select a tool to use for the cutting activity. Since this study, two of Panbanisha's sons (Nyota, now eight years old and Nathan, now six years old) have started flaking stone, primarily from observing Kanzi and Panbanisha. In effect, we now have set forth a flaked lithic cultural tradition in this bonobo group which is now long-term and transgenerational.

Biomechanical studies by Harlacker (2006), studying the kinesiology of Oldowan tool-making in bonobos and in unskilled and skilled modern humans have demonstrated that the bonobos are only accelerating their hammerstones to about one-half of the impact velocities of the expert human sample (3.67 meters/second versus 7.12 meters/second, respectively). This lower impact velocity of the bonobos will almost certainly affect their lithic assemblage, which will be discussed below.

The history of the bonobo acquisition of stone tool-making is presented in Savage-Rumbaugh and Fields (this volume). (For more details on bonobo acquisition and development of stone tool-making skills, see Toth *et al*., 1993; Schick *et al*., 1999; and Savage-Rumbaugh *et al*., 2006). The study of bonobo stone tool-making is part of a long-term, ongoing research program that will soon also include chimpanzees (*Pan troglodytes)* and orangutans (*Pongo pongo*) as subjects.

Gona Hominins

The archaeological sample was from two contemporaneous sites in the Afar Rift at Gona, Ethiopia named EG (East Gona) 10 and EG 12, located a few hundred meters from each other. These two sites are almost identical in their lithic technology (Semaw, 1997), so for this study the two sites were combined for a statistically larger sample size. These sites have been dated to ap-

Figure 6

6. *Sample of bonobo cores. Note the predominance of end choppers. (Small squares on scale represent one cm).*

Figure 7

7. *Bonobo unifacial end chopper.*

Figure 8

8. *Large bonobo end chopper with some bifacial flaking.*

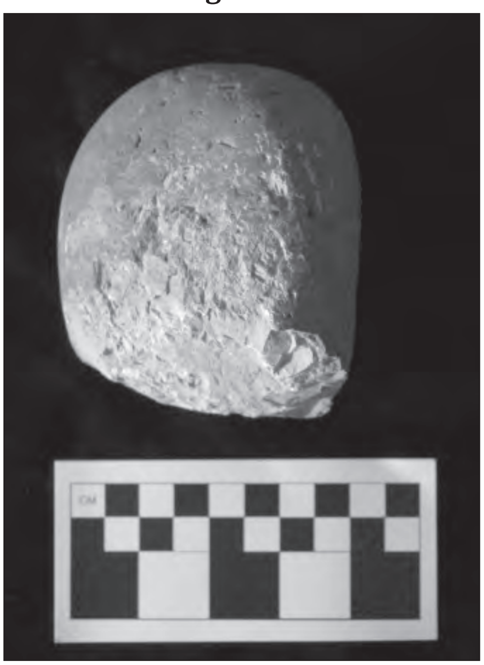
Figure 9

9. *Large bonobo unifacial side chopper.*

Figure 10

10. *Bonobo unifacial chopper.*

Figure 11



11. *Bonobo end chopper exhibiting very heavy hammerstone battering.*

Figure 12

12. *Sample of bonobo flakes. Note the abundance of side-struck flakes. Flakes oriented with striking platforms at top.*

proximately 2.6 Ma. Although the species of tool-maker is not known, the only species known in the Afar Rift during this time period is *Australopithecus garhi*, known from the Middle Awash some 60 km from Gona (Asfaw *et al*., 1999; White *et al*., 2005). The cranial capacity of this taxon, based on one skull from Bouri, Middle Awash (the holotype, BOU-VP-12/130), is 450 cc, about 70cc larger than the *Pan* mean. The EQ value for *A.* garhi is not known. Fossils representing a non-robust *Australopithecus* that may also be attributable to *A. garhi* include a mandible fragment (GAM-VP-1/1) and parietal fragments (GAM-VP-1/2) from Gamedah, Middle Awash (White *et al*., 2005) and isolated teeth from the Omo Shungura Formation (Suwa *et al.*, 1996). (See Figures 13, *A. garhi*, and 14 through 23, setting of and artifacts from the Gona EG sites).

Geoarchaeological evidence suggests that there has not been significant hydrological action at theses sites: they are found in fine-grained slickenside clays and contain not only heavier cores but also a debitage sample including very small flakes and fragments (Semaw, 1997, 2000; Semaw *et al*., 1997, 2003). Thus far, fossil bone has been found only on the surface at these archaeological localities and may have derived from higher deposits, but cut-marked bones have been found in the same stratigraphic level elsewhere in the study area (Dominguez-Rodrigo *et al*., 2005).

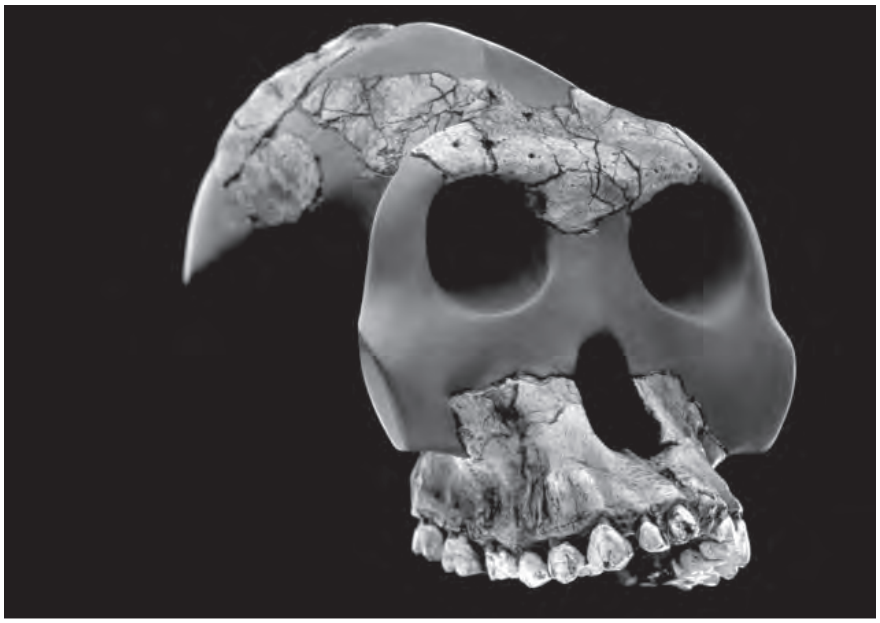
Modern Humans

The modern human sample consisted of two experienced stone tool-makers (NT and KS) that had, at the time of these experiments, flaked stone for over two decades. The mean cranial capacity for modern humans is about 1350 cc, with a Homocentric EQ value of 1.0. Gona cobbles were flaked unifacially and bifacially to reduce them by roughly half of their original cobble mass. As the aim was to produce a control sample of cores and resultant debitage representing approximately 50% cobble reduction, rather than to replicate precisely the Gona assemblage, there was somewhat more bifacial flaking in the human sample than was represented at the Gona sites (roughly 68% of the human flakes are from unifacial flaking, versus ~79% of Gona flakes). Direct, freehand, hard-hammer percussion was employed using Gona cobble percussors, and no special attempt was made to prepare platforms or remove especially long or thin flakes: the goal was to produce serviceable flakes that could be used for cutting activities. The human experimental sample thus provided an important baseline that could be compared to the bonobo and archaeological samples (Figures 21 and 22) to examine for similarities and differences with the bonobo and Gona stone technologies.

As analysis proceeded, it became clear that preferentially later stages of cobble reduction were typical of the Gona EG sites, whereas the experimental samples of bonobo and human reduction differed in two major aspects: they contained all stages of flaking, from initiation of cobble reduction to cessation of flaking, and, overall, their cores were not as extensively reduced. In the case of the human experiments, this had been a deliberate design to produce a control sample of cores and debitage with reduction of the cobble mass held at approximately 50%, in order to effectively compare the products to the other two samples. Comparisons with the experimental human sample highlighted the much heavier reduction of the Gona cores. Thus, in an attempt to more closely match the Gona pattern, ten of the experimental human cores (five unifacial choppers, five bifacial choppers) were subsequently reduced further in order to examine assemblage characteristics in such later stages of core reduction. These "later stage" experiments provided a database that were then used in more direct comparisons with the Gona sites, and especially salient results of these comparisons are highlighted in special sections in this analysis.

A major aim of the human experimental sample was to produce data to generate models to understand how the Gona archaeological assemblages could have formed. As will be discussed below, this experimentation has suggested that the Gona sites represent preferentially later stages of core reduction with subsequent selection of certain artifacts that were transported off-site. Another

Figure 13



13. *Reconstructed cranium of Australopithecus garhi. Original housed in National Museum of Ethiopia, Addis Ababa. © 1999 David L. Brill*

Figure 14

14. Gona site EG 10, dated to approximately 2.6 mya.

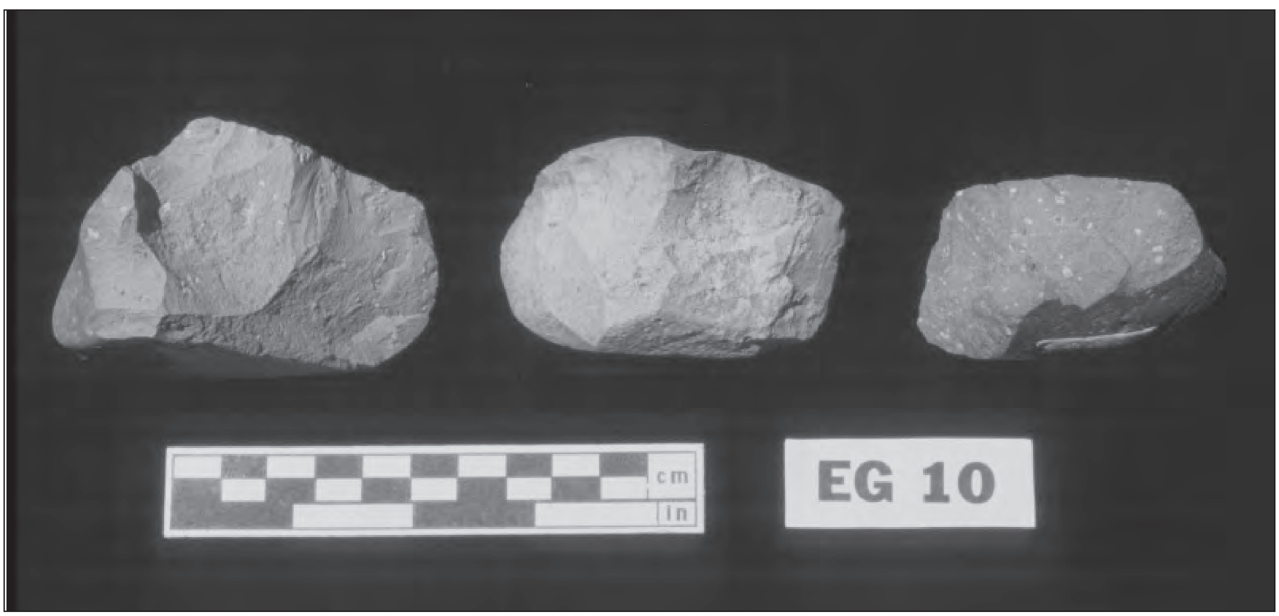
Figure 15

15. The fossil river gravel conglomerate at East Gona: the source of raw material for the Gona hominins and the experimental sample.

Figure 16

16. Gona artifacts from EG 10: cores (below) and flakes (above).

Figure 17



17. Gona unifacial side choppers from EG 10.

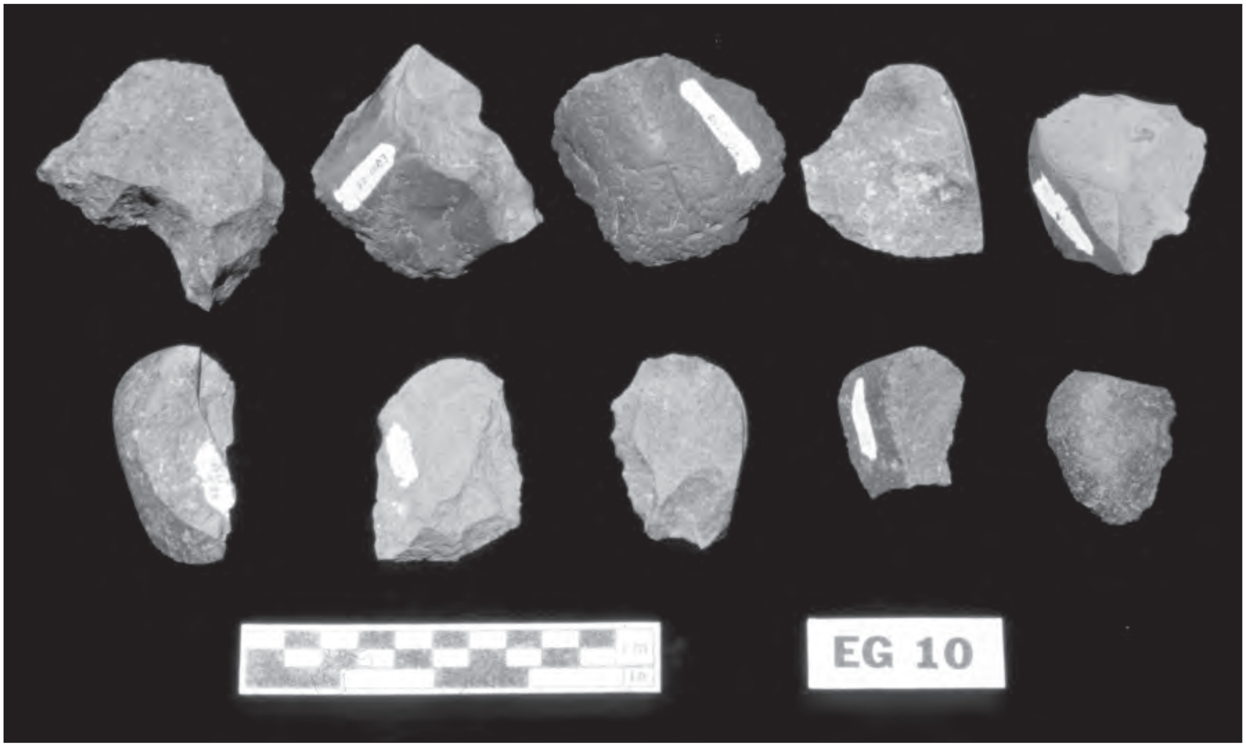
Figure 18

18. A set of six Gona EG cores. (Photo courtesy of Tim White).

Figure 19

19. The other opposite face of the six Gona cores in Figure 18. (Photo courtesy of Tim White)

Figure 20



20. More flakes from Gona EG 10.

important aim of this study was to compare the human sample with the bonobo sample (each having all stages of reduction represented) to evaluate levels of skill and gain insight into possible stages of development of stone technology in the course of hominin evolution.

Methodology

This study was designed as a detailed examination of the lithic assemblages produced by three samples: modern African apes (*Pan paniscus*, called bonobos or "pygmy chimpanzees"), prehistoric Gona hominins (possibly *Australopithecus garhi*), and modern humans or *Homo sapiens*. This analysis would also address basic epistemological questions in Palaeolithic archaeology: why do we measure and record the attributes that we do? Beyond pure description, what do the attributes that we study tell us about levels of cognitive and/or biomechanical skills, and what stages of core reduction (e.g. early, late) are represented in an assemblage, and what does this imply regarding transport and land-use patterning?

Analysis and Statistics

It was decided that this analysis would include the detailed statistical descriptions and testing that was employed. For more qualitative attributes (e.g. flake scar types, flake shapes) chi-square tests were employed, while for metrical, quantitative attributes (e.g. linear measurements, weights, and angles) the Mann-Whitney/Wilcoxon test (and sometimes additionally the Kolmogorov-Smirnov test) was used. In both cases, the threshold for assessing statistical significance was at the .05 confidence level. A summary of statistical tests and overview of results are presented in appendices at the end of this chapter.

Raw Materials

The raw materials for the experiments were selected from the 2.6 Ma river gravels at East Gona, the source for the Gona hominins as well. With the permission of the Ethiopian government, unmodified cobbles (i.e. geological samples) were collected from the surface scatter and in situ gravels. In practice, only one of perhaps every fifty cobbles in the Gona conglomerates was considered suitable for flaking. Cobbles were chosen for 1) their smooth cortex, suggesting a fine-grained rock type; 2) shapes that would be suitable for flaking: not too spherical and not too thin; 3) a range of sizes (from about 10 to 20 cm); and 4) absence of heavy cortical pitting or hairline fractures, which would suggest a poor-quality rock with unwanted vesicles or weathering flaws. All raw materials in the experimental sample (and it appears almost all from the archaeological sites) started as water-worn river pebbles composed of a range of volcanic raw materials.

The experimental sample of raw material was randomly divided into two groups, one for the bonobo subjects and one for the human sample. As will be discussed, the experimental raw material sample was very similar to that exploited by the Gona hominins, so that there was an excellent control of raw materials between the experimental and archaeological samples. The hammer-

Figure 21

21. A selection of cores from the human experimental sample. Note the predominance of side choppers.

Figure 22

22. A selection of flakes from the human experimental sample. Note the abundance of end-struck flakes.

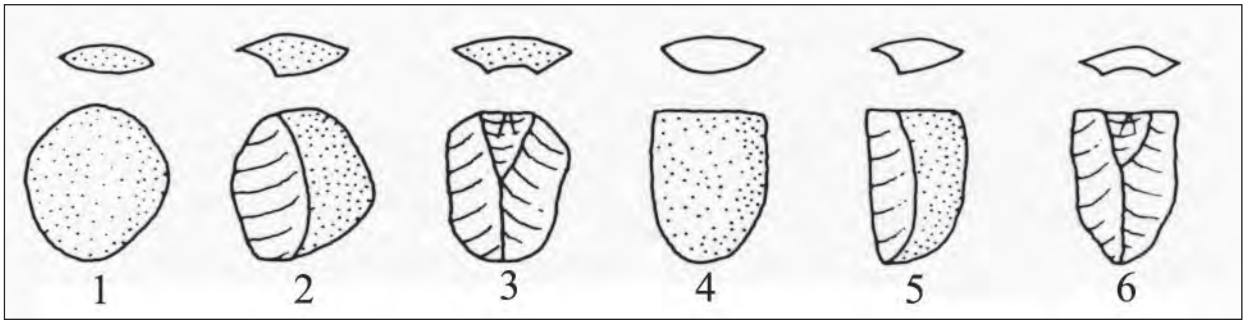
stones used to flake cores were also Gona cobbles. Several Gona cores show battering on their cortical surfaces showing that they were also used as percussors, and it is likely that other hammerstones were transported off-site. For this analysis, only stone artifacts greater or equal to 20 mm in maximum dimension were examined.

Attributes Analyzed

The following lithic attributes were used in this study:

1. Assemblage composition (lithic class: cores/flakes/fragments)
2a. Debitage breakdown [whole flakes/broken flakes (splits & snaps)/angular fragments & chunks]
2b. Ratio of split flakes to whole flakes
3. Raw material breakdown (cores)

Figure 23



23. Flake types. Flake types 1-3: cortical platforms with, in order, all dorsal cortex, partial dorsal cortex, and no dorsal cortex. Flake types 4-6: non-cortical platforms with, in order, all dorsal cortex, partial dorsal cortex, and no dorsal cortex. Examination of these flake types in an artifact assemblage can yield critical technological information regarding core reduction.

4. Quality of raw material (cores)
5. Cores: Original form (blank)
6. Cores: Flaking mode (Unifacial, bifacial, etc.)
7. Cores: Invasiveness of flaking
8. Cores: Percentage of circumference flaked
9. Cores: Quality of flaking
10. Cores: Platform edge battering/microstepping/crushing
11. Cores: Modified Leakey typology
12. Cores: Weight
13. Cores: Maximum dimension (length)
14. Cores: Breadth
15. Cores: Thickness
16. Cores: Ratio of breadth to length
17. Cores: Modified ratio of breadth to length
18. Cores: Ratio of thickness to breadth
19. Cores: Maximum dimension of largest scar
20. Cores: Ratio of largest scar to core maximum dimension
21. Cores: Percentage of original cobble remaining (estimate)
22. Cores: Number of flake scars
23. Cores: Ratio of step & hinge scars to total scars
24. Cores: Edge angle
25. Cores: Percentage of surface cortex remaining

26a. Flakes: Flake types
26b. Flakes: Simulated flake type population after selection and the removal of the best flakes
26c. Flakes: Simulated flake type population: later stages of flaking
26d. Flakes: Simulated flake type population: later stages after selection and removal

27. Flakes: Location of Cortex
28. Flakes: Dorsal scar pattern
29. Flakes: Flake shape
30. Flakes: Platform battering/microstepping, crushing
31. Flakes: Weight
32. Flakes: Maximum dimension
33. Flakes: Thickness
34. Flakes: Ratio of flake breadth to length
35. Flakes: Ratio of flake thickness to breadth
36. Flakes: Ratio of platform thickness to platform breadth
37. Flakes: Number of platform scars
38. Flakes: Number of dorsal scars
39. Flakes: Ratio of step & hinge scars to all scars
40. Flakes: Exterior platform angle (“core angle”)
41. Flakes: Interior platform angle (“bulb angle”)
42. Flakes: Percentage of dorsal cortex (“cortex index”)

Results

In this study, these 42 separate attributes, both qualitative and quantitative, were examined and compared/contrasted among the three lithic assemblages, and then interpreted with regard to similarities and differences. When appropriate, statistical tests were conducted to examine for significant differences among the three toolmaker samples in their attribute characteristics.

1. Assemblage: Composition (Lithic Class)

Rationale

The major classes of flaked stone artifacts consist of cores, flakes, and fragments. Fragments comprise a variety of broken portions of flakes, including split flakes (broken more or less perpendicular to the platform), snapped flakes (broken more or less parallel to the platform, into proximal, distal, and sometimes also mid-section snaps), angular fragments (fairly flat fragments, apparent portions of conchoidally flaked pieces but without clear indication of which part is represented), and chunks (miscellaneous, usually thicker, nondescript fragments of conchoidally flaked materials). Here we examine whether there are significant differences in the major flaked artifact categories among the three toolmaker samples (bonobos, Gona knappers, humans).

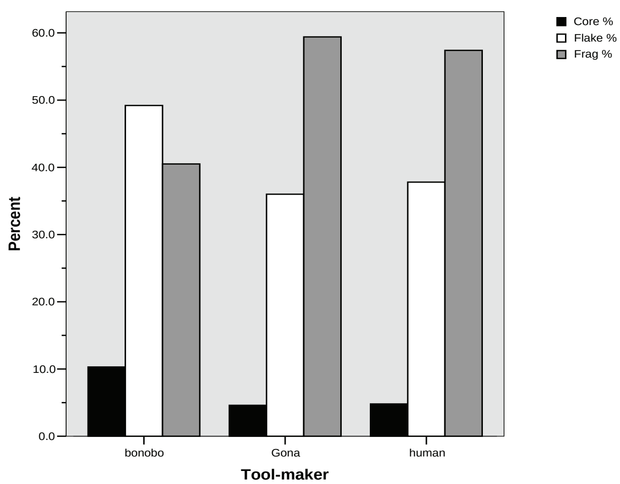
Results

The overall breakdown of the assemblages into the major lithic classes (cores, flakes, and fragments) by tool-maker is shown in the table and graph below:

Assemblage Composition by Tool-maker

			Core flake frag			
			core	flake	frag	Total
Tool-maker	bonobo	Count	33	158	130	321
		% within Tool-maker	10.3%	49.2%	40.5%	100.0%
	gona	Count	23	178	294	495
		% within Tool-maker	4.6%	36.0%	59.4%	100.0%
	human	Count	31	244	370	645
		% within Tool-maker	4.8%	37.8%	57.4%	100.0%
Total		Count	87	580	794	1461
		% within Tool-maker	6.0%	39.7%	54.3%	100.0%

Assemblage Composition by Tool-maker



Chi-Square tests revealed that the Gona and human tool-makers group together in terms of their general assemblage composition (.788 level of significance), while the artifact assemblages produced by the bonobo tool-makers were significantly different from both the Gona and the human samples (at the .000 level of significance). The bonobo assemblage differed from both the Gona and human samples in its much higher core proportion, higher flake proportion, and much lower fragment proportion.

Chi-Square Test: Assemblage Composition, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	30.703[a]	2	.000
Likelihood Ratio	30.716	2	.000
N of Valid Cases	816		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 22.03.

Chi-Square Test: Assemblage Composition, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	28.157[a]	2	.000
Likelihood Ratio	27.888	2	.000
N of Valid Cases	966		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 21.27.

Chi-Square Test: Assemblage Composition, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	.478[a]	2	.788
Likelihood Ratio	.478	2	.787
N of Valid Cases	1140		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 23.45.

Discussion

While the Gona and human proportions of cores, flakes, and fragments are similar, the bonobo sample has a higher core percentage (more than double the assemblage percent in the Gona and human samples), indicating the bonobos are removing less debitage per core. Interestingly, they are producing more whole flakes than fragments, while in both the Gona and human samples there are proportionally more fragments than whole flakes. While some lithic analysts might argue that a higher flake-to-fragment ratio may be an indication of greater skill, it is unlikely in the case of the bonobos. Their hammerstone velocities were much lower than the modern human subjects, and the bonobos would often repeatedly strike the core at a location until fracture finally occurred and proceed to "chew" down the cobble with further flaking. The majority of spalls so produced by the bonobos tend to be whole flakes. In contrast, modern humans (and probably Gona hominins) appear to have exploited cores more efficiently, reducing raw material in flake production more readily and with much higher hammerstone velocities, in the process producing more shatter (fragments) relative to whole flakes.

2a. Assemblage: Debitage Breakdown

Rationale

The more subtle differences between debitage categories (whole flakes, split and snapped flakes, and angular fragments/chunks) can be a useful means of comparing different lithic assemblages. Although we had no clearly-defined expectations, we were interested to see if there were any major differences between the tool-making groups in the types of debitage they produced.

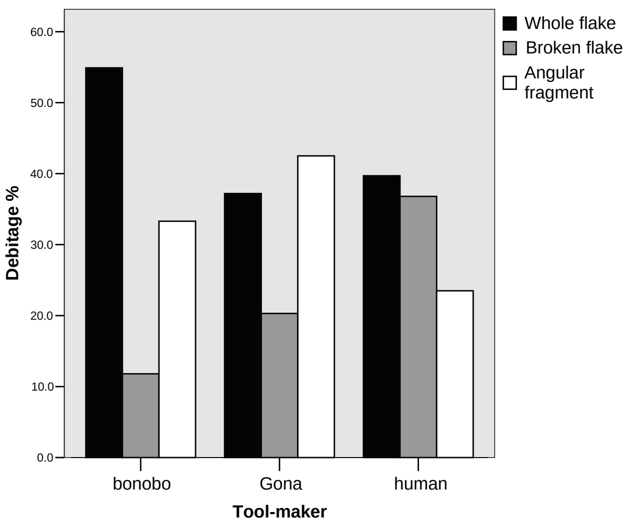
Results

The overall breakdown of the debitage type by tool-maker is shown in the table and graph below:

Debitage Breakdown by Tool-maker (Whole Flakes, Broken Flakes, Angular Fragments)

			Deb type			
			Flake	Flk brok	Frag-ment	Total
Tool-maker	bonobo	Count	158	34	96	288
		% within Tool-maker	54.9%	11.8%	33.3%	100.0%
	gona	Count	178	95	199	472
		% within Tool-maker	37.7%	20.1%	42.2%	100.0%
	human	Count	244	226	144	614
		% within Tool-maker	39.7%	36.8%	23.5%	100.0%
Total		Count	580	355	439	1374
		% within Tool-maker	42.2%	25.8%	32.0%	100.0%

Debitage Breakdown by Tool-maker



Chi-Square tests revealed that each of the three tool-making groups produced debitage breakdowns that were statistically different from the other two groups (at the .000 level of significance).

Chi-Square Test: Debitage Breakdown, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.786[a]	2	.000
Likelihood Ratio	22.959	2	.000
N of Valid Cases	760		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 48.88.

Chi-Square Test: Debitage Breakdown, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	59.767[a]	2	.000
Likelihood Ratio	66.431	2	.000
N of Valid Cases	902		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 76.63.

Chi-Square Test: Debitage Breakdown, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	54.975[a]	2	.000
Likelihood Ratio	55.655	2	.000
N of Valid Cases	1086		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 139.51.

Discussion

Bonobos produced higher percentages of whole flakes and lower percentages of broken flakes than the other two samples. As mentioned above, it is likely that this pattern results from knapping with lower hammerstone velocities, so that less spontaneous flake fragmentation occurs during the manufacturing process. To test this, as a follow-up experiment, we reduced cobbles with high-velocity/high-impact hammerstone percussion as well as low-velocity/low-impact hammerstone percussion. The low-velocity/low-impact flaking yielded debitage with an appreciably a greater proportion of whole flakes (31% higher) than did high-velocity/high-impact flaking. This supports our contention that the higher percentage of whole flakes in the bonobo sample and the smaller mean flake size are primarily due to their lower-velocity impacts.

In addition, the Gona sample has appreciably more angular fragments and fewer broken flakes than the human sample. It is possible that the elevated proportion of angular fragments may partially be a result of post-depositional breakage of debitage (Hovers, 2003). Also, some subtle signs of conchoidal fracture are more difficult to identify on volcanic archaeological specimens, as their fractured surfaces tend to be slightly weathered; therefore it is likely that some pieces that would be assigned to splits or snaps on fresh specimens would be demoted to angular fragments on archaeological specimens. Finally, as will be discussed below, it appears that a portion of the larger, sharper whole flakes and broken flakes at Gona may have been subsequently transported off-site, which would increase the percentage of angular fragments in the debitage population.

2b. Ratio of Split to Whole Flakes

Rationale

A higher ratio of split flakes to whole flakes could be an indication of the average impact velocity of hammerstones when flaking cores. As noted above, experiments have shown that for a given raw material, higher percussion forces tend to produce higher ratios of split to whole flakes (but also larger whole flakes).

Results

The bonobos had the lowest number of split to whole flakes (ratio of .095, 8.7% split flakes), with Gona hominins intermediate (ratio of .331, 24.9% split flakes) and the human sample the highest (ratio of .643, 39.2% split flakes). Each of these samples showed significant difference from the other two in their whole and split flake proportions at the .05 confidence level.

Whole and Split Flakes by Tool-maker

			Whole or split flake: split	Whole or split flake: whole	Total
Tool-maker	bonobo	Count	15	158	173
		% within Tool-maker	8.7%	91.3%	100.0%
	gona	Count	59	178	237
		% within Tool-maker	24.9%	75.1%	100.0%
	human	Count	157	244	401
		% within Tool-maker	39.2%	60.8%	100.0%
Total		Count	231	580	811
		% within Tool-maker	28.5%	71.5%	100.0%

Chi-Square Test: Whole and Split Flakes, All Tool-makers

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	57.243[a]	2	.000
Likelihood Ratio	64.190	2	.000
N of Valid Cases	811		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 49.28.

Chi-Square Test: Whole and Split Flake Proportions, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	17.796[b]	1	.000		
Continuity Correction[a]	16.716	1	.000		
Likelihood Ratio	19.135	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	410				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 31.22.

Chi-Square Test: Whole and Split Flake Proportions, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	53.509[b]	1	.000		
Continuity Correction[a]	52.066	1	.000		
Likelihood Ratio	62.038	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	574				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 51.84.

Chi-Square Test: Whole and Split Flake Proportions, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	13.522[b]	1	.000		
Continuity Correction[a]	12.893	1	.000		
Likelihood Ratio	13.861	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	638				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 80.24.

Discussion

It would appear that the bonobos has the lowest hammerstone velocity, the Gona hominins intermediate, and the humans the highest velocities. As previously mentioned, experiments and analysis by Harlacker (2006) have demonstrated that the mean hammerstone velocities just prior to impact of the bonobos was 3.67 meters per second, and the hammerstone velocities of the experienced human sample was 7.12 meters per second. If the split to whole flake ratio is strongly correlated with hammerstone velocities, then the extrapolated mean hammerstone velocity of the Gona hominins could be estimated to have been a minimum of 5 meters per second (and perhaps more if, as we believe, the Gona hominins were selectively removing numbers of larger flakes, as discussed in section 26 below).

3. Assemblage: Raw Material Type

Rationale

Examining differential use of raw materials can give insights into possible selectivity of early hominin tool-makers. Raw materials in the Gona archaeological sample were divided three major types: lighter volcanics (especially trachyte), darker volcanics (especially rhyolite), and vitreous volcanics (very fine-grained). Subsequent geological classification by Jay Quade (reported in Stout et al. (2005), has subsequently separated Gona raw materials into a number of more discrete types. The distribution of raw material types was examined in the archaeological sample and the experimental sample (knapped by humans and bonobos) for possible differences among the tool-makers in the flaked cores (as a proxy for cobble selections).

The experimental sample of cobbles was selected in proximity to the EG sites from the 2.6 million year old conglomerate that lies stratigraphically just below the sites. At the time of occupation of these sites, this conglomerate would have been a readily accessible cobble source in the overall region as exposed gravel bars along stream courses, and the raw material types at the EG sites are found within this conglomerate. Selection was based upon sizes and shapes of cobbles deemed suitable for flaking (excluding very large or very small cobbles, spherical clasts, etc.), as well as the likelihood or expectation of good, fine-grained stone (normally indicated by a cobble with smooth cortex but without extensive pitting or incipient cracks). Selection was based on these criteria, and not upon observable indications of the rock type itself. No initial testing (flaking) was done prior to the experiments. In practice, only approximately one in fifty cobbles from these conglomerates was selected via this procedure. We were interested to see whether the Gona EG sites showed more selectivity than this sampling procedure.

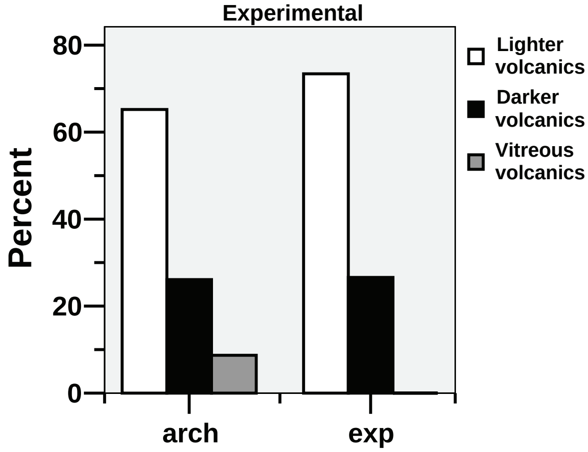
Results

The experimental and archaeological samples can be placed in placed in one of three general raw material categories. The types observable among cores include, in order of prevalence, lighter volcanics (approximately two-thirds to three-quarters of each sample), darker volcanics (approximately one-quarter of each sample), and a small proportion (approximately 9%) of vitreous volcanic material in the Gona archaeological sample.

Raw Material Types for Cores: Experimental v. Archaeological

			Raw material			
			lighter volcanics	darker volcanics	vitreous volcanics	Total
Exp or arch	arch	Count	15	6	2	23
		% within Exp or arch	65.2%	26.1%	8.7%	100.0%
	exp	Count	47	17	0	64
		% within Exp or arch	73.4%	26.6%	.0%	100.0%
Total		Count	62	23	2	87
		% within Exp or arch	71.3%	26.4%	2.3%	100.0%

Raw Materials for Cores: Archaeological and Experimental



Chi-Square Test: Raw Material for Cores, Archaeological v. Experimental

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.727[a]	2	.057
Likelihood Ratio	5.487	2	.064
N of Valid Cases	87		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is .53.

Discussion

Although the two samples show some small differences in their raw material types, the assemblage differences are not significant at the .05 level. One difference is the presence at Gona of two cores in a vitreous volcanic material that was absent in the experimental sample. In other words, the experimental sample (already highly selected for "flakability") is largely similar to the Gona sample with regard to the major rock types flaked. As Stout *et al*. (2005) have shown, Gona hominins selected higher-quality cobbles compared to the proportions found in the stream conglomerates, especially the light trachytes. This pattern is also seen in the sample selected for experiments. More interesting, however, is the assessment of raw material quality from a knapper's perspective, which will be discussed in the next section.

4. Assemblage: Raw Material Quality

Rationale

The cores from the assemblages were assigned a quality-of-flaking value (excellent/good/fair) based on how fine-grained the rock type and how homogeneous the fracture surface. This was done from a stone-knapper's perspective to examine possible selectivity by early hominin tool-makers and to examine possible similarities or differences between the Gona archaeological sample and the experimental samples (bonobo and human) in terms of raw material quality. Again, the experimental sample was highly selected in the field based on size, shape, and cortex appearance but without any testing of the cobble (flaking) or examination of the interior rock quality.

Results

The archaeological and experimental samples do not significantly differ at the .05 confidence level. Nevertheless, there are some differences, for example, the Gona archaeological material has more "excellent" raw material.

Raw Material Quality for Cores: Archaeological and Experimental

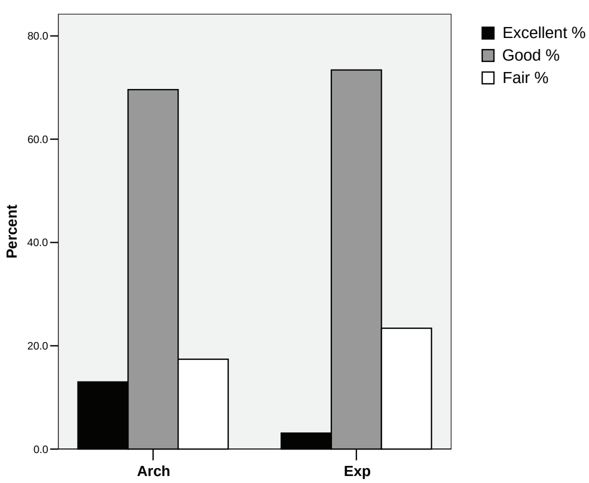
			Raw Material Quality			Total
			excellent	good	fair	
Exp or arch	arch	Count	3	16	4	23
		% within Exp or arch	13.0%	69.6%	17.4%	100.0%
	exp	Count	2	47	15	64
		% within Exp or arch	3.1%	73.4%	23.4%	100.0%
Total		Count	5	63	19	87
		% within Exp or arch	5.7%	72.4%	21.8%	100.0%

Chi-Square Tests: Raw Material Quality for Cores, Archaeological and Experimental

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	3.214[a]	2	.200
Likelihood Ratio	2.813	2	.245
N of Valid Cases	87		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.32.

Raw Material Quality for Cores: Experimental and Archaeological



Discussion

The archaeological and experimental populations are similar and not significantly different, although there is a higher proportion of "excellent" raw material observed in the archaeological sample from Gona than in the experimental samples. This is probably due to the Gona hominins testing the raw materials at the conglomerate sources before transporting cores to the floodplain sites for further reduction (which was deliberately not done for the experimental sample). It should be noted that selecting raw materials merely on their exterior characteristics (size, shape, cortex appearance), as was done for the experimental sample, yielded a sample with superior flaking characteristics overall (over 75% of the experimental sample assessed to have "good" to "excellent" flaking quality).

5. Cores: Original Form

Rationale

Cores were examined to identify what the original (blank) form was. In the early Oldowan, most cores were made on natural water-rounded river cobbles and this can readily be observed in the archaeological assemblage. However, sometimes heavily-reduced cores retain little or no evidence of their original form, and are assigned to an indeterminate category. Other, miscellaneous categories for original core form include flakes or flake fragments, tabular chunks, or broken cobbles.

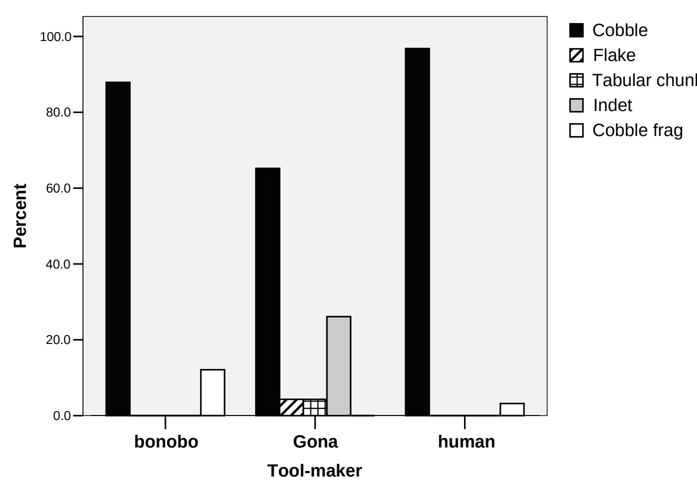
Results

In all three samples, the dominant original forms for cores were cobbles. In addition at Gona, six cores were placed in the indeterminate category, with one more core made on a flake and another on a tabular chunk. The bonobos also primarily reduced whole cobbles but also made four simple cores from broken cobble fragments (broken in half during the knapping process).

Core Original Form by Tool-maker

			Original form					Total
			cobble	flake, flake frag-ment	tabular chunk	indet	broken cobble	
Tool-maker	bonobo	Count	29	0	0	0	4	33
		% within Tool-maker	87.9%	.0%	.0%	.0%	12.1%	100.0%
	gona	Count	15	1	1	6	0	23
		% within Tool-maker	65.2%	4.3%	4.3%	26.1%	.0%	100.0%
	human	Count	30	0	0	0	1	31
		% within Tool-maker	96.8%	.0%	.0%	.0%	3.2%	100.0%
Total		Count	74	1	1	6	5	87
		% within Tool-maker	85.1%	1.1%	1.1%	6.9%	5.7%	100.0%

Core Original Form by Tool-maker



As the frequencies of original forms other than cobbles were small to absent, comparisons were also made between the tool-makers looking at cobbles v. "other" original forms (lumping flakes, tabular chunks, indeterminate, and cobble fragments). Chi-square tests indicate a difference between the Gona sample and the two experimental samples, bonobo and human, in the original forms of their cores (.042 and .002 levels of significance, respectively). The difference between the two experimental samples, bonobos and humans, was not significant.

Core Original Form by Tool-maker (Cobble v. Other)

			Original form lumped		
			Cobble	Other	Total
Tool-maker	bonobo	Count	29	4	33
		% within Tool-maker	87.9%	12.1%	100.0%
	gona	Count	15	8	23
		% within Tool-maker	65.2%	34.8%	100.0%
	human	Count	30	1	31
		% within Tool-maker	96.8%	3.2%	100.0%
Total		Count	74	13	87
		% within Tool-maker	85.1%	14.9%	100.0%

Chi-Square Tests: Core Original Form (Cobble v. Other), Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.134[b]	1	.042		
Continuity Correction[a]	2.898	1	.089		
Likelihood Ratio	4.097	1	.043		
Fisher's Exact Test				.054	.045
N of Valid Cases	56				

a. Computed only for a 2x2 table.

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.93.

Chi-Square Tests: Core Original Form (Cobble v. Other), Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.756[b]	1	.185		
Continuity Correction[a]	.738	1	.390		
Likelihood Ratio	1.882	1	.170		
Fisher's Exact Test				.356	.198
N of Valid Cases	64				

a. Computed only for a 2x2 table.

b. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.42.

Chi-Square Tests: Core Original Form (Cobble v. Other), Gona v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.467[b]	1	.002		
Continuity Correction[a]	7.331	1	.007		
Likelihood Ratio	10.105	1	.001		
Fisher's Exact Test				.003	.003
N of Valid Cases	54				

a. Computed only for a 2x2 table.

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.83.

Discussion

With regard to the original form of cores, the presence at Gona of a number of cores (n=6) whose original blank form was indeterminate constitutes the major difference between the experimental samples and the archaeological sample. This proportion of Gona cores (26.1%) assigned to the "indeterminate" category with regard to original form strongly suggests that these cores were more heavily-reduced, obliterating most or all signs of the original blank type used. Most likely these were all cobbles, but in the absence of refitting this cannot be demonstrated conclusively. That Gona cores overall were more heavily reduced than the experimental samples will also become evident in further attributes examined below. Nevertheless, cobbles were by far the predominant original form in all samples in this study, with the Gona indeterminate core forms likely representing an interesting indication of higher intensity of core reduction.

6. Cores: Flaking Mode

Rationale

The dominant flaking mode was recorded to examine the major patterns of cobble reduction for the Gona and bonobo samples, thus focusing on the nonhuman subjects. The major flaking modes were:

a) unifacial (normal), or flaking on one face along a core edge (unidirectional flaking)
b) bifacial, or flaking on two faces along a core edge (bidirectional flaking)
c) unifacial plus bifacial, or flaking unifacially along one core edge and bifacially along another edge
d) unifacial alternate, or flaking unifacially on one face along one core edge and then unifacially on the opposite face from another edge

Results

Overall, both the bonobo and Gona samples showed a preponderance of unifacial flaking of cobbles (from 63.6 to 78.3% respectively), with relatively low incidence of the other flaking modes. These populations did not differ significantly in flaking mode at the .05

confidence level [nor was there a significant difference when all flaking modes (b) through (d) were combined as "other," resulting in a chi-square value of .253 with 0 cells having expected value of less than 5]. The table of results and chi-square test for all four flaking modes are presented below:

Cores: Mode of Flaking by Tool-maker

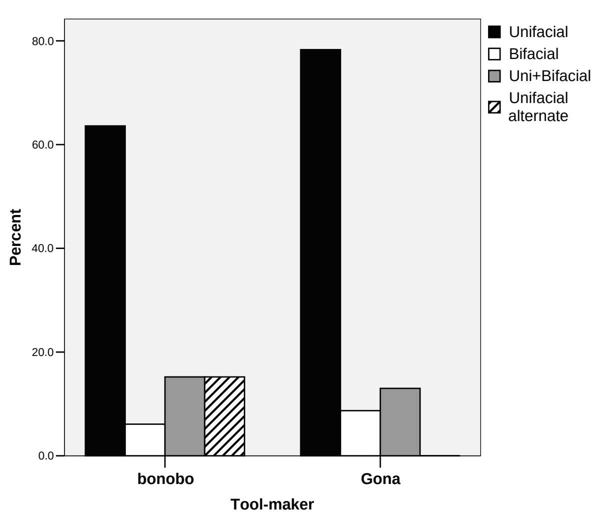
			Mode of flaking				
			unifacial (normal)	bifacial	uni -+ bifacial	uni-facial alter-nate	Total
Tool-maker	bonobo	Count	21	2	5	5	33
		% within Tool-maker	63.6%	6.1%	15.2%	15.2%	100.0%
	gona	Count	18	2	3	0	23
		% within Tool-maker	78.3%	8.7%	13.0%	.0%	100.0%
	human	Count	17	13	1	0	31
		% within Tool-maker	54.8%	41.9%	3.2%	.0%	100.0%
Total		Count	56	17	9	5	87
		% within Tool-maker	64.4%	19.5%	10.3%	5.7%	100.0%

Chi-Square Tests: Mode of Flaking, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	4.075[a]	3	.253
Likelihood Ratio	5.872	3	.118
Linear-by-Linear Association	2.789	1	.095
N of Valid Cases	56		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.64.

Cores, Mode of Flaking: Bonobo v. Gona



Discussion

Both the bonobo and Gona samples have a preponderance of unifacial flaking of cobbles. It can be argued that this is the simplest, easiest approach to reducing cobbles and producing sharp flakes. This tendency towards unifacial flaking could also have been a habitual norm among the hominins who produced these EG sites at Gona, or, at the very least, their tendency at these particular sites but perhaps variable at other sites and other times.

7. Cores: Invasiveness.

Rationale

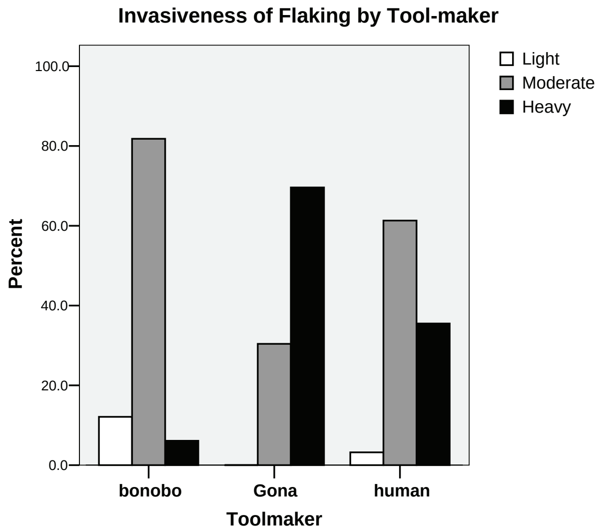
This attribute is an assessment of how invasive flake scars are relative to core morphology (heavily, moderate, light). This assessment is a qualitative one, based on the distance flake scars have traveled across the core surfaces. Heavy invasiveness suggests that tool-makers are either driving larger flakes off of cores or heavily reducing cores, or both.

Results

The bonobo cores are characterized by higher percentages of light and moderate invasiveness, and low percentage of heavy invasiveness. The Gona cores have a preponderance of heavy invasiveness. Differences between the bonobo, Gona, and human samples were significant at the .05 level.

Invasiveness of Flaking by Tool-maker

			Degree of invasiveness			
			light, shallow	moderate	heavy, invasive	Total
Tool-maker	bonobo	Count	4	27	2	33
		% within Tool-maker	12.1%	81.8%	6.1%	100.0%
	gona	Count	0	7	16	23
		% within Tool-maker	.0%	30.4%	69.6%	100.0%
	human	Count	1	19	11	31
		% within Tool-maker	3.2%	61.3%	35.5%	100.0%
Total		Count	5	53	29	87
		% within Tool-maker	5.7%	60.9%	33.3%	100.0%



Chi-Square Tests: Degree of Invasiveness, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	25.687[a]	2	.000
Likelihood Ratio	28.705	2	.000
N of Valid Cases	56		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 1.64.

Chi-Square Tests: Degree of Invasiveness, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	9.369[a]	2	.009
Likelihood Ratio	10.123	2	.006
N of Valid Cases	64		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 2.42.

Chi-Square Tests: Degree of Invasiveness, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.420[a]	2	.040
Likelihood Ratio	6.882	2	.032
N of Valid Cases	54		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is .43.

Discussion

The bonobo cores have a low and moderate invasiveness because they are lightly reduced with small flakes being detached for the most part, whereas the Gona cores have a heavy invasiveness, indicating that they have been heavily and effectively reduced with larger flakes being detached overall. As mentioned previously, the experimental human sample intentionally tried to reduce most cores by about 50% of their original cobble mass in order to provide a controlled sample for comparisons with the bonobo and Gona samples. In this attribute, the human sample is intermediate between the more lightly flaked bonobo cores and the more heavily flaked Gona cores.

8. Cores: Percentage of Circumference Flaked

Rationale

The percentage of cobble circumference flaked is yet another criterion that can be used to determine how extensively an Oldowan core has been exploited. Although a very long, roller-shaped cobble can be extensively reduced and still retain a relatively low percentage of circumference flaked, most of the cobbles available to Gona hominins tend to fall into the disc and sphere categories of geological clast shape, so that their percentage of circumference flaked is reasonably indicative of the extent of flaking.

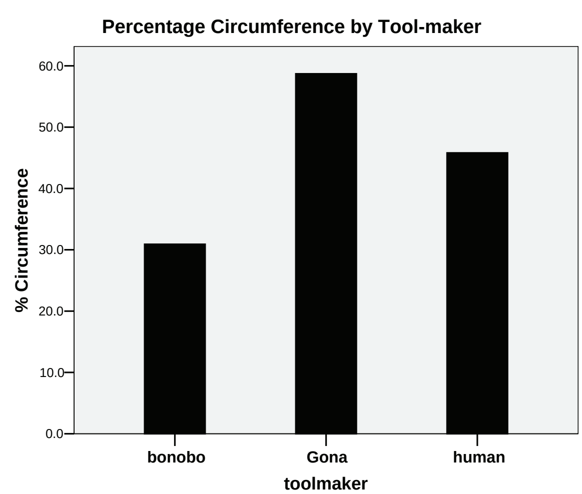
Results

The bonobo cores showed the lowest percentage of circumference flaked, with the human sample intermediate and the Gona sample having a very high percentage of circumference flaked. The Gona cores were flaked along nearly twice as much of the cobble circumference overall than the bonobo cores. The differences between the bonobos and both the Gona and human core samples were significant at the .05 level, but the difference between the Gona and human samples was not significant at this level.

Extent of Core Reduction by Tool-maker

Extent of core reduction

Tool-maker	Mean	N	Std. Deviation
bonobo	30.91	33	9.475
gona	58.67	23	23.799
human	45.81	31	9.924
Total	43.56	87	18.362



Test Statistics: Extent of Core Reduction, Bonobo v. Gona[a]

	Extent of core reduction
Mann-Whitney U	96.000
Wilcoxon W	657.000
Z	-4.855
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Extent of Core Reduction, Bonobo v. Human[a]

	Extent of core reduction
Mann-Whitney U	152.000
Wilcoxon W	713.000
Z	-4.982
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Extent of Core Reduction, Gona v. Human[a]

	Extent of core reduction
Mann-Whitney U	263.000
Wilcoxon W	759.000
Z	-1.684
Asymp. Sig. (2-tailed)	.092

a. Grouping Variable: Toolmkrcod

Discussion

The bonobos relatively low percentage of circumference flaked (~31%) is an indication of minimal reduction of cobbles, while the high percentage of circumference flaked in the archaeological sample (~59%) is an indication of much heavier reduction of cobble cores by the Gona hominin tool-makers. Again, the experimental human sample, which intentionally reduced most cores by about half their original mass, was intermediate (~46%).

9. Cores: Quality of Flaking

Rationale

From a flintknapper's perspective, cores were ranked by the quality of flaking. Higher quality of flaking denoted well-reduced cores, clean flake detachments, and crisp non-battered edges. Although a very subjective category, experience has shown us that this is nonetheless a useful category in assessing different levels of skill. Such cores are typically illustrated in Oldowan site reports. Quality categories were excellent, good, fair, and poor.

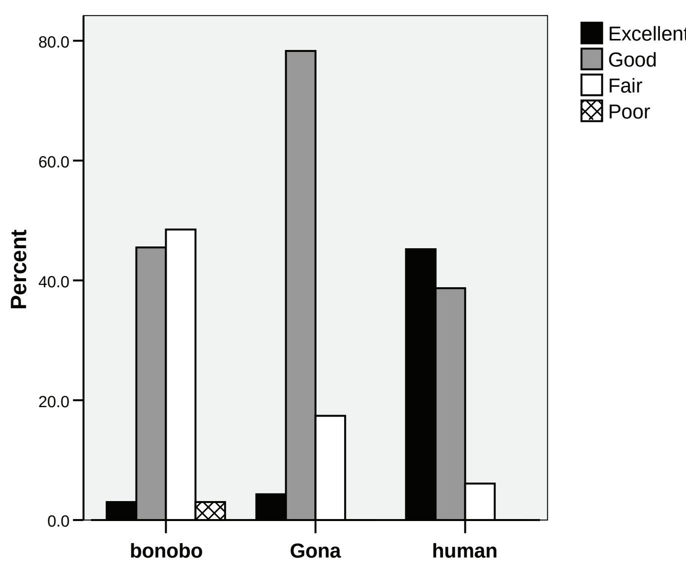
Results

The bonobo core sample was characterized by a modal value of fair-quality flaking, the Gona sample by good-quality flaking, and the human sample by excellent-quality flaking. Using all four quality categories, statistical testing showed differences between the human sample and the other two samples but not between the bonobo and Gona samples at the .05 level of significance, although 4 cells had expected counts less than 5. Testing after combining categories (good to excellent as "high" and poor to fair as "low"), on the other hand, points to a significant difference between the bonobo sample and the other two samples in this attribute, while the Gona and human samples show a much higher and relatively equivalent quality of flaking.

Quality of Flaking by Tool-maker

			Quality of flaking (skill)				
			excellent	good	fair	poor	Total
Tool-maker	bonobo	Count	1	15	16	1	33
		% within Tool-maker	3.0%	45.5%	48.5%	3.0%	100.0%
	gona	Count	1	18	4	0	23
		% within Tool-maker	4.3%	78.3%	17.4%	.0%	100.0%
	human	Count	14	12	5	0	31
		% within Tool-maker	45.2%	38.7%	16.1%	.0%	100.0%
Total		Count	16	45	25	1	87
		% within Tool-maker	18.4%	51.7%	28.7%	1.1%	100.0%

Quality of Flaking by Tool-maker



Chi-Square Tests: Quality of Flaking, Bonobo v. Gona, 4 categories

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.907[a]	3	.075
Likelihood Ratio	7.574	3	.056
N of Valid Cases	56		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is .41.

Chi-Square Tests: Quality of Flaking, Bonobo v. Human, 4 categories

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	18.317[a]	3	.000
Likelihood Ratio	21.164	3	.000
N of Valid Cases	64		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is .48.

Chi-Square Tests: Quality of Flaking, Gona v. Human, 4 categories

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.648[a]	2	.003
Likelihood Ratio	13.576	2	.001
N of Valid Cases	54		

a. 1 cells (16.7%) have expected count less than 5. The minimum expected count is 3.83.

Quality of Flaking (2 categories) by Tool-maker

			Quality of flaking (2 categories)		
			excellent or good	fair or poor	Total
Tool-maker	bonobo	Count	16	17	33
		% within Tool-maker	48.5%	51.5%	100.0%
	gona	Count	19	4	23
		% within Tool-maker	82.6%	17.4%	100.0%
	human	Count	26	5	31
		% within Tool-maker	83.9%	16.1%	100.0%
Total		Count	61	26	87
		% within Tool-maker	70.1%	29.9%	100.0%

Chi-Square Tests: Quality of Flaking, Bonobo v. Gona, 2 categories

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	6.734[b]	1	.009		
Continuity Correction[a]	5.357	1	.021		
Likelihood Ratio	7.124	1	.008		
Fisher's Exact Test				.012	.009
N of Valid Cases	56				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 8.63.

Chi-Square Tests: Quality of Flaking, Bonobo v. Human, 2 categories

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	8.873[b]	1	.003		
Continuity Correction[a]	7.373	1	.007		
Likelihood Ratio	9.258	1	.002		
Fisher's Exact Test				.004	.003
N of Valid Cases	64				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 10.66.

Chi-Square Tests: Quality of Flaking, Gona v. Human, 2 categories

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.015[b]	1	.902		
Continuity Correction[a]	.000	1	1.000		
Likelihood Ratio	.015	1	.902		
Fisher's Exact Test				1.000	.592
N of Valid Cases	54				

a. Computed only for a 2x2 table.

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.83.

Discussion

Examination of the distribution of flaking quality among the samples shows, in fact, a gradient among the three samples. The bonobo sample, characterized by cores that showing primarily fair (~49%) and good (~46%) flaking quality, showed the lowest overall level of skill of the three samples. The Gona sample showed a preponderance of good flaking (~78%), and the human sample was characterized by cores showing excellent (~45) and good (~39%) flaking quality. Thus, in terms of overall quality of flaking, the Gona sample was intermediate between the bonobo and human samples.

10. Cores: Edge Battering

Rationale

Core edges exhibiting heavy battering (hammerstone percussion marks, crushing, and small-scale step flaking) may be an indication of less skilled flaking and numerous unsuccessful attempts to remove flakes with a percussor. This criterion was developed after examination of the bonobo cores appeared to show much more edge battering than had been observed on archaeological cores or on experimental cores produced by humans. Edge battering was divided into four categories: none, low, moderate, and high.

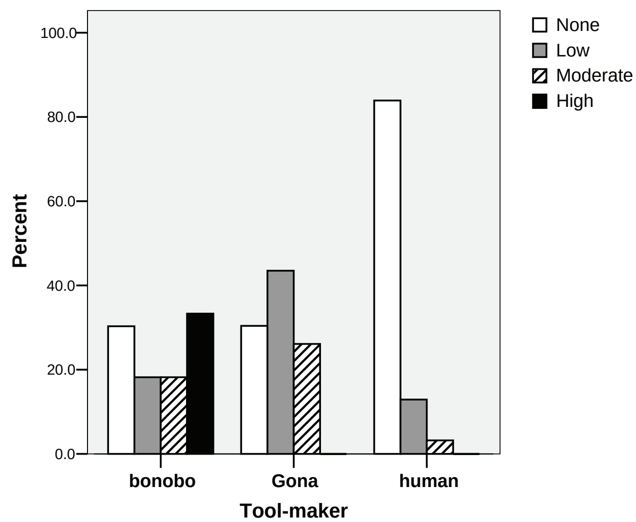
Results

The bonobo sample is characterized by an appreciable percentage of cores (~33%) showing high levels of edge battering from hammerstone percussion. The modal value for Gona cores was a low degree of edge battering (~44%), but appreciable quantities of also showed moderate battering (~26%). The great majority of cores in the human sample (~84%) exhibited no edge battering. Interestingly, none of the cores from the Gona and human samples showed a high degree of edge battering. Each of the three tool-making populations was significantly different from the other two (at the .05 confidence level) in terms of core edge battering.

Core Edge Battering by Tool-maker

			Edge battering, microstepping, crushing				
			none	low	mod-erate	high	Total
Tool-maker	bonobo	Count	10	6	6	11	33
		% within Tool-maker	30.3%	18.2%	18.2%	33.3%	100.0%
	gona	Count	7	10	6	0	23
		% within Tool-maker	30.4%	43.5%	26.1%	.0%	100.0%
	human	Count	26	4	1	0	31
		% within Tool-maker	83.9%	12.9%	3.2%	.0%	100.0%
Total		Count	43	20	13	11	87
		% within Tool-maker	49.4%	23.0%	14.9%	12.6%	100.0%

Edge Battering by Tool-maker



Chi-Square Tests: Core Edge Battering, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.098[a]	3	.011
Likelihood Ratio	14.997	3	.002
N of Valid Cases	56		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 4.52.

Chi-Square Tests: Core Edge Battering, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.042[a]	3	.000
Likelihood Ratio	26.918	3	.000
N of Valid Cases	64		

a. 3 cells (37.5%) have expected count less than 5. The minimum expected count is 3.39.

Chi-Square Tests: Core Edge Battering, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.254[a]	2	.000
Likelihood Ratio	17.071	2	.000
N of Valid Cases	54		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 2.98.

Discussion

Over half of the bonobo cores (~52%) showed either a moderate or high degree of edge battering. This indicates high numbers of unsuccessful hammerstone blows by the bonobos in attempts to remove usable flakes and a significantly lower level of skill than the Gona and human samples. Also, ~49% of bonobo cores showed little or no edge battering compared to ~74 % for Gona and almost all of the human cores (~97%). In terms of the criterion of edge battering, then, the Gona hominins are intermediate in skill level relative to the bonobos and humans.

11. Cores: Modified Leakey Typology

Rationale

Mary Leakey's (1971) typology of Oldowan cores is one of the most widely used systems, especially if one views these forms as core morphologies rather than functional classes. Her major categories of cores made on cobbles (her "heavy-duty tools") are choppers, discoids, heavy-duty scrapers, proto-bifaces, polyhedrons, discoids, heavy-duty scrapers, and spheroids. In this study, there were no polyhedrons, protobifaces, or spheroids in any of the samples. We added one new category, "casual core," for very minimally-flaked cobbles (probably closest to Mary Leakey's "modified and battered nodules and blocks" category). In addition, we decided to separate choppers into their two major categories, side choppers and end choppers, based upon whether the flaked edge was along the end or side of the cobble.

Results

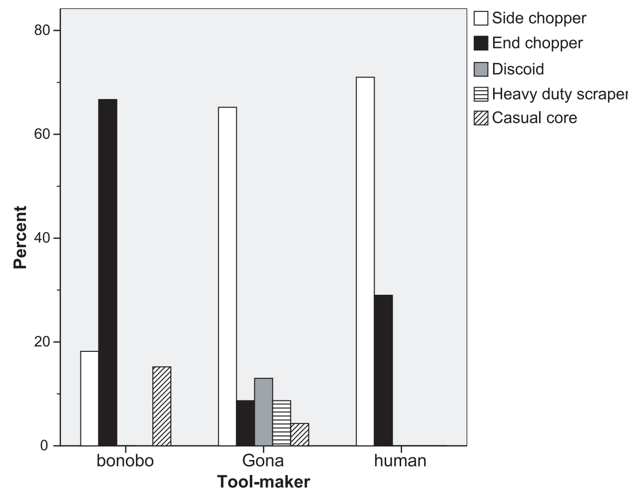
The bonobo cores were characterized by an abundance of end choppers (~64%), in comparison with the Gona and human cores, which had predominantly side choppers (~65% and 71% respectively). The bonobo sample was significantly different from the other two samples in the numbers of end v. side choppers, while the Gona and human samples did not differ significantly at the .05 level. In view of the high proportion of choppers in each of the three tool-making samples (bonobos 82%, Gona ~74%, and humans 100%), they would all be assigned to the "Oldowan Industry" in Leakey's classification system (1971). The bonobo sample also has a number of cores assigned to the "casual core" category, and the Gona sample has small numbers of other core types (discoids, end choppers, heavy-duty scrapers, and one casual core).

Chi-Square Tests: Leakey Core Types, All Tool-makers

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	43.131[a]	8	.000
Likelihood Ratio	46.596	8	.000
N of Valid Cases	87		

a. 9 cells (60.0%) have expected count less than 5. The minimum expected count is .53.

Leakey Core Types by Tool-maker



Chi-Square Tests: End and Side Choppers, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	18.968[b]	1	.000		
Continuity Correction[a]	16.379	1	.000		
Likelihood Ratio	20.771	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	45				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 7.93.

Leakey Core Type by Tool-maker

			Mary Leakey core type					
			Side chopper	End chopper	Discoid	Heavy-duty scraper	Casual core	Total
Tool-maker	bonobo	Count	6	22	0	0	5	33
		% within Tool-maker	18.2%	66.7%	.0%	.0%	15.2%	100.0%
	gona	Count	15	2	3	2	1	23
		% within Tool-maker	65.2%	8.7%	13.0%	8.7%	4.3%	100.0%
	human	Count	22	9	0	0	0	31
		% within Tool-maker	71.0%	29.0%	.0%	.0%	.0%	100.0%
Total		Count	43	33	3	2	6	87
		% within Tool-maker	49.4%	37.9%	3.4%	2.3%	6.9%	100.0%

Chi-Square Tests: End and Side Choppers, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	14.479[b]	1	.000		
Continuity Correction[a]	12.561	1	.000		
Likelihood Ratio	15.191	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	59				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 13.29.

Chi-Square Tests: End and Side Choppers, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.853[b]	1	.173		
Continuity Correction[a]	1.005	1	.316		
Likelihood Ratio	2.007	1	.157		
Fisher's Exact Test				.284	.158
N of Valid Cases	48				

a. Computed only for a 2x2 table.

b. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.90.

Discussion

Although all three samples are dominated by core forms that would be designated as choppers in Mary Leakey's classification, the bonobo assemblage stands out in its high proportion of end rather than side choppers. This is a result of bonobos reducing a cobble significantly less, resulting in a preponderance of end choppers rather than side choppers. This is in contrast to the cores produced by the humans and Gona tool-makers, which tend to be more heavily reduced; many of these cores almost certainly started as end choppers, but with further, more efficient reduction, they were transformed into side choppers (in the human sample, in which reduction was held to approximately 50% of the original cobble, as well as in the Gona archaeological sample).

12. Cores: Weight

Rationale

Core weights in a given raw material can help show differences between assemblages that may be due to differences in the weights of the original cobble forms and/or differences in the amount of core reduction. For both of the experimental samples, an equivalent range of sizes and shapes of pre-selected cobbles (discussed above) was made available to the subjects.

Results

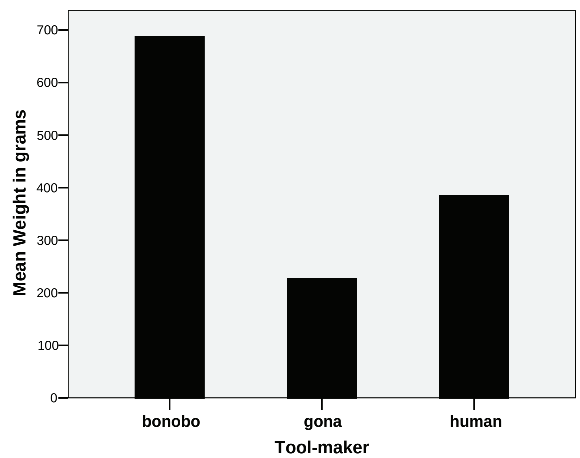
The bonobos produced the heaviest cores, averaging about 687 g, with a much larger standard deviation than the other two samples as well. The Gona cores were the smallest (~226 g average), with the modern human sample intermediate (~385 g). Each tool-maker sample differed significantly from the other two in terms of final core weight at the .000 level.

Core Weight by Tool-maker

Weight in grams

Tool-maker	Mean	N	Std. Deviation
bonobo	686.82	33	328.682
gona	226.22	23	111.925
human	384.55	31	117.893
Total	457.34	87	290.953

Cores: Mean Weight by Tool-maker



Test Statistics: Core Weight, Bonobo v. Gona[a]

	Weight in grams
Mann-Whitney U	35.000
Wilcoxon W	311.000
Z	-5.738
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Weight, Bonobo v. Human[a]

	Weight in grams
Mann-Whitney U	179.500
Wilcoxon W	675.500
Z	-4.460
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Weight, Gona v. Human[a]

	Weight in grams
Mann-Whitney U	105.000
Wilcoxon W	381.000
Z	-4.400
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The bonobo cores are markedly heavier than the Gona or human samples. This is due to the fact that bonobos almost invariably chose larger cobbles for flaking, since their hands are large with long fingers and a very short thumb and are less dexterous than those of modern humans (and also, presumably, than those of Gona hominins as well), and also because the bonobo cobble cores were much less reduced than the Gona or human samples. The human cores are intermediate in weight between the bonobo and Gona cores, but, on average, are closer to the mean weight of Gona cores. A number of other attributes examined (above and below) suggest that the human cores are not as extensively reduced as the Gona cores; if they were, the mean weights would likely be very similar.

13. Cores: Length (Maximum Dimension)

Rationale

This measurement gives an indication of the size of cores based on the largest linear measurement. It also shows the minimum size of cobble blanks selected by early hominins. This measurement is also used to calculate core breadth/length ratios, as well as the ratio of the largest flake scar/core maximum dimension (discussed below).

Results

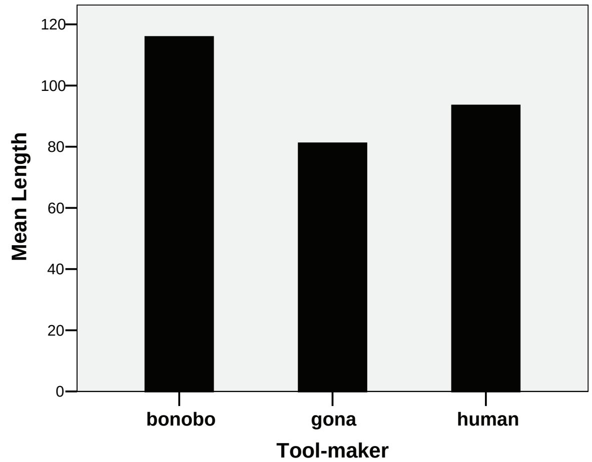
As with weight, the bonobo core maximum dimensions were the largest (mean ~116 mm), with humans intermediate (~93 mm), and the Gona cores the smallest (~81 mm); the bonobo cores also showed a much higher standard deviation. Each tool-making population produced cores whose mean maximum dimension differed significantly (at the .000 level) from the other two samples.

Cores: Maximum Dimension by Tool-maker

Length

Tool-maker	Mean	N	Std. Deviation
bonobo	115.85	33	18.171
gona	81.09	23	10.816
human	93.45	31	11.331
Total	98.68	87	20.083

Cores: Mean Length by Tool-maker



Test Statistics: Core Maximum Dimension, Bonobo v. Gona[a]

	Length
Mann-Whitney U	39.000
Wilcoxon W	315.000
Z	-5.673
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Maximum Dimension, Gona v. Human[a]

	Length
Mann-Whitney U	138.000
Wilcoxon W	634.000
Z	-5.019
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Maximum Dimension, Gona v. Human[a]

	Length
Mann-Whitney U	147.000
Wilcoxon W	423.000
Z	-3.668
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

As with weight, the differences seen in core maximum dimension in the three tool-making samples can be explained. As the bonobos tended to choose larger cobbles (because of their hand morphology) and also reduced the cobble cores less extensively, their resultant cores tended to be larger. The human core sample was closer in size to the Gona cores. As previously discussed, the human cores are somewhat less reduced overall than the archaeological cores and thus somewhat larger.

14. Cores: Breadth

Rationale

Breadth was defined as the dimension of the core measured at a right angle to the length or maximum dimension. This measurement is also useful in determining breadth/length ratios and thickness/breadth ratios.

Results

The mean breadth of cores in the three samples differed greatly. As with core length, the bonobo core sample showed the greatest mean breadth (~90 mm), with the human sample intermediate (~75 mm) and the Gona sample the smallest (~61 mm). Each population differed from the other two at the .000 level of significance.

Cores: Breadth by Tool-maker

Breadth

Tool-maker	Mean	N	Std. Deviation
bonobo	90.06	33	16.948
gona	60.52	23	9.375
human	74.94	31	8.675
Total	76.86	87	17.182

Test Statistics: Core Breadth, Bonobo v. Gona[a]

	Length
Mann-Whitney U	37.500
Wilcoxon W	313.500
Z	-5.698
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Breadth, Bonobo v. Human[a]

	Length
Mann-Whitney U	191.000
Wilcoxon W	687.000
Z	-4.309
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Breadth, Gona v. Human[a]

	Length
Mann-Whitney U	89.500
Wilcoxon W	365.500
Z	-4.675
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

As with core length (maximum dimension), the larger core breadth seen in the bonobo sample seems to be primarily a function of their selecting larger cobbles for flaking. The greater breadth seen in the human cores relative to the Gona sample is probably due to the fact that the human cores are not as extensively reduced as the Gona cores; with further reduction of especially side choppers, breadth measurements would probably decrease accordingly.

15. Cores: Thickness

Rationale

Thickness was measured at a right angle to breadth, and represents the smallest of the three length/breadth/thickness measurements. Interestingly, this measurement on Oldowan cobble cores probably often represents a reasonable estimate of the thickness of the original cobble blank that was flaked.

Results

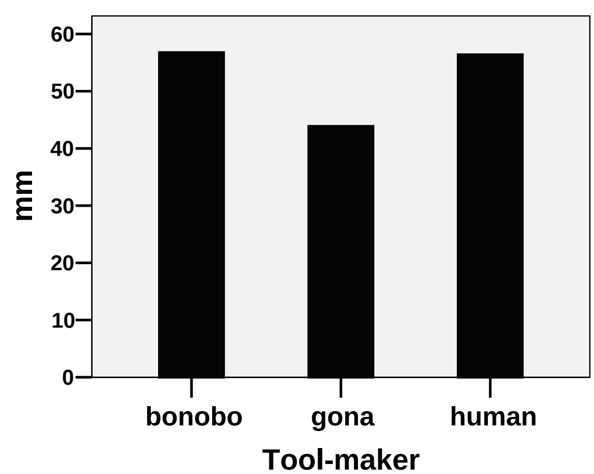
The Gona cores were the thinnest (~44 mm), while the bonobo and human samples were almost identical in terms of absolute thickness (~57 mm and ~56 mm respectively). Statistical tests indicated that the Gona sample differed from the bonobo and human samples (at the .001 and .000 confidence levels, respectively), while the bonobo and human samples were not significantly different (.824 significance level).

Cores: Thickness by Tool-maker

Thickness

Tool-maker	Mean	N	Std. Deviation
bonobo	56.76	33	14.908
gona	43.87	23	11.022
human	56.39	31	9.222
Total	53.22	87	13.238

Cores: Mean Thickness



Test Statistics: Core Thickness, Bonobo v. Gona[a]

	Length
Mann-Whitney U	184.000
Wilcoxon W	460.000
Z	-3.257
Asymp. Sig. (2-tailed)	.001

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Thickness, Bonobo v. Human[a]

	Length
Mann-Whitney U	495.000
Wilcoxon W	991.000
Z	-.222
Asymp. Sig. (2-tailed)	.824

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Thickness, Gona v. Human[a]

	Length
Mann-Whitney U	113.000
Wilcoxon W	389.000
Z	-4.264
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

Core thicknesses on the Gona sample suggest that the early hominin tool-makers were selecting thinner cobbles than the experimental samples. This may have been done in part because thinner cobbles tend to be easier to flake, with thinner edges more amenable to flake detachment with a hammerstone. It should be noted that, although the bonobo cores had a mean thickness equivalent to the human cores, their absolute length was considerably greater. These point to an overall size and shape difference in the bonobo cores, a pattern that will be explored further below.

16. Cores: Ratio Breadth/Length

Rationale

This ratio is an indication of how relatively elongated a core is with regard to breadth. A low ratio indicates a more elongated core, whereas a higher ratio indicates a more equilateral core.

Results

Although all three populations have roughly similar breadth/length mean ratios (from about 75 to 81%), the difference between the means of the Gona sample (with the smallest ratio) and human sample (with the largest ratio) was significant at the .05 confidence level. There were no significant differences between the bonobo sample (with an intermediate breadth/length value) and the other two samples.

Cores: Breadth to Length Ratio

b_by_l

Tool-maker	Mean	N	Std. Deviation
bonobo	.7826	33	.11858
gona	.7493	23	.08815
human	.8077	31	.09408
Total	.7827	87	.10407

Test Statistics: Breadth to Length Ratio, Bonobo v. Gona[a]

	b_by_l
Mann-Whitney U	298.000
Wilcoxon W	574.000
Z	-1.357
Asymp. Sig. (2-tailed)	.175

a. Grouping Variable: Toolmkrcod

Test Statistics: Breadth to Length Ratio, Bonobo v. Human[a]

	b_by_l
Mann-Whitney U	448.000
Wilcoxon W	1009.000
Z	-.853
Asymp. Sig. (2-tailed)	.394

a. Grouping Variable: Toolmkrcod

Test Statistics: Breadth to Length Ratio, Gona v. Human[a]

	b_by_l
Mann-Whitney U	229.000
Wilcoxon W	505.000
Z	-2.230
Asymp. Sig. (2-tailed)	.026

a. Grouping Variable: Toolmkrcod

Discussion

This attribute is actually somewhat problematic as a point of comparison between different assemblages: this ratio can change dramatically as the axes of length and breadth change dimension in the process of core reduction, and can even reverse direction of change when continued flaking transforms the "length" into the "breadth." It should be noted that although the bonobo mean was not significantly different than the Gona and human samples, the bonobo sample was composed mainly of end choppers, with the worked edge roughly perpendicular to the long axis of the core, while the Gona and human samples were composed largely of side choppers, with the worked edge roughly parallel to the long axis of the core. As a hypothetical case, the reduction of an elongate cobble could give the following progression of breadth/length ratios and core typology as flaking proceeded: .74 (end chopper), .84 (end chopper), .95 (end chopper), .96 (side chopper) [after the worked "end" becomes the worked "side"], .79 (side chopper), .60 (side chopper), .51 (an extremely reduced side chopper). Thus, an end chopper can progress upward in breadth/length ratio until it is equidimensional, and then further working of the same edge as a side chopper will continue to reduce this ratio.

As the Gona and human samples were dominated by side choppers, continued flaking of their primary edges would tend to decrease the breadth/length ratio (as flake removals remove additional material from the breadth of the core). Thus, the fact that the Gona cores have a somewhat smaller mean breadth/length ratio than the human cores may reflect the more intensive reduction of the archaeological cores (with further reduction of the human side choppers tending to reduce their mean and moving it further toward the Gona value). Reduction of the bonobo end choppers, on the other hand, is acting to increase their breadth/length ratio to artificially place it within the human-Gona range; further flaking along the cobble end would tend to increase it further (until the core is equidimensional).

17. Cores: Modified Breadth/Length Ratio

Rationale

Perhaps a better indicator of core morphology would be to define length as the dimension perpendicular to the flaked edge and breadth as the dimension parallel to the flaked edge. This attribute would then discriminate fully between side choppers and end choppers. By doing this, the modified breadth:length ratio of end choppers would always be less the 1.0, while the modified breadth:length ratio of side choppers would be greater than 1.0. This new ratio was applied to the choppers from the three samples.

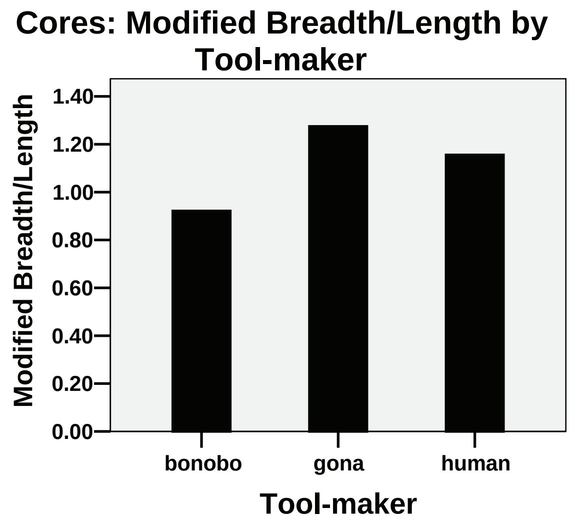
Results

The bonobo cores, with a preponderance of end choppers, had the lowest mean modified breadth/length ratio (~0.92), and the Gona cores, with a preponderance of side choppers, the highest (~1.27). The human cores were intermediate at ~1.16. Statistical tests showed a significant difference between the bonobo sample and both the Gona and human samples (at the .000 significance level), but not between the Gona and human core samples at the .05 level of significance.

Cores: Modified Breadth by Length

Mod breadth by length

Tool-maker	Mean	N	Std. Deviation
bonobo	.9211	27	.26246
gona	1.2745	17	.26293
human	1.1554	31	.24763
Total	1.0981	75	.28977



Test Statistics: Modified Breadth by Length, Bonobo v. Gona[a]

	Mod breadth by length
Mann-Whitney U	80.000
Wilcoxon W	458.000
Z	-3.603
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Modified Breadth by Length, Bonobo v. Human[a]

	Mod breadth by length
Mann-Whitney U	194.500
Wilcoxon W	572.500
Z	-3.492
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Modified Breadth by Length, Gona v. Human[a]

	Mod breadth by length
Mann-Whitney U	182.000
Wilcoxon W	678.000
Z	-1.757
Asymp. Sig. (2-tailed)	.079

a. Grouping Variable: Toolmkrcod

Discussion

These results show a likely continuum in the reduction of somewhat elongated cobbles from end choppers to side choppers. The bonobo sample, whose cores are characterized by less reduction, show a relatively low ratio indicating a dominance of end choppers, while the Gona sample and, to a lesser extent, the human sample, have higher ratios, in line with being more heavily reduced and having a dominance of side choppers. Thus, this modified breadth/length ratio more accurately reflects technological differences in the core assemblages in the samples than does the simple breadth/length ratio.

18. Cores: Ratio Thickness/Breadth

Rationale

This ratio was analyzed to help quantify the relative shape of core forms made on cobbles. As with the breadth/length ratio, this ratio treats a core as a geological clast irregardless of the orientation of the flaked edge.

Results

The bonobo core sample has the lowest thickness/breadth ratio (~.64), the human sample the highest (~.76), and the Gona sample an intermediate ratio (~.73). Statistical tests showed that only the bonobo and human samples differed at the .05 confidence level.

Cores: Thickness to Breadth Ratio by Tool-maker

th_by_b

Tool-maker	Mean	N	Std. Deviation
bonobo	.6439	33	.18172
gona	.7283	23	.15469
human	.7559	31	.10749
Total	.7061	87	.15796

Test Statistics: Thickness to Breadth Ratio, Bonobo v. Gona[a]

	th_by_b
Mann-Whitney U	280.500
Wilcoxon W	841.500
Z	-1.649
Asymp. Sig. (2-tailed)	.099

a. Grouping Variable: Toolmkrcod

Test Statistics: Thickness to Breadth Ratio, Bonobo v. Human[a]

	th_by_b
Mann-Whitney U	310.000
Wilcoxon W	871.000
Z	-2.707
Asymp. Sig. (2-tailed)	.007

a. Grouping Variable: Toolmkrcod

Test Statistics: Thickness to Breadth Ratio, Gona v. Human[a]

	th_by_b
Mann-Whitney U	316.500
Wilcoxon W	592.500
Z	-.700
Asymp. Sig. (2-tailed)	.484

a. Grouping Variable: Toolmkrcod

Discussion

The low ratio for bonobo cores relative to the human cores is probably a function of the bonobos using larger cobbles with larger absolute breadth and length than the human sample, although with similar thicknesses. The bonobos are also tending to make more end choppers and thus are tending to reduce the length, rather than the breadth, of these larger clasts as reduction proceeds.

19. Cores: Maximum Dimension Largest Scar

Rationale

The maximum dimension of the largest scar was measured; this was an absolute measurement, without consideration as to whether the scar was truncated by later flaking. This measurement can give an indication of the size of flakes being detached, although as reduction proceeds, it is likely that some large flake scars are truncated by later scars and thus their maximum dimension reduced.

Results

The bonobo flake scars had the highest mean (~62 mm), with human cores intermediate (~58 mm), and the Gona sample showing the lowest mean (~46 mm). Statistical tests showed that the means of the Gona flake scars differed significantly from both the other samples, while the human and bonobo samples showed very little difference.

Cores: Mean Length Largest Scar by Tool-maker

Length of largest scar

Tool-maker	Mean	N	Std. Deviation
bonobo	61.73	33	23.018
gona	45.91	23	10.352
human	57.84	31	13.902
Total	56.16	87	18.248

Test Statistics: Core Mean Length Largest Scar, Bonobo v. Gona[a]

	Length of largest scar
Mann-Whitney U	204.500
Wilcoxon W	480.500
Z	-2.918
Asymp. Sig. (2-tailed)	.004

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Mean Length Largest Scar, Bonobo v. Human[a]

	Length of largest scar
Mann-Whitney U	505.500
Wilcoxon W	1066.500
Z	-.081
Asymp. Sig. (2-tailed)	.936

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Mean Length Largest Scar, Gona v. Human[a]

	Length of largest scar
Mann-Whitney U	167.500
Wilcoxon W	443.500
Z	-3.309
Asymp. Sig. (2-tailed)	.001

a. Grouping Variable: Toolmkrcod

Discussion

The mean largest flake scar dimension for cores appears in part to be a function of the size of the cobble that was chosen as the blank and the size of the largest flakes removed, in combination with the amount of truncation of these scars by subsequent flaking (i.e., intensity of reduction). This latter factor, the truncation and even removal of earlier flake scars by later core reduction, appears to be a major factor reducing the mean of this attribute in the human core sample, as the largest flakes removed in the human sample for each core (77.5 mm) averaged approximately 15 mm larger than the largest bonobo flakes per core (62.2 mm). Thus, the dimensions of flake scars on the bonobo cores tend to be representative of the largest flakes removed (both approximately 62 mm), largely because their cores are less intensively reduced and thus flake scars tend to be more complete.

The human sample had largest mean scar value (57.8 mm), an underestimate for the largest flake from each core, which averaged approximately 77.5 mm. The relatively smaller size of flake scars on the Gona cores is likely due to the smaller core size and their more intensive reduction, which would have tended to truncate and reduce the size of flake scars on the cores. For more heavily reduced cores, then, the absolute size of the largest flake scar on a core has more limited utility in predicting dimensions of the flake populations removed.

20. Cores: Ratio of Largest Scar/Core Maximum Dimension

Rationale

This ratio is used to arrive at a quantifiable assessment of the invasiveness of the flaking. A ratio that is approaches 1.0 indicates that the largest flake scar is almost the same length as the maximum dimension of the core, in other words, denoting a very invasively flaked core.

Results

The bonobo cores were the least invasively flaked by this measure (largest scar-to-length ratio of approximately .53); the human sample was the most invasive (.62), with the Gona sample intermediate (.57). Statistical testing indicated that only the groups with the smallest and largest means, i.e. the bonobo and human samples, differed at the .05 level of significance.

Cores: Ratio of Largest Scar to Length by Tool-maker

lscar_l

Tool-maker	Mean	N	Std. Deviation
bonobo	.5278	33	.15330
gona	.5708	23	.12649
human	.6195	31	.13539
Total	.5718	87	.14420

Test Statistics: Core Ratio Largest Scar to Length, Bonobo v. Gona[a]

	lscar_l
Mann-Whitney U	286.500
Wilcoxon W	847.500
Z	-1.549
Asymp. Sig. (2-tailed)	.121

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Ratio Largest Scar to Length, Bonobo v. Human[a]

	lscar_l
Mann-Whitney U	287.000
Wilcoxon W	848.000
Z	-3.016
Asymp. Sig. (2-tailed)	.003

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Ratio Largest Scar to Length, Gona v. Human[a]

	lscar_l
Mann-Whitney U	262.000
Wilcoxon W	538.000
Z	-1.653
Asymp. Sig. (2-tailed)	.098

a. Grouping Variable: Toolmkrcod

Discussion

Although the size of the bonobo cores was the largest of the three samples, they were the least invasively flaked as assessed by this attribute. Even though the human cores were somewhat larger than Gona cores in terms of maximum dimension, their largest scar/length ratio was slightly higher. This may point to slightly more optimal flake production in the human sample (optimizing flake size per core), along with more intensive reduction of the Gona sample (truncating, and thus minimizing, the size of flake scars on the core).

21. Cores: Percentage of Original Cobble (Estimate)

Rationale

The technology exhibited in early Oldowan cores often makes it possible to arrive at reasonable estimates of the size of the original cobble clast and what percentage of that cobble mass remains in the final core form. This estimate is based on the presence and curvature of cortex on cores and extrapolating the continuation of cortical surface in areas that have been flaked, thereby reconstructing the original size and shape of the cobble. Obviously, cores that retain much of their cortex are better candidates for more accurate reconstruction of original cobble weight.

This subjective method is based on a great deal of experience in the analysis of Oldowan lithic technology. A blind test was conducted on an experimental sample of 25 cores (with known original cobble weights) to check our accuracy in inferring the original cobble weight of cores similar to those found at the Gona sites. The mean margin of error was plus or minus 5%, suggesting that this method is a useful guide to the intensity of core reduction.

As previously mentioned, the mass of the cobbles in the human experimental sample was intentionally reduced by approximately 50% to provide a baseline when analyzing the archaeological sample. This is reflected in the mean percentage of original cobble in the human sample.

Results

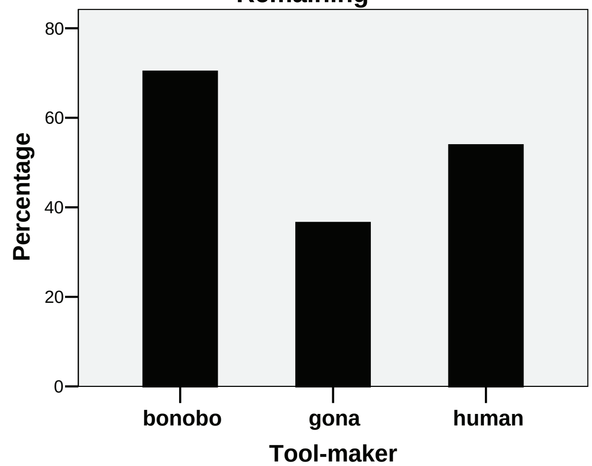
The bonobo cores were the least reduced (~70% of original cobble) and the Gona cores were the most reduced (~37%), with the human sample (~54%) intermediate. Statistical testing indicated that each of the three samples were significantly different from the other two at the .00 confidence level.

Cores: Percentage Original Cobble Remaining (Estimate) by Tool-maker

Percentage of original core left

Tool-maker	Mean	N	Std. Deviation
bonobo	70.30	33	16.490
gona	36.50	23	11.120
human	53.90	31	10.860
Total	55.50	87	18.850

Cores: Estimate Percentage of Original Cobble Remaining



Test Statistics: Percentage Original Cobble, Bonobo v. Gona[a]

	Percentage of original core left
Mann-Whitney U	51.500
Wilcoxon W	327.500
Z	-5.520
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Percentage Original Cobble, Bonobo v. Human[a]

	Percentage of original core left
Mann-Whitney U	199.500
Wilcoxon W	695.500
Z	-4.259
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Percentage Original Cobble, Gona v. Human[a]

	Percentage of original core left
Mann-Whitney U	99.000
Wilcoxon W	375.000
Z	-4.612
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The high mean percentage of original cobble remaining in the bonobo core sample is a clear indication of the low intensity of reduction (removing ~ 30% of the cobble mass), while the low mean percentage in the Gona sample is a clear indication of much higher intensity of reduction (removing 63% of the cobble mass). The ability to efficiently reduce a cobble and produce larger populations of usable flakes and fragments for a given range of raw materials is one measure of skill. Clearly the Gona hominins were able to reduce their cores more than twice as efficiently as the bonobos, suggesting better mastery of stone reduction.

22. Cores: Number of Flake Scars

Rationale

The number of flake scars (≥10 mm maximum dimension) on cores gives a minimum estimate of the number of flakes that have been removed from a core. Cores with low scar counts tend to be less reduced; cores with high scar counts often are heavily reduced. Of course, on more heavily reduced cores, later core reduction may remove earlier flake scars, so the total number of flakes removed can be considerably greater than the flake scar count estimate.

Results

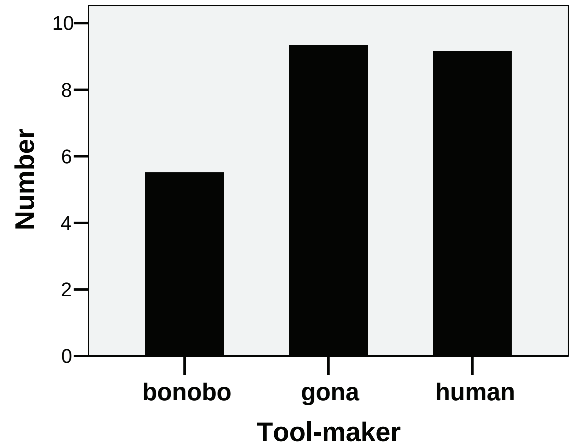
The bonobo cores showed a much lower mean flake scar count (~5.5) than the Gona (~9.3) or human (~9.1) sample. Statistical testing showed that the bonobo core sample differed significantly from both the Gona sample and the human sample at the .00 confidence level. The Gona and human samples, however, were almost identical regarding mean flake scar number.

Cores: Number of Flake Scars by Tool-maker

Number of flake scars

Tool-maker	Mean	N	Std. Deviation
bonobo	5.48	33	3.537
gona	9.30	23	3.948
human	9.13	31	3.074
Total	7.79	87	3.903

Cores: Mean Number of Flake Scars by Tool-maker



Test Statistics: Core Flake Scars, Bonobo v. Gona[a]

	Number of flake scars
Mann-Whitney U	145.000
Wilcoxon W	706.000
Z	-3.926
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Flake Scars, Bonobo v. Human[a]

	Number of flake scars
Mann-Whitney U	178.000
Wilcoxon W	739.000
Z	-4.510
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Flake Scars, Gona v. Human[a]

	Number of flake scars
Mann-Whitney U	354.000
Wilcoxon W	630.000
Z	-.044
Asymp. Sig. (2-tailed)	.965

a. Grouping Variable: Toolmkrcod

Discussion

The bonobo cores were much less heavily flaked, with between three and four fewer flake scars on average than the Gona and human samples. This is yet another indication of the low degree of reduction of bonobo cores relative to the Gona and human cores.

It is also useful to compare the actual number of flakes removed from a core to the number of core flake scars, which is possible to do on the experimental samples. As an indication of the *total* number of flakes produced in a sample, the number of whole flakes, number of split flakes (judged from the number of left or right splits, whichever is greater), and the number of proximal snaps were added together to derive the minimum number of whole flakes produced. Via this procedure, the bonobo sample produced 177 reconstructed flakes, the Gona sample 216, and the human sample 368. The ratio of reconstructed flakes to cores was 5.36 for bonobos, 9.39 for Gona, and 11.87 for humans. It is likely that the Gona flake counts would be higher if all the debitage was represented, since the Gona cores are more heavily reduced than the human cores and because there is evidence (to be discussed below) that certain flakes in the reduction history of cores are not represented at the excavated sites in expected numbers.

23. Cores: Ratio of Steps & Hinges/Total Scars

Rationale

Flake scars terminating in steps and hinges are often viewed as representing misguided flaking, since the flakes did not feather off neatly from the core. (Steps are flake scars that terminate at a right angle break, usually producing a piece of debitage that would be classified as a proximal snap, while hinges are flake scars that terminate in a curved termination). The ratio of steps and hinges to total number of flake scars has been used by some archaeologists as an assessment of skill level. A low number and low ratio of steps and hinges to other scars has sometimes been interpreted as an indication of greater skill in flaking, whereas a higher number and higher ratio of steps and hinges has been interpreted as an indication of a lower level of skill.

Results

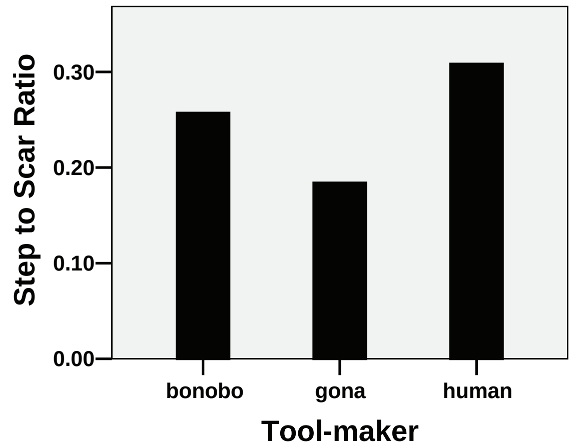
Surprisingly, the human 50% reduction sample had the highest ratio of steps and hinges to scars (~.31); the bonobos were intermediate (~.26) and the Gona sample the lowest (~.18). Statistical testing found that only the Gona and human samples showed significant differences at the .05 confidence level.

Cores: Step to scar ratio by tool-maker

step_scr

Tool-maker	Mean	N	Std. Deviation
bonobo	.2570	33	.21476
gona	.1839	23	.14908
human	.3083	31	.16444
Total	.2560	87	.18616

Cores: Mean Step to Scar Ratio by Tool-maker



Test Statistics: Core Step-to-Scar Ratio, Bonobo v. Gona[a]

	step_scr
Mann-Whitney U	304.000
Wilcoxon W	580.000
Z	-1.271
Asymp. Sig. (2-tailed)	.204

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Step-to-Scar Ratio, Bonobo v. Human[a]

	step_scr
Mann-Whitney U	435.000
Wilcoxon W	996.000
Z	-1.033
Asymp. Sig. (2-tailed)	.302

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Step-to-Scar Ratio, Gona v. Human[a]

	step_scr
Mann-Whitney U	202.000
Wilcoxon W	478.000
Z	-2.709
Asymp. Sig. (2-tailed)	.007

a. Grouping Variable: Toolmkrcod

Discussion

Initially, analysis of the results of this attribute was perhaps the most surprising of the entire study. If a high proportion of steps and hinges to flake scars is indeed an indication of lesser skill, then why would the human sample exhibit the highest proportion of step and hinge scars, when other attributes investigated here indicate greater flaking skill in the human sample than in the Gona or bonobo samples? There appear to be a number of factors that would help explain the observed pattern.

It is likely that the shape of the cobble chosen as a core blank could have a strong effect on the incidence of steps and hinges in an assemblage. Tool-makers selecting thinner cobbles or wedge-shaped cobbles with a thin edge that are much easier to flake might produce significantly lower proportions of steps and hinges. This could be the case with the Gona assemblage, in which relatively thinner, easier-to-flake cobbles may have been selected relative to those cobbles in the experimental samples. If there were enough type 1 flakes (flakes with a cortical striking platform and total cortex dorsal surface, normally the first flake to be removed from a cobble), this might be tested: the morphology of the cortex of that flake could be indicative of the ease of flaking of the cobble edge; unfortunately, there is only one type 1 flake from the Gona sites. Another test of clast shape would be refitting entire cobbles, but unfortunately, this is rarely possible in significant numbers at Oldowan sites.

In fact, investigation of the difference in core thickness may yield information pertinent to the patterns observed in experimental samples. The human cores tended to be thicker than the Gona cores, not only absolutely but also relative to core length (see below). This difference in relative thickness would tend to provide steeper edges for flaking and thus more opportunity to produce step or hinge flakes, increasingly so as a core is reduced and flaking forces are directed more steeply into the mass of the core. Although similar in absolute thickness to the human cores, the bonobo cores are thinner relative to their length and are not as heavily reduced, both of which factors may reduce the tendency for stepping to occur relative to the human sample.

As will be discussed below, in order to see how preferentially later stages of flaking might influence core and debitage characteristics (as this appears to be a major factor differentiating the human and Gona core samples), a subset of the human core sample (n=10, out of the total sample of 33 cores) was further reduced to a level more comparable to the Gona cores. Interestingly, these more heavily reduced cores had a step-to-scar ratio of .1565 (S.D. of .08), a ratio even lower than at Gona (.1839). The Mann-Whitney test did not find significant difference in step-to-scar ratios between the Gona sample and the human later stage sample.

Test Statistics: Core Step-to-Scar Ratio, Gona v. Human Later Stages[b]

	step_scr
Mann-Whitney U	111.000
Wilcoxon W	166.000
Z	-.157
Asymp. Sig. (2-tailed)	.875
Exact Sig. [2*(1-tailed Sig.)]	.893[a]

a. Not corrected for ties.

b. Grouping Variable: Toolmkrcod

It would thus appear that later stages of Oldowan cobble core reduction produce less step and hinge fractures, possibly because flakes are able to travel down established core ridges produced by previous flake removals. Earlier stages of cobble reduction, however, appear to produce relatively higher proportions of steps and hinges, possibly because flakes travel down curved cortical surfaces of cobble cores less successfully and terminate more frequently in steps or hinges.

In sum, the ratio of steps and hinges to total flake scars is probably not a reliable indicator of skill, but is likely influenced by a number of variables. Of special importance is the degree of reduction of the core, with more heavily reduced cores tending to exhibit fewer step and hinge scars. In addition, step and hinge scar frequencies are likely related to the overall ease of flaking the cobble, influenced in turn by variables such as presence of a thin edge for flaking, the absolute thickness of the core, and core thickness relative to length.

24. Cores: Edge Angle

Rationale

This measurement gives an indication of potential functional qualities of a core edge as well as an indication as to whether a given core could be easily flaked further. A flaked core edge will yield different angles depending on where you measure, so for this analysis the minimal edge angle was recorded. An edge angle of 70°, for example, suggests a possible cutting/chopping tool and a core that could still be reduced, assuming the core was still large enough for further reduction, whereas an angle of 95° suggests a non-functional edge for cutting or chopping and an exhausted core form.

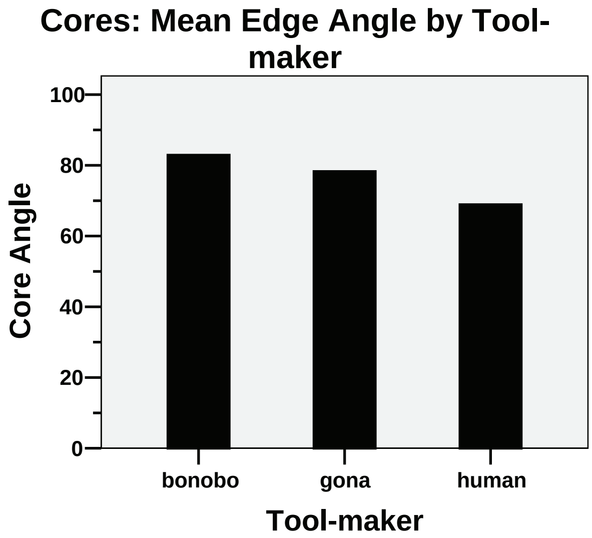
Results

The bonobo cores showed the steepest angles (~83 degrees), the human sample showed the most acute angles (~69 degrees) with the Gona cores intermediate (~78 degrees). Statistical testing indicated that the human sampled differed from both the bonobo and Gona samples at the .000 confidence level, but that the bonobo and Gona sample were not different at the .05 level.

Cores: Core angle by tool-maker

Core angle, nearest 5 degrees

Tool-maker	Mean	N	Std. Deviation
bonobo	82.88	33	13.231
gona	78.26	23	6.676
human	68.87	31	9.722
Total	76.67	87	12.120



Test Statistics: Core Edge Angles, Bonobo v. Gona[a]

	Core angle, nearest 5 degrees
Mann-Whitney U	305.500
Wilcoxon W	581.500
Z	-1.246
Asymp. Sig. (2-tailed)	.213

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Edge Angles, Bonobo v. Human[a]

	Core angle, nearest 5 degrees
Mann-Whitney U	207.000
Wilcoxon W	703.000
Z	-4.126
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Core Edge Angles, Gona v. Human[a]

	Core angle, nearest 5 degrees
Mann-Whitney U	148.500
Wilcoxon W	644.500
Z	-3.682
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The ability of a stone knapper to maintain acute angles as flaking proceeds is one index of skill. By this criterion, the human sample showed the most skill, with the most acute angles, with the Gona cores intermediate (though not significantly different from the bonobo sample), and the bonobo cores showing the least skill. The exterior platform angle on whole flakes, to be discussed below, is perhaps an even better indicator of core edge angle, as every flake bears evidence of the core angle immediately prior to this flake detachment and can represent all stages of core reduction rather than just the cores final form (at which time it was abandoned or lost).

25. Cores: Percentage of Surface Cortex

Rationale

The amount of surface cortex on Oldowan cobble cores, relative to flaked core surface, can be a gross estimate of the amount of reduction of these cobbles. (A possible exception might be a roller-shaped cobble that is unifacially reduced along its long axis; even if the mass is reduced by over 50 percent, the surface cortex may still be ca. 80 percent). This attribute is estimated to the nearest 5% based on visual examination.

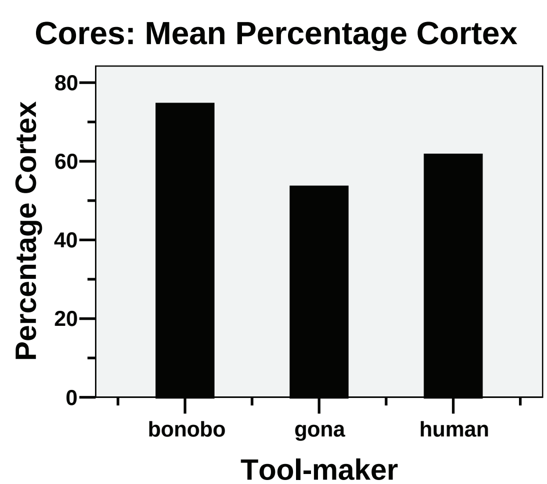
Results

The bonobo cores had the greatest mean cortex value at ~75 percent; the human cores were intermediate at ~62 percent, with the Gona core surfaces the most heavily flaked at ~53 percent. Statistical tests indicated that each of the three samples significantly differed from the other two samples at the .05 confidence level.

Cores: Percentage cortex remaining by tool-maker

Percentage of cortex

Tool-maker	Mean	N	Std. Deviation
bonobo	74.50	33	9.710
gona	53.48	23	16.130
human	61.61	31	11.280
Total	64.37	87	14.840



Test Statistics: Percentage Cortex, Bonobo v. Gona[a]

	Percentage of cortex
Mann-Whitney U	86.000
Wilcoxon W	362.000
Z	-5.009
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Percentage Cortex, Bonobo v. Human[a]

	Percentage of cortex
Mann-Whitney U	202.000
Wilcoxon W	698.000
Z	-4.300
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Percentage Cortex, Gona v. Human[a]

	Percentage of cortex
Mann-Whitney U	247.000
Wilcoxon W	523.000
Z	-2.009
Asymp. Sig. (2-tailed)	.045

a. Grouping Variable: Toolmkrcod

Discussion

Percentage of cortex on core surfaces is an index of how reduced a given cobble core is: 90 percent cortex would suggest minimal reduction, while 10 percent cortex would suggest very heavy reduction. The bonobo cores are the least reduced, and the Gona cores the most reduced. The extent of Gona core reduction, based on the low percentage of surface cortex, suggests a higher level of skill in the ability to remove substantial debitage as reduction proceeded.

26a. Flakes: Flake Types

Rationale

Classifying whole flakes into six distinct types (with a seventh indeterminate category) helps identify different stages of cobble reduction and preferential modes of flaking (Figure 23). These include:

Type 1: cortex platform; total cortex dorsal surface
Type 2: cortex platform; partial cortex dorsal surface
Type 3: cortex platform; non-cortex dorsal surface
Type 4: non-cortex platform; total cortex dorsal surface
Type 5: non-cortex platform; partial cortex dorsal surface
Type 6: non-cortex platform; non-cortex dorsal surface
Type 7: indeterminate; blown or punctiform platform or too weathered

As discussed by Toth (1982, 1985), examination of proportions of these flake types can also be employed to make predictions about what flake type populations would be expected in early stages (e.g. types 1, 2, 4, and 5 flakes) vs. later stages (e.g. types 3 and 6 flakes) of Oldowan cobble reduction, as well as about expected changes in flake type proportions in the event of hydrological winnowing during sedimentation and burial (e.g. preferentially winnowing away from a flaking locale the lighter types 3 and 6 flakes and leaving the heavier types 1, 2, 4, and 5). It is also possible to predict what flake types might be depleted in an assemblage if highly functional flakes were to be transported by hominins away from a flaking area (discussed below in section 27b). For the following analysis, the type 7 indeterminate flakes are omitted, since they are lacking technological information, usually missing identifiable striking platforms.

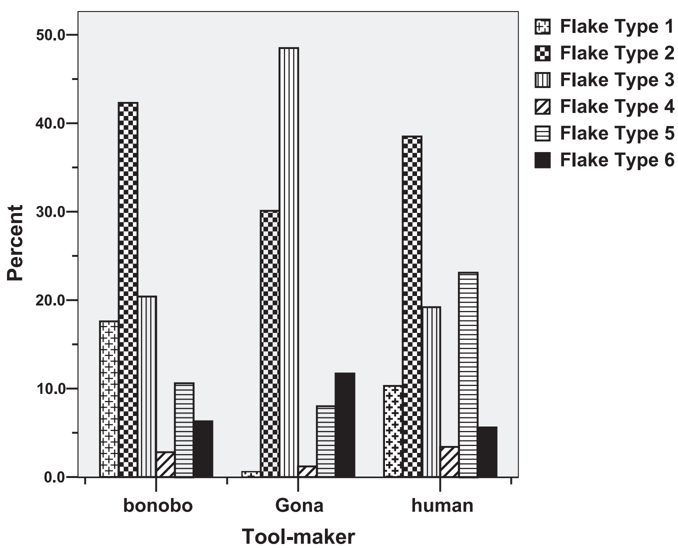
Results

The bonobo flake population is characterized by high proportions of type 2 flakes, with moderate proportions of flake types 3, 1, and 5 and low proportions of flake types 4 and 6. The Gona population has a predominance of flake types 3 and 2, with moderate proportions of type 6 flakes and low proportions of flake types 5, 4, and 1. The human sample, like the bonobo samples, has high proportions of flake type 2, but with more bifacial reduction also shows moderate proportions of types 5 and 3 flakes as well as type 1 flakes, and low proportions of flake types 6 and 4. Chi square tests indicated that all samples differed from one another at the .05 level of significance. The Kolmogorov-Smirnov test of cumulative frequency distributions indicate a significant difference between Gona and the other two samples, but found the human and bonobo sample were not significantly different at the .05 confidence level. The Chi-square test, which detected a significant difference between these two samples, was likely more sensitive to the specific features of the flake type distributions, particularly the higher frequencies of type 5 flakes and lower frequencies of type 1 flakes in the human sample relative to the bonobo sample.

Flake Type Frequencies by Tool-maker

			Flake Type						
			flake type 1	flake type 2	flake type 3	flake type 4	flake type 5	flake type 6	Total
Tool-maker	bonobo	Count	25	60	29	4	15	9	142
		% within Tool-maker	17.6%	42.3%	20.4%	2.8%	10.6%	6.3%	100.0%
	gona	Count	1	49	79	2	13	19	163
		% within Tool-maker	.6%	30.1%	48.5%	1.2%	8.0%	11.7%	100.0%
	human	Count	24	90	45	8	54	13	234
		% within Tool-maker	10.3%	38.5%	19.2%	3.4%	23.1%	5.6%	100.0%
Total		Count	50	199	153	14	82	41	539
		% within Tool-maker	9.3%	36.9%	28.4%	2.6%	15.2%	7.6%	100.0%

Flakes: Flake Types by Tool-maker



Chi-Square Tests: Flake Types 1-6, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	49.582[a]	5	.000
Likelihood Ratio	55.761	5	.000
N of Valid Cases	305		

a. 2 cells (16.7%) have expected count less than 5. The minimum expected count is 2.79.

Kolmogorov-Smirnov Test: Flake Types 1-6, Bonobo v. Gona[a]

		Flake type number
Most Extreme Differences	Absolute	.292
	Positive	.000
	Negative	-.292
Kolmogorov-Smirnov Z		2.542
Asymp. Sig. (2-tailed)		.000

a. Grouping Variable: Toolmkrcod

Chi-Square Tests: Flake Types 1-6, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.778[a]	5	.038
Likelihood Ratio	12.297	5	.031
N of Valid Cases	376		

a. 1 cells (8.3%) have expected count less than 5. The minimum expected count is 4.53.

Kolmogorov-Smirnov Test: Flake Types 1-6, Bonobo v. Human[a]

		Flake type number
Most Extreme Differences	Absolute	.123
	Positive	.008
	Negative	-.123
Kolmogorov-Smirnov Z		1.159
Asymp. Sig. (2-tailed)		.136

a. Grouping Variable: Toolmkrcod

Chi-Square Tests: Flake Types 1-6, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	61.665[a]	5	.000
Likelihood Ratio	67.151	5	.000
N of Valid Cases	397		

a. 1 cells (8.3%) have expected count less than 5. The minimum expected count is 4.11.

Kolmogorov-Smirnov Test: Flake Types 1-6, Gona v. Human[a]

		Flake type number
Most Extreme Differences	Absolute	.180
	Positive	.180
	Negative	-.112
Kolmogorov-Smirnov Z		1.769
Asymp. Sig. (2-tailed)		.004

a. Grouping Variable: Toolmkrcod

Discussion

Inspection of the flake type distributions and the Kolmogorov-Smirnov test indicate strong similarities between the bonobo and human samples, with a preponderance of types 2, then 3, then 1 flakes. The human sample has more bifacial flaking, however, which can be seen especially in a higher proportion of type 5 flakes than in the bonobo (or Gona) samples.

The most striking difference between the Gona flake population and the bonobo and human population is the high percentage of Gona flakes with no dorsal cortex (types 3 and 6); for Oldowan technology this is usually an indication of later stages of flaking being preferentially represented. The flake population found at the EG sites at Gona suggests that the Gona cores were substantially flaked off-site and the partially reduced cores transported to the floodplain sites where they were further reduced. It is also likely that a subset of the debitage produced from flaking at the floodplain sites was subsequently transported off-site for potential use at another location. This pattern will be discussed in more detail in the following sections.

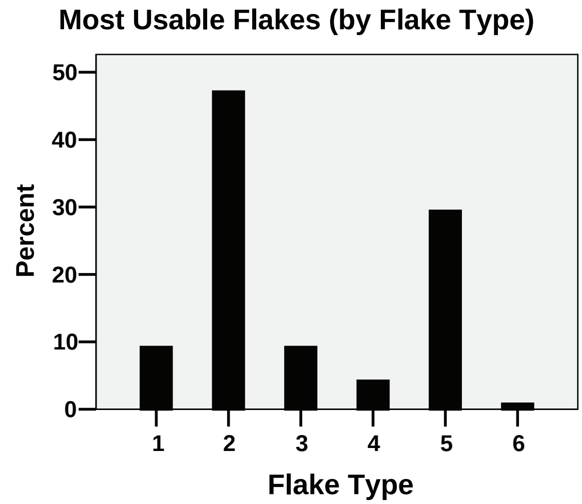
26b. Flakes: Simulated Selection of Most Useful Flake Types

We were interested in examining how flake populations could be altered by selecting only the most efficient flakes for cutting activities. Out of the total population of debitage produced by modern humans in these experiments (n=614), representing all stages of reduction, we selected the largest and sharpest pieces that, based on our experience in using stone tools, we would use for processing animal carcasses (skinning, dismembering, and defleshing). In this simulation, these usable flakes and fragments would then be carried off-site for later use, leaving behind the less useful debitage.

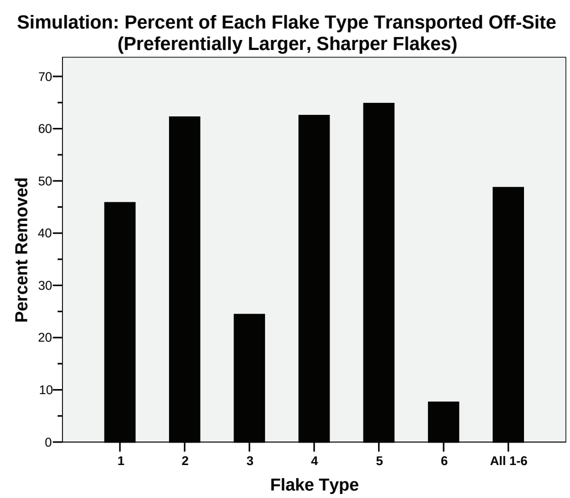
From the total sample of human debitage in these experiments, a sample of 166 debitage pieces (27.0% of the total) was thus selected for what was deemed to be their superior cutting utility. Of the 166 selected debitage pieces, the great majority consisted of whole flakes (n=126, or 75.9%). The flakes removed from the site in this simulation would constitute roughly half of the original flake population (51.6%). Of the 119 selected ("most usable") whole flakes that could be assigned to one of the six major types, the flake type breakdown was as follows in the table and graph below:

MOST USABLE FLAKES

Flake Type	Frequency	Percent	Cumulative Percent
Type 1	11	9.2	9.2
Type 2	56	47.1	56.3
Type 3	11	9.2	65.5
Type 4	5	4.2	69.7
Type 5	35	29.4	99.1
Type 6	1	0.8	100.0
Total:	**119**	**100.0**	



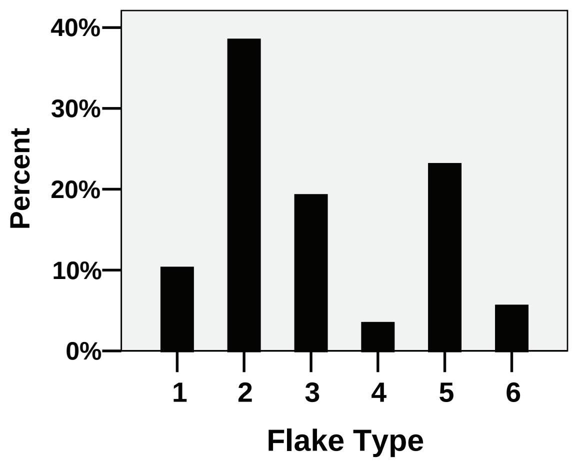
The graph below shows the percentage of each flake type that would have been removed in this simulation (larger, sharper flakes) for later use off-site. Note that in this simulation roughly half of the total flake population, and especially large percentages of types 1, 2, 4 and 5, would be transported away for later use. This would therefore leave behind elevated percentages of types 3 and 6.



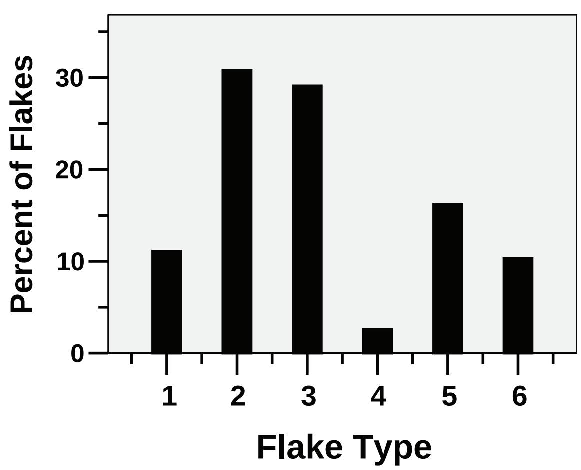
This simulation is based on selection of usable flakes from a *complete* assemblage of cobble reduction. At Gona, however, it appears that later stages of flaking are preferentially represented; in this case, the selection of usable flakes would be especially biased towards flake types 2 and 5 (common products of flaking heavily reduced cores, while types 1 and 4 are not produced), thereby inflating the percentages of flake types 3 and 6 even more in the residual assemblage.

It can be deduced from the tables and graphs above that selection and removal of more usable flakes from the general flake population would produce a residual flake population with depressed proportions of flake type 2 and flake type 5 (through flake transport away from the site by hominins) and elevated proportions of flake type 3 and, especially, flake type 6. The following three graphs show (1) the flake type distribution resulting from Oldowan flaking in the human sample, (2) a simulation of the flake types that would be left behind if more usable flakes were removed, and (3) the flake type distribution at the Gona EG sites, which is much closer to the residual population of flakes left behind in this simulation than to the entire human flake population. The Gona sites exhibit further depletion of Type 1 flakes, which may have resulted from Gona hominins 'testing' cobbles at the river cobbles and leaving behind these flakes when transporting cores to the floodplain sites.

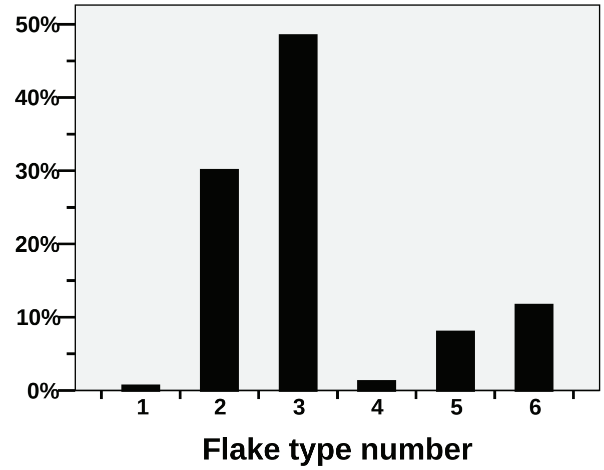
Flake Types: Human Flake Population



Simulation: Flake Types Left Behind (All Stages of Flaking)



Gona EG Sites Flake Types



26c. Flakes: Simulation of Later Stages of Flaking

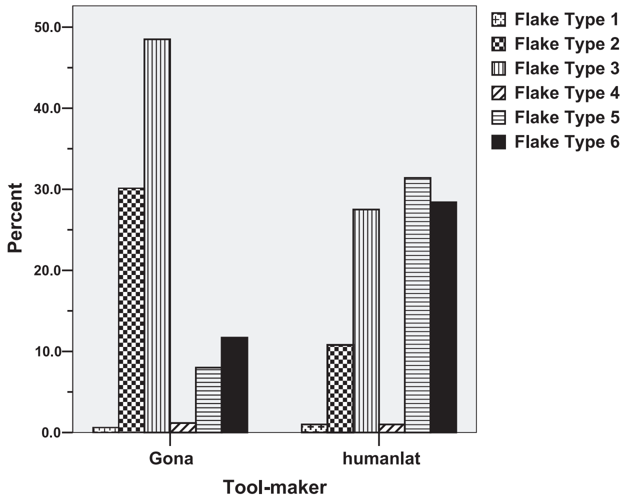
As analysis proceeded, it became clear that later stages of cobble reduction were typical of the Gona EG sites. In an attempt to replicate this pattern, ten of the experimental human cores (five unifacial chopper, five bifacial choppers) were further reduced to see what the later stage flake type population would look like. Interestingly, the more reduced cores produced had very similar mean attributes compared to the Gona cores (maximum dimensions, flake scar numbers, breadth/length ratios, percentage of circumference flaked, percentage of cobble left, percentage of cortical surface) and were not significantly different at the .05 confidence level). Visually, they also looked very much like the Gona cores.

The flake type frequencies produced by the human later stage of flaking was also compared to the Gona sample. Now, as with Gona, the human later stage sample showed higher percentages of type 3 to type 2 flakes (~28% v. 11%); however, unlike the Gona sample, type 5 flakes still outnumbered type 6 flakes (~31% v. 28%).

Flake Type Frequencies, Gona v. Human Later Stages

			Flake Type						Total
			1	2	3	4	5	6	
Tool-maker	gona	Count	1	49	79	2	13	19	163
		% within Tool-maker	.6%	30.1%	48.5%	1.2%	8.0%	11.7%	100.0%
	human-lat	Count	1	11	28	1	32	29	102
		% within Tool-maker	1.0%	10.8%	27.5%	1.0%	31.4%	28.4%	100.0%
Total		Count	2	60	107	3	45	48	265
		% within Tool-maker	.8%	22.6%	40.4%	1.1%	17.0%	18.1%	100.0%

Flake Types, Gona v. Human Later Stages



The later stage flake population was then compared with the Gona sample with regard to maximum dimension, breadth/length ratio, and thickness/breath ratio. The only significant difference at the .05 confidence level was the thickness/breadth ratio, indicating that Gona flakes were somewhat thicker relative to flake breadth, on average, than the human later stage flakes.

Flake Maximum Dimension, Gona v. Human Later Stages

Maximum dimension

Tool-maker	Mean	N	Std. Deviation
gona	41.37	174	15.037
humanlat	40.96	104	13.073
Total	41.22	278	14.311

Test Statistics: Flake Maximum Dimension, Gona v. Human Later Stages[a]

	Maximum dimension
Mann-Whitney U	8961.500
Wilcoxon W	24186.500
Z	-.133
Asymp. Sig. (2-tailed)	.894

a. Grouping Variable: Toolmkrcod

Flake Breadth/Length, Gona v. Human Later Stages

Breadth by Length

Tool-maker	Mean	N	Std. Deviation
gona	1.0047	174	.27968
humanlat	1.0711	104	.40945
Total	1.0295	278	.33500

Test Statistics: Breadth/Length, Gona v. Human Later Stages[a]

	Breadth by Length
Mann-Whitney U	8436.000
Wilcoxon W	23661.00
Z	-.944
Asymp. Sig. (2-tailed)	.345

a. Grouping Variable: Toolmkrcod

Flake Thickness/Breadth, Gona v. Human Later Stages

th_by_b

Tool-maker	Mean	N	Std. Deviation
gona	.3688	174	.11522
humanlat	.3099	104	.11295
Total	.3467	278	.11769

Test Statistics: Flake Thickness/Breadth, Gona v. Human Later Stages[a]

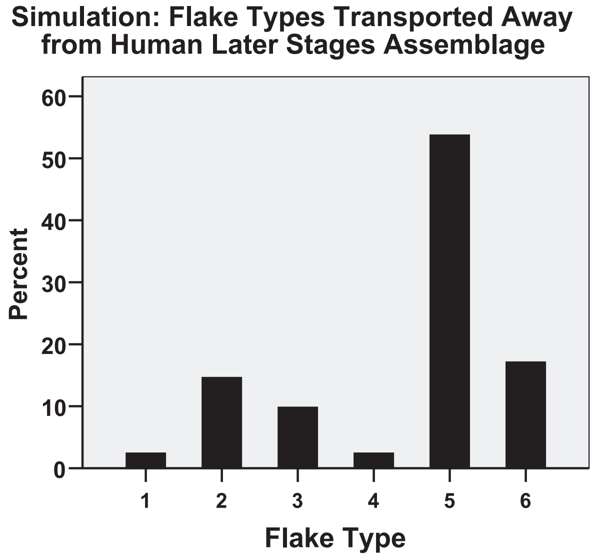
	th_by_b
Mann-Whitney U	6451.000
Wilcoxon W	11911.00
Z	-4.004
Asymp. Sig. (2-tailed)	.000

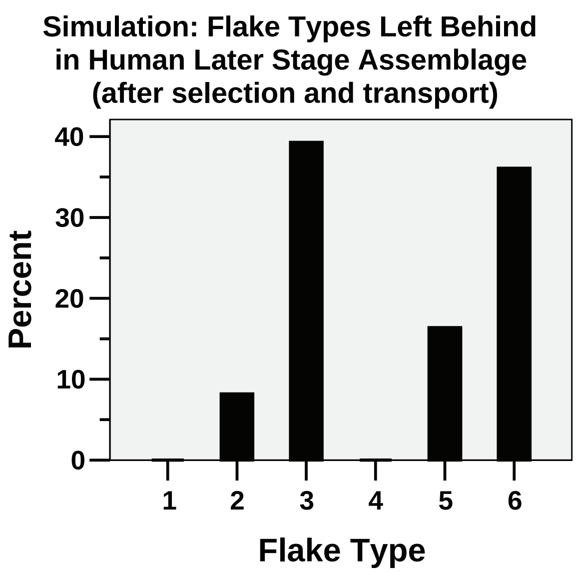
a. Grouping Variable: Toolmkrcod

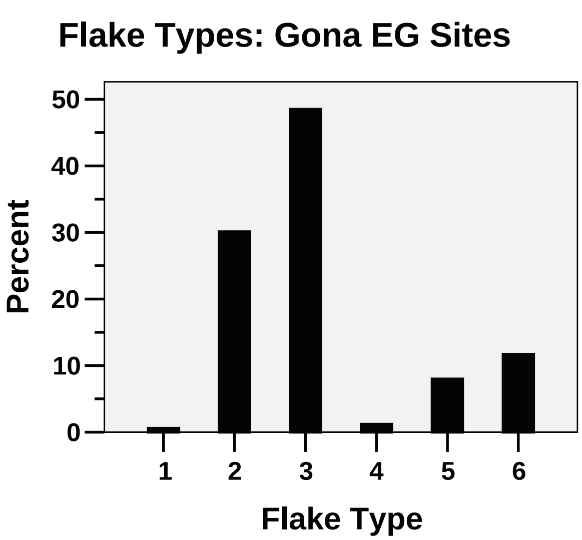
26d. Flakes: Simulation of Later Stages of Flaking and Subsequent Removal of Larger, Sharper Flakes

We then proceeded to see how the later stage flake population would change (and compare/contrast to the Gona sample) if we were to remove the largest, sharpest flakes. The graph below shows the proportion of each flake type removed in this simulation, with a high proportion of flake type 5 removed, as well as quantities of flake types 6, 4 and 3. This simulates early hominins selecting and transporting the most useful flakes off-site for future use. Interestingly, the residual flake populations produced in this experimental simulation (the second graph below) more closely matched the Gona flake population (the third graph below): after this simulated transport and removal of more useful flakes from the flake population, type 3 and type 6 flakes outnumbered type 2 and type 5 flakes among the flakes left behind, producing a flake type distribution much closer to that in the Gona sample.

In sum, these simulations strongly suggest that the Gona archaeological sites have a somewhat complex history: first cobbles were significantly reduced before transport to the floodplain sites, then later stages of cobble reduction took place at the sites, then many of the largest and sharpest flakes were transported away from the sites.







The working hypothesis presented here describes a behavioral pattern of tool-making hominins that could explain the nature of the EG Gona sites:

1) Cobble blanks were selected by Gona hominins in the gravel bars of the paleo-stream system. The cobbles are probably tested at the gravel bars, and the less suitable raw materials immediately discarded. For the better raw materials, it would appear that an appreciable amount of the mass of each cobble, perhaps on average one-half of the cobble mass, had been flaked off-site. So by the time the Gona cores were transported to the EG sites, they may have retained, on average, only about half the original cobble mass. The flakes produced away from the EG floodplain sites would have been dominated by flake type 2 if unifacial flaking is carried out, with type 5 flakes as well if bifacial flaking is carried out. This suggests that there may have been considerable tool use by the hominin group(s) prior to their occupation of these floodplain sites, as the extent of previous core reduction would appear to be far beyond mere testing of raw materials at the river gravel sources.

2) The partially flaked cores are transported to the EG floodplain sites (probably with several percussors) and are reduced further, the resultant cores now averaging about one-quarter to one-third of the mass of the original cobble blanks.

3) Some of the cores (perhaps more than half) are subsequently transported off-site, along with the percussors and many of the larger, sharper flakes (preferentially types 2 and 5). The removal of many of these key flakes would make archaeological refitting much more difficult. The remaining flake population would be dominated by type 3 flakes, and to a lesser extent, type 2 flakes (produced by unifacial flaking) as well as type 6 flakes, and to a lesser extent, type 5 flakes (produced by bifacial flaking) (e.g., similar to the EG site flake type distribution).

This scenario, then, would go a long way toward explaining major EG Gona site patterns, including the flake types represented at the EG sites (with their elevated levels of types 3 and 6) as well as the low frequency of refitting pieces, as due to hominins flaking cores prior to bringing them to the EG sites and then transporting some flakes away after on-site flaking. What is clear from this assessment is that Gona hominins 2.6 million years ago showed a complex behavioral pattern of core reduction and transport of flaked artifactual materials on the landscape, and only portions of the entire history of stone flaking and technological behavior of Gona hominins occurred in the excavated site areas.

27. Flakes: Location of Cortex.

Rationale

The location of cortex on dorsal surfaces of flakes (top, bottom, left, right, center, all, etc.) gives important information about core morphology prior to flake removal, as well as about the order and procedure of flake removal. Location of cortex can give important information about core morphology and stage of flaking. Location of cortex was divided into all (totally cortical); left; right; bottom; top; center; other; left and right; circumference; and no cortex.

Results

The bonobo sample showed high percentages of flakes with no cortex (~29%), all cortex (~18%), right cortex (~17%), and left cortex (~17%), and bottom cortex (~12%). The Gona flake sample had very high percentages of flakes with no cortex (~57%), left cortex (~16%), and right cortex (~13%). The human sample was dominated by roughly equal proportions of flakes with right cortex (~24%), no cortex (~23%), and left cortex (~21%) but also had numbers with bottom cortex (~14%) and all cortex (~13%).

Flakes: Location of Cortex by Tool-maker

			Location of cortex										
			all cortex	left	right	bottom	top	center	other	left and right	circum-ference	no cortex	Total
Tool-maker	bonobo	Count	29	26	27	19	2	3	0	3	4	45	158
		% within Tool-maker	18.4%	16.5%	17.1%	12.0%	1.3%	1.9%	.0%	1.9%	2.5%	28.5%	100.0%
	gona	Count	5	26	22	7	1	2	7	0	0	94	164
		% within Tool-maker	3.0%	15.9%	13.4%	4.3%	.6%	1.2%	4.3%	.0%	.0%	57.3%	100.0%
	human	Count	32	52	58	35	3	3	0	2	4	55	244
		% within Tool-maker	13.1%	21.3%	23.8%	14.3%	1.2%	1.2%	.0%	.8%	1.6%	22.5%	100.0%
Total		Count	66	104	107	61	6	8	7	5	8	194	566
		% within Tool-maker	11.7%	18.4%	18.9%	10.8%	1.1%	1.4%	1.2%	.9%	1.4%	34.3%	100.0%

Discussion

The high percentage of Gona flakes with no dorsal cortex (over half of the flakes) is a clear indication of later stages of flaking being preferentially represented at the sites (and also Gona cores being more heavily reduced than the experimental samples). The Gona core also has lower percentages of flakes with all cortex and bottom cortex, again because early stages of flaking are generally missing from these archaeological sites.

28. Flakes: Scar Patterning

Rationale

The scar patterning on the dorsal surface of a flake yields information about core morphology and the history of previous flake removals on cores before the flake being analyzed was struck off. Categories include plain (all cortex), same platform (unidirectional), non-cortex (featureless, no scar), opposed scars (bidirectional), transverse (“crest” flake), blade-like, convergent, subradial, and other.

Results

Compared to the other two samples, the bonobos had elevated percentages of plain (all cortex) flakes. The Gona sample had elevated percentages of flakes with opposed scars (bidirectional), while the human sample had higher percentages of same platform (unidirectional) flakes.

Flakes: Scar Pattern by Tool-maker

			Flake scar pattern									Total
			plain (cortex)	same platform, simple	non-cortex, feature-less	opposed scars	trans-verse, crest	blade-like, same	conver-gent	subradial	other	
Tool-maker	bonobo	Count	30	100	6	13	5	0	1	1	2	158
		% within Tool-maker	19.0%	63.3%	3.8%	8.2%	3.2%	.0%	.6%	.6%	1.3%	100.0%
	gona	Count	4	120	6	21	1	1	1	3	15	172
		% within Tool-maker	2.3%	69.8%	3.5%	12.2%	.6%	.6%	.6%	1.7%	8.7%	100.0%
	human	Count	32	179	14	4	7	2	0	4	2	244
		% within Tool-maker	13.1%	73.4%	5.7%	1.6%	2.9%	.8%	.0%	1.6%	.8%	100.0%
Total		Count	66	399	26	38	13	3	2	8	19	574
		% within Tool-maker	11.5%	69.5%	4.5%	6.6%	2.3%	.5%	.3%	1.4%	3.3%	100.0%

Discussion

The higher percentages of plain (all dorsal cortex) flakes observed in the bonobo sample is a reflection of early stages of flaking (flake types 1 and 4), and less reduction of cores. For the opposite reason (later stages of flaking preferentially represented), plain flakes are rare in the Gona sample. The higher percentage of flakes with opposed scars at Gona may be a reflection of debitage from the few discoidal cores represented at the site.

29. Flakes: Shape

Rationale

Flake shape gives some indication of core morphology, flake scar patterning, and functional feasibility. For example, for cutting activities, parallel-sided and convergent flakes are often ideal flake shapes, while divergent flakes are often less suitable. Flakes were divided into the following shapes: convergent; divergent; irregular; déjeté (skewed) left (oriented with platforms at top and dorsal surface facing up); déjeté (skewed) right; oval; and parallel-sided.

Results

The bonobo flake sample, relative to the Gona and human samples, had elevated percentages of oval and divergent flake shapes, and lower percentages of parallel flakes. The Gona sample had higher percentages of parallel and irregular shaped flakes, and lower percentages of oval flakes. The human sample showed higher percentages of parallel and convergent flakes, and lower percentages of divergent and irregular flakes. Each tool-maker group significantly differed from the other two groups at the .05 confidence level.

Flakes: Shape by Tool-maker

			Flake shape							Total
			conver-gent	divergent	irregular	dejete left	oval	parallel	dejete right	
Tool-maker	bonobo	Count	22	30	17	14	47	17	11	158
		% within Tool-maker	13.9%	19.0%	10.8%	8.9%	29.7%	10.8%	7.0%	100.0%
	gona	Count	27	20	31	17	22	40	17	174
		% within Tool-maker	15.5%	11.5%	17.8%	9.8%	12.6%	23.0%	9.8%	100.0%
	human	Count	43	21	19	36	44	58	23	244
		% within Tool-maker	17.6%	8.6%	7.8%	14.8%	18.0%	23.8%	9.4%	100.0%
Total		Count	92	71	67	67	113	115	51	576
		% within Tool-maker	16.0%	12.3%	11.6%	11.6%	19.6%	20.0%	8.9%	100.0%

Chi-Square Tests: Flake Shape, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	25.797[a]	6	.000
Likelihood Ratio	26.301	6	.000
N of Valid Cases	332		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 13.33.

Chi-Square Tests: Flake Shape, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	27.785[a]	6	.000
Likelihood Ratio	28.210	6	.000
N of Valid Cases	402		

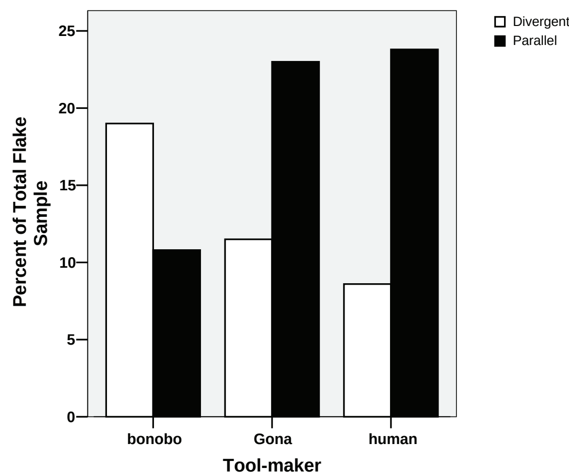
a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 13.33.

Chi-Square Tests: Flake Shape, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.570[a]	6	.035
Likelihood Ratio	13.514	6	.036
N of Valid Cases	418		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 16.65.

Flake Shape: Divergent v. Parallel by Tool-maker



Chi-Square Tests: Divergent or Parallel Flake Shape, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	9.847[b]	1	.002		
Continuity Correction[a]	8.660	1	.003		
Likelihood Ratio	9.981	1	.002		
Fisher's Exact Test				.002	.002
N of Valid Cases	107				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 21.96.

Discussion

The most interesting pattern that emerged from the analysis of this attribute was that the bonobos had a high percentage of divergent flakes, while the Gona and human samples showed higher percentages of parallel flakes, within their respective flake assemblages.

Bonobos:
- a. Divergent: 19.0%
- b. Parallel: 10.8%

Gona:
- a. Divergent: 11.5%
- b. Parallel: 23.0%

Human:
- a. Divergent: 8.6%
- b. Parallel: 23.8%

Chi-Square Tests: Divergent or Parallel Flake Shape, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	16.969[b]	1	.000		
Continuity Correction[a]	15.458	1	.000		
Likelihood Ratio	17.069	1	.000		
Fisher's Exact Test				.000	.000
N of Valid Cases	126				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 19.02.

Chi-Square Tests: Divergent or Parallel Flake Shape, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.747[b]	1	.387		
Continuity Correction[a]	.458	1	.499		
Likelihood Ratio	.744	1	.388		
Fisher's Exact Test				.454	.249
N of Valid Cases	139				

a. Computed only for a 2x2 table.

b. 0 cells (.0%) have expected count less than 5. The minimum expected count is 17.70.

Parallel-sided flakes tend to be excellent cutting tools, while divergent (usually side-struck) flakes are, on average, less functionally useful. The fact that the Gona and human flakes contain over two times the proportion of parallel-sided flakes is probably a function of better flaking skills, producing longer flakes relative to breadth (discussed below), and showing the ability to follow ridges between flake scars on cores to produce more parallel flakes.

The low percentages of oval-shaped flakes (often cortical) in the Gona sample is almost certainly a function of the early stages of flaking (i.e. flake types 1 and 4, and early stages of flake types 2 and 5) not being well-represented at the archaeological sites. Oval-shaped flakes are much better represented in the bonobo and human samples, where all stages of reduction are present. The prevalence of oval and divergent flakes in the bonobo sample would appear to reflect earlier stages of flaking, with flakes removed from more highly cortical surfaces and less following of ridges in the flaking process.

The predominance of asymmetrical left-skewed flakes relative to right-skewed in the human sample (14.8% and 9.4%, respectively) could be an indication of preferential right handedness in the knappers; this pattern deserves more consideration in the future (through experimentation and analysis of archaeological assemblages).

30. Flakes: Platform Battering/Stepping

Rationale

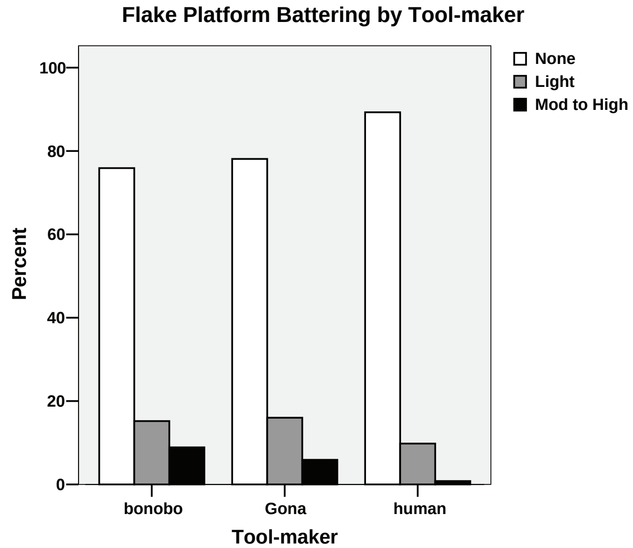
This attribute recorded the relative degree of battering (as well as microstepping and crushing) along the striking platform and proximal dorsal surface of flakes (none, light, moderate, heavy). Such damage is the equivalent to the attribute of battering on core edges (attribute no. 10), since the striking platform of a flake was part of the core edge prior to flake detachment. And, as with core edge battering, this attribute was developed specifically after seeing some bonobo flakes with unusually heavy battering.

Results

The bonobo sample showed the highest degree of battering, with moderate/high levels at 8.8% (eleven times as much as the human sample). The Gona sample was intermediate, with moderate/high levels at 5.9%, and the human sample very low, at 0.8%. In addition, the human sample had higher percentages of flakes with no battering (89.3%) relative to Gona (78.1%) and bonobos (75.9%). The human sample was significantly different than both the bonobo and Gona sample at the .05 confidence level, although the bonobo and Gona samples were not significantly different.

Flakes: Platform Battering & Stepping by Tool-maker

			Platform battering				
			none	low	moderate	high	Total
Tool-maker	bonobo	Count	120	24	10	4	158
		% within Tool-maker	75.9%	15.2%	6.3%	2.5%	100.0%
	gona	Count	132	27	7	3	169
		% within Tool-maker	78.1%	16.0%	4.1%	1.8%	100.0%
	human	Count	218	24	1	1	244
		% within Tool-maker	89.3%	9.8%	.4%	.4%	100.0%
Total		Count	470	75	18	8	571
		% within Tool-maker	82.3%	13.1%	3.2%	1.4%	100.0%



Chi-Square Tests: Flake Platform Battering, Bonobo v. Gona

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.051[a]	3	.789
Likelihood Ratio	1.054	3	.788
N of Valid Cases	327		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 3.38.

Chi-Square Tests: Flake Platform Battering, Bonobo v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	20.100[a]	3	.000
Likelihood Ratio	20.760	3	.000
N of Valid Cases	402		

a. 3 cells (37.5%) have expected count less than 5. The minimum expected count is 1.97.

Chi-Square Tests: Flake Platform Battering, Gona v. Human

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.638[a]	3	.003
Likelihood Ratio	13.939	3	.003
N of Valid Cases	413		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 1.64.

Discussion

If low frequencies of platform battering/microstepping/crushing is taken as an indication of highly skilled flaking, then the human sample is the most skilled, the bonobo sample the least skilled, and the Gona sample intermediate. The lower incidence of platform battering in the human sample indicates that the human subjects were more successful at flake detachment, leading to "cleaner" core edges (and thus subsequent flake platforms) with less battering.

31. Flakes: Weight

Rationale

Flake weight is a rough indication of the size of the flake (length x breadth x thickness) and often the stage of flake reduction (early stages of flake reduction tend to have heavier flakes) (Sahnouni *et al*., 1997). In addition, for a given Oldowan core form, mean flake weight may be an indication of knapping skill level: larger flakes with longer cutting edges can be detached with a higher level of skill.

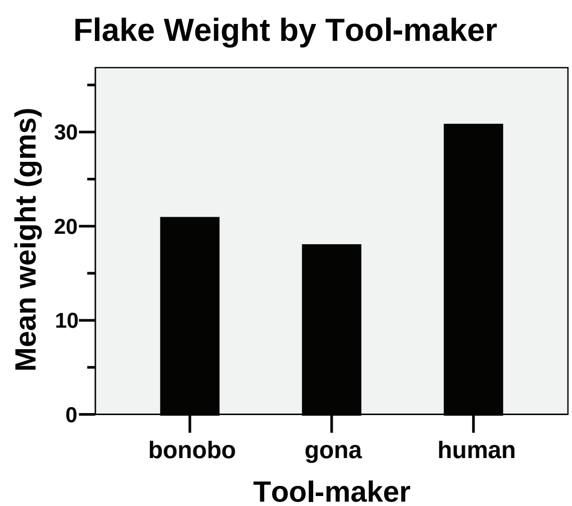
Results

The Gona flakes had the lowest mean weight (~18 g) with the bonobo sample intermediate (~21g), and the human sample a significantly higher mean weight (~31g). The human sample was significantly different from both the bonobo and Gona samples at the .00 confidence level, but the bonobo and Gona samples did not significantly differ from each other at the .05 level.

Flakes: Mean Weight by Tool-maker

Weight in grams

Tool-maker	Mean	N	Std. Deviation
bonobo	20.84	158	50.845
gona	17.94	174	23.983
human	30.74	244	37.616
Total	24.16	576	38.859



Test Statistics: Flake Weight, Bonobo v. Gona[a]

	Weight in grams
Mann-Whitney U	12819.000
Wilcoxon W	25380.000
Z	-1.063
Asymp. Sig. (2-tailed)	.288

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Weight, Bonobo v. Human[a]

	Weight in grams
Mann-Whitney U	13434.500
Wilcoxon W	25995.500
Z	-5.138
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Weight, Gona v. Human[a]

	Weight in grams
Mann-Whitney U	15846.000
Wilcoxon W	31071.000
Z	-4.423
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The Gona sample showed the lowest mean flake weight; this is probably because later stages of flaking were preferentially represented at the EG site, with core size reduced, and also because it is possible that cobbles selected for cores at Gona may have been, on average, smaller than the bonobo and human sample. Also, as has been discussed, it is likely that larger, sharper flakes produced on the floodplain sites were subsequently taken away, which could also significantly lower the mean flake weight.

The bonobo mean is interesting, since these subjects were preferentially selecting larger cobbles and reducing them less than the Gona and human samples. One would think that larger flakes would therefore be produced, but, interestingly, the mean bonobo weights are similar to the Gona sample and significantly less than the human sample. This is almost certainly an indication of lower skill levels in the bonobo subjects in detaching flakes, and the lower impact velocities of their hammerstones.

The human sample, not surprisingly, suggests greater skill in detaching large flakes. The mean flake weight is 1.5 times as great as the Gona sample, and 1.7 times as great as the bonobo sample. This is probably due to high impact velocities and better exploitation of acute core edge angles and core morphologies.

32. Flakes: Maximum Dimension

Rationale

Flake maximum dimension (as opposed to oriented length) is the longest linear measurement that can be taken on a flake. It is partially a reflection of the size of the core from which a flake is detached (the maximum dimension of the flake cannot be larger than the maximum dimension of the core prior to flake detachment), and possibly the level of skill of the knapper. From a given core size and morphology, a skilled knapper can often remove larger flakes than a less skilled knapper, producing more cutting edge and a larger, more comfortable flake to use.

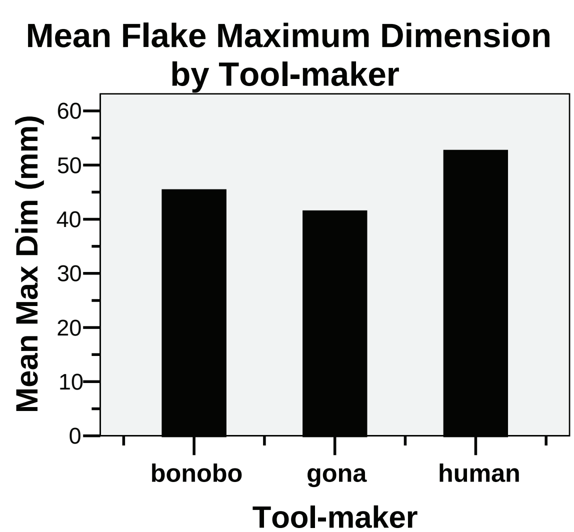
Results

As with the data of flake weight, the Gona sample had the smallest flakes (~41 mm), the bonobo sample was intermediate (~45 mm), and the human sample the largest (~53 mm). The human sample showed significant differences with both the bonobo and Gona samples at the .00 confidence level, although the bonobo and Gona samples were not significantly different at the .05 level.

Report

Maximum dimension

Tool-maker	Mean	N	Std. Deviation
bonobo	45.29	158	19.879
gona	41.37	174	15.037
human	52.56	244	17.915
Total	47.19	576	18.303



Test Statistics: Flake Maximum Dimension, Bonobo v. Gona[a]

	Weight in grams
Mann-Whitney U	12357.000
Wilcoxon W	27582.000
Z	-1.591
Asymp. Sig. (2-tailed)	.112

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Maximum Dimension, Bonobo v. Human[a]

	Weight in grams
Mann-Whitney U	14054.500
Wilcoxon W	26615.500
Z	-4.590
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Maximum Dimension, Gona v. Human[a]

	Weight in grams
Mann-Whitney U	13471.500
Wilcoxon W	28696.500
Z	-6.372
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The results of the analysis of this attribute are similar to those for flake weight in the previous section. Bonobos showed a lower degree of skill in removing large flakes (even though their cobble blanks were larger). The human flakes showed a higher skill level, producing flakes that were on average 2.4 centimeters larger than the bonobo flakes and 1.2 cm larger than Gona flakes. The fact that Gona flakes appear to represent later stages of flaking (and therefore smaller cores), and the fact that Gona hominins may have been removing significant numbers of larger, sharp flakes from the excavated EG sites, suggests that the Gona mean flake size might be more similar to the human sample if all flakes from all stages of core reduction were represented at the archaeological sites. If so, then the skill level of Gona hominins in consistently producing larger flakes may have been similar to the human subjects, with well-struck hammerstone blows.

33. Flakes: Thickness

Rationale

The maximum thickness of flakes (often at the striking platform or bulb of percussion) helps describe the morphology of a flake. Clearly, as overall size of flakes goes up, the thickness tends to increase as well. Some archaeologists would argue that thinner flakes in an assemblage can be an indication of greater skill (in theory producing more cutting edge per weight of debitage).

Results

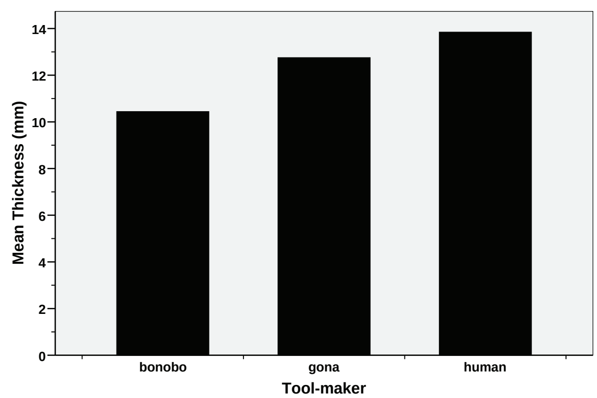
Surprisingly, the bonobo flakes were the thinnest, averaging 10.4 mm. The Gona flakes were intermediate (12.6 mm) and the human flakes the thickest (13.8 mm). The bonobo sample was different from the Gona and human sample at the .00 confidence level, although the Gona and human sample were not significantly different at the .05 level.

Flakes: Thickness by Tool-maker

Thickness

Tool-maker	Mean	N	Std. Deviation
bonobo	10.44	158	7.369
gona	12.64	174	6.126
human	13.84	244	7.343
Total	12.54	576	7.130

Mean Flake Thickness by Tool-maker



Test Statistics: Flake Thickness, Bonobo v. Gona[a]

	Thickness
Mann-Whitney U	9737.500
Wilcoxon W	22298.500
Z	-4.599
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Thickness, Bonobo v. Human[a]

	Thickness
Mann-Whitney U	12939.500
Wilcoxon W	25500.500
Z	-5.577
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Thickness, Gona v. Human[a]

	Thickness
Mann-Whitney U	19296.500
Wilcoxon W	34521.500
Z	-1.589
Asymp. Sig. (2-tailed)	.112

a. Grouping Variable: Toolmkrcod

Discussion

The bonobo flakes were the thinnest. Although some lithic analysts might argue that this suggests higher skill, observation of bonobo flaking showed that they would often "chew" on an edge by hammerstone percussion until a flake came off. This repeated percussion of an edge would normally produce observable attrition to the core edge (battering, microstepping, crushing), but when a flake was finally detached it tended to be relatively small, side-struck, and thin.

The Gona flakes tended to be absolutely thicker (2.2 mm thicker on average) than the bonobo flakes, even though the bonobo flakes were absolutely larger in maximum dimension (4 mm larger on average). The human flake sample was also thicker (3.4 mm on average) than the bonobo flakes. The thicker flakes produced by Gona hominins and the human knappers are probably a function of higher impact velocities (being able to strike further away from a core edge and still have fracture, producing a thicker striking platform), and the ability of the Gona and human tool-makers to follow ridges more systematically on cores, creating flakes with a thicker, often triangular cross-section.

In sum, the Gona and human samples suggest better flaking skills than the bonobo sample. This is a case where assumptions about skill (thinner flakes meaning better flaking skill) are not confirmed by experimentation and archaeological analysis.

34. Flakes: Ratio of Breadth/Length

Rationale

Breadth/length ratios on flakes gives an indication of how relatively elongated ("end struck") or short ("side struck") a flake population is. Flakes were oriented by bisecting the bulb of percussion and delineating an imaginary rectangle around the flake. Oriented length was the longest measurement parallel to the bulb axis (roughly perpendicular to the striking platform), while breadth was the largest measurement perpendicular to the bulb axis. A ratio of less than 1.0 denotes an end-struck flake; a ratio of greater than 1.0 denotes a side-struck flake.

Results

The bonobo mean flake breadth/length ratio tended to be side-struck (1.22), the Gona flakes intermediate and averaging equidimensional (1.00), and the human sample slightly end-struck (~0.98).

The bonobo sample showed significant differences from the Gona and human sample at the .00 confidence level, although the Gona and human sample were not significantly different at the .05 confidence level.

Flakes: Breadth/Length Ratio by Tool-Maker

b_by_l

Tool-maker	Mean	N	Std. Deviation
bonobo	1.2203	158	.40523
gona	1.0047	174	.27968
human	.9799	244	.38247
Total	1.0533	576	.37531

Test Statistics: Flake Breadth/Length, Bonobo v. Gona[a]

	b_by_l
Mann-Whitney U	9190.000
Wilcoxon W	24415.000
Z	-5.216
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Breadth/Length, Bonobo v. Human[a]

	b_by_l
Mann-Whitney U	12073.500
Wilcoxon W	41963.500
Z	-6.330
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Breadth/Length, Gona v. Human[a]

	b_by_l
Mann-Whitney U	19089.000
Wilcoxon W	48979.000
Z	-1.757
Asymp. Sig. (2-tailed)	.079

a. Grouping Variable: Toolmkrcod

Discussion

The bonobo flakes were significantly different from the Gona and human samples, being appreciably more side-struck (and, as previously mentioned, significantly thinner). It would appear that the bonobos, compared to the Gona and human tool-makers, were not as skilled at producing longer flakes relative to breadth. Again, this is probably due to lower hammerstone impact velocities generated by the bonobos, as well as to their tendency to remove flakes right behind a previous flake scar (rather than directing the blow along a ridge between scars, which generally allows the flaking blow to travel further and detach at a greater distance from the point of percussion).

35. Flakes: Ratio of Thickness/Breadth

Rationale

This ratio is used to determine how relatively thick or thin flakes are in cross-section. In bifacial and blade industries a low thickness/breadth ratio is often interpreted as a function of high skill levels. In the Oldowan, however, a higher thickness/breadth ratio may indicate that early hominin tool-makers were following ridges on cores to produce longer flakes; these flakes tend to be more triangular in cross-section and may have a higher thickness/breadth ratio.

Results

The bonobo flake sample had the lowest mean thickness/breadth ratio at ~.26. The human sample was intermediate at ~.33, while the Gona archaeological sample was the highest at ~.37. Statistical tests showed that each tool-maker group differed significantly from the other two groups at the .000 confidence level.

Flake Thickness/Breadth by Tool-maker

th_by_b

Tool-maker	Mean	N	Std. Deviation
bonobo	.2600	158	.10920
gona	.3688	174	.11522
human	.3325	244	.12623
Total	.3236	576	.12548

Test Statistics: Flake Thickness/Breadth, Bonobo v. Gona[a]

	th_by_b
Mann-Whitney U	6347.500
Wilcoxon W	18908.50
Z	-8.471
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Thickness/Breadth, Bonobo v. Human[a]

	th_by_b
Mann-Whitney U	12276.50
Wilcoxon W	24837.50
Z	-6.152
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Thickness/Breadth, Gona v. Human[a]

	th_by_b
Mann-Whitney U	16870.50
Wilcoxon W	46760.50
Z	-3.579
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The bonobo sample had the thinnest flakes relative to breadth, followed by the human and Gona samples. Thus, bonobo flakes were not only absolutely thinner but also relative to the overall mass of the flake. The fact that the human and Gona samples had significantly larger thickness/breadth ratios is likely a result of a greater tendency to follow ridges in reducing the core. It is interesting that the Gona flakes are even thicker relative to their breadth than the human sample, despite being absolutely somewhat thinner (though not significantly so). In any case, in Oldowan flaking, a higher ratio of flake thickness to breadth appears to be an indication of greater skill and precision in reducing cores.

36. Flakes: Ratio of Platform Thickness/ Platform Breadth

Rationale

The ratio of platform thickness/platform breadth gives an indication of the morphology of the striking platform. A higher ratio denotes a thicker platform (often associated with hard-hammer percussion), whereas a lower ratio denotes a thinner platform (associated, for example, with soft-hammer percussion in later technologies. The flake populations include flake types 1 through 6 for each sample, omitting flake type 7 whose platform tends to be missing or punctiform.

Results

The platforms of the bonobo flakes were proportionately the thinnest relative to breadth (~.34). The human sample was intermediate at (~.39), and the Gona sample was the thickest (~.44). Statistical testing showed that the all three samples differed significantly from the other two.

Flakes: Platform Thickness/Platform Breadth by Tool-maker

pth_by_b

Tool-maker	Mean	N	Std. Deviation
bonobo	.3385	104	.16978
gona	.4374	142	.15316
human	.3828	202	.14054
Total	.3898	448	.15581

Test Statistics: Flake Platform Thickness/ Platform Breadth, Bonobo v. Gona[a]

	pth_by_b
Mann-Whitney U	4424.000
Wilcoxon W	9884.000
Z	-5.370
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Platform Thickness/ Platform Breadth, Bonobo v. Human[a]

	pth_by_b
Mann-Whitney U	8227.000
Wilcoxon W	13687.000
Z	-3.106
Asymp. Sig. (2-tailed)	.002

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Platform Thickness/ Platform Breadth, Gona v. Human[a]

	pth_by_b
Mann-Whitney U	11309.00
Wilcoxon W	31812.00
Z	-3.341
Asymp. Sig. (2-tailed)	.001

a. Grouping Variable: Toolmkrcod

Discussion

It would appear that the bonobos were striking off the thinnest flakes and the Gona hominins the thickest flakes, with the human sample intermediate. As will be discussed below (regarding flake thickness/breadth ratios) it is possible that Gona hominins were able to identify prominent ridges on cores and systematically detach flakes along these ridges. The cross-section of many of the flakes produced would be triangular.

37. Flakes: Number of Platform Scars

Rationale

Number of platform scars is an attribute often used in archaeology to examine patterns of platform preparation and faceting (e.g. biface thinning flakes and Levallois flakes and points). (In this study, the cut-off for platform scar count was 1 mm or larger in the scar's maximum dimension). In the Oldowan, a larger number of mean platform scars are usually associated with core forms such as bifacial choppers, bifacial discoids, and polyhedrons. It is sometimes useful to examine the means of all flakes (types 1-6) as well as the means of flakes only with non-cortical platforms (types 4-6). A preponderance of unifacial flaking of cobbles (platforms scars= 0, or cortical) will clearly bring down the total mean values for platform scars, so that by also considering non-cortical platforms (types 4-6), an appreciation of the platform scar patterning produced by the non-cortical platform flakes could also be assessed.

Results

When considering all flake types, the bonobo and Gona flakes had the same average number of platform scars (.32), while the human sample had a larger mean number (.47). When considering only flake types 4-6 (i.e., with non-cortical platforms), however, the human sample had the lowest value, with a mean platform scar count of ~1.3. The bonobo and Gona samples were very similar, with a mean count of ~1.6. Statistical testing indicated that only the bonobo and human sample were significantly different at the .05 confidence level.

Flakes: Number of Platform Scars, Types 1-6, by Tool-maker

No. platform scars

Tool-maker	Mean	N	Std. Deviation
bonobo	.32	142	.698
gona	.32	162	.736
human	.47	234	.998
Total	.38	538	.854

Test Statistics: Platform Scars, Types 1-6, Bonobo v. Gona[a]

	No. platform scars
Mann-Whitney U	11473.000
Wilcoxon W	21626.000
Z	-.054
Asymp. Sig. (2-tailed)	.957

a. Grouping Variable: Toolmkrcod

Test Statistics: Platform Scars, Types 1-6, Bonobo v. Human[a]

	No. platform scars
Mann-Whitney U	14776.000
Wilcoxon W	24929.000
Z	-2.282
Asymp. Sig. (2-tailed)	.022

a. Grouping Variable: Toolmkrcod

Test Statistics: Platform Scars, Types 1-6, Gona v. Human[a]

	No. platform scars
Mann-Whitney U	16865.000
Wilcoxon W	30068.000
Z	-2.372
Asymp. Sig. (2-tailed)	.018

a. Grouping Variable: Toolmkrcod

Flakes: Number of Platform Scars (Types 4-6) by Tool-maker

No. platform scars

Tool-maker	Mean	N	Std. Deviation
bonobo	1.57	28	.690
gona	1.55	33	.869
human	1.31	75	.677
Total	1.42	136	.736

Test Statistics: Platform Scars, Types 4-6, Bonobo v. Gona[a]

	No. platform scars
Mann-Whitney U	426.500
Wilcoxon W	987.500
Z	-.586
Asymp. Sig. (2-tailed)	.558

a. Grouping Variable: Toolmkrcod

Test Statistics: Platform Scars, Types 4-6, Bonobo v. Human[a]

	No. platform scars
Mann-Whitney U	798.000
Wilcoxon W	3648.000
Z	-2.371
Asymp. Sig. (2-tailed)	.018

a. Grouping Variable: Toolmkrcod

Test Statistics: Platform Scars, Types 4-6, Gona v. Human[a]

	No. platform scars
Mann-Whitney U	1048.500
Wilcoxon W	3898.500
Z	-1.644
Asymp. Sig. (2-tailed)	.100

a. Grouping Variable: Toolmkrcod

Discussion

For all flake types, the human sample had a higher platform scar count since more of the flaking was on bifacial cores; the preponderance of unifacial flaking in the bonobo and Gona samples was due to the preponderance of unifacial flaking of cobbles, producing more flakes with cortical butts. These flakes would give a flake scar count of 0, thereby lowering the mean platform scar count.

For flake types 4-6, the human flake sample had the lowest platform scar count. It is possible that the human knappers were more proficient at isolating core flake scars as potential striking platforms, thus the lower platform scar count. This difference is especially seen between the human and bonobo sample. In sum, a higher platform scar count, considering Oldowan technology, does not seem to be indicative of better stone-working skills.

38. Flakes: Number of Dorsal Scars

Rationale

The number of scars (10 mm or larger) on the dorsal surface of flakes is an indication of the morphology and extent of flaking of a core at the time the flake was detached. For a Mode 1 industry, higher numbers of dorsal scars usually implies more heavily reduced cores, with less cortex and more flake scars. Size is also a consideration: at a given stage of core reduction, a larger flake will, on average, have more dorsal scars than a smaller flake.

Results

When all flake types are examined, the bonobo sample shows the lowest mean number of scars (2.14), the human sample intermediate (2.22) and the Gona sample the highest (3.07). Statistical tests showed that the Gona sample differs from the experimental groups at the .000 level of significance, while the bonobo and human samples were not significantly different.

All Flakes: Number of Dorsal Scars by Tool-maker

No. dorsal scars

Tool-maker	Mean	N	Std. Deviation
bonobo	2.14	158	1.732
gona	3.07	169	1.580
human	2.22	244	1.576
Total	2.45	571	1.669

Test Statistics: All Flakes, Number of Dorsal Scars, Bonobo v. Gona[a]

	No. dorsal scars
Mann-Whitney U	8703.000
Wilcoxon W	21264.000
Z	-5.563
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: All Flakes, Number of Dorsal Scars, Bonobo v. Human[a]

	No. dorsal scars
Mann-Whitney U	18331.500
Wilcoxon W	30892.500
Z	-.847
Asymp. Sig. (2-tailed)	.397

a. Grouping Variable: Toolmkrcod

Test Statistics: All Flakes, Number of Dorsal Scars, Gona v. Human[a]

	No. dorsal scars
Mann-Whitney U	14278.000
Wilcoxon W	44168.000
Z	-5.434
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The Gona sample had a significantly higher flake dorsal scar value compared to the bonobo and the human sample. This is almost certainly due to the fact that the Gona flakes appear to represent later stages of the reduction of cobble cores, with the subsequent flakes having much less cortex and higher dorsal scar counts. The bonobo and human samples are not statistically different, as both samples represent all stages of cobble reduction and thus have a greater percentage of dorsal cortex and subsequently relatively fewer dorsal scars than the Gona sample.

39. Flakes: Ratio of Dorsal Hinges & Steps/Total Dorsal Scars

Rationale

As discussed with cores (attribute no. 23), the ratio of hinge and steps to total scars on dorsal surfaces of flakes has been used as an indicator of knapping skill. Traditionally, a lower ratio has been interpreted as higher skill, a higher ratio interpreted as lower skill.

Results

The Gona flake sample had the lowest mean step/hinge to scar ratio, at ~.05. The human sample was intermediate (~.10) with the bonobo sample showing the highest ratio (~14). Statistical testing showed that the Gona sample differed significantly from both the bonobo and human samples at the .05 confidence level; the bonobo and human sample, however, did not show significant difference at the .05 level.

Flakes: Step+Hinge to Scar Ratio by Tool-maker

Flake step to scar ratio

Tool-maker	Mean	N	Std. Deviation
bonobo	.1350	129	.23160
gona	.0450	171	.11857
human	.1049	211	.19514
Total	.0924	511	.18736

Test Statistics: Flake Step to Scar Ratio, Bonobo v. Gona[a]

	Flake step to scar ratio
Mann-Whitney U	9090.000
Wilcoxon W	23796.000
Z	-3.641
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Step to Scar Ratio, Bonobo v. Human[a]

	Flake step to scar ratio
Mann-Whitney U	12943.500
Wilcoxon W	35309.500
Z	-.954
Asymp. Sig. (2-tailed)	.340

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Step to Scar Ratio, Gona v. Human[a]

	Flake step to scar ratio
Mann-Whitney U	15609.500
Wilcoxon W	30315.500
Z	-3.156
Asymp. Sig. (2-tailed)	.002

a. Grouping Variable: Toolmkrcod

Discussion

As with the step/hinge to scar ratio on cores, the flake ratio indicated that the Gona sample was the outgroup, with less than half of the stepping and hinging seen of the dorsal scars of the bonobo and human samples. Again, this was surprising, since conventional wisdom would suggest that the Gona hominins, with a lower step-to-scar ratio, were the most skilled of the three groups.

In order to test whether the later stages of flaking preferentially represented at the Gona sites were influencing this attribute, we then examined step-to-scar ratios on the later stages of reduction of the human sample. As with core step-to-scar ratios, the mean step-to-scar ratio on flakes produced in the later stages of reduction in the human sample was very similar to the Gona sample mean (.059 and .046 respectively), with no significant difference between the samples (Mann-Whitney 2-tailed Asymp. Sig.=.447).As mentioned previously, it is also possible that the lower ratio in the Gona sample could be partially due to the hominins intentionally selecting thinner, morphologically easier cobbles to flake, making it easier to produce flakes without stepping or hinging throughout the reduction sequence.

40. Flakes: Exterior Platform Angle (“Core Angle”)

Rationale

This angle, measured with a goniometer, is formed between the striking platform and the dorsal surface, essentially showing the morphology and angle of the core edge before flake detachment. A skilled stone knapper knows, however intuitively, that acute angles (less than 90 degrees) are required to flake stone efficiently, so that more acute exterior platform angles in Oldowan assemblages may be an indication of more skilled flaking and intentionally making cognitive decisions in selecting such angles. Such acute angles can sometimes also be maintained by the continuous unifacial flaking of a flat, thin cobble, where flakes keep detaching on the underside of the cobble (in an “outrepassé-like” manner); an acute edge angle can often be maintained in this manner. (In some later technologies, such as bifacial thinning of handaxes or projectile points or blade manufacture, knappers often intentionally steepened edge angles to strengthen edges for soft hammer, punch, or pressure flaking, but this is not a consideration in this study).

Results

The bonobo flake sample showed the highest mean external platform (“core”) angles at ~84 degrees. The Gona sample was intermediate (~82 degrees) with the human sample the lowest (~76 degrees). Statistical testing showed that the human sample differed significantly from both the bonobo and Gona sample at the .00 confidence level; differences between the bonobo and Gona sample were not, however, significant at the .05 level.

Flakes: Exterior Platform (“Core”) Angle by Tool-maker

Core angle, nearest 5 degrees

Tool-maker	Mean	N	Std. Deviation
bonobo	83.81	97	15.939
gona	81.77	150	11.986
human	76.36	195	14.699
Total	79.83	442	14.456

Test Statistics: Exterior Platform Angle, Bonobo v. Gona[a]

	Core angle, nearest 5 degrees
Mann-Whitney U	6546.500
Wilcoxon W	17871.500
Z	-1.340
Asymp. Sig. (2-tailed)	.180

a. Grouping Variable: Toolmkrcod

Test Statistics: Exterior Platform Angle, Bonobo v. Human[a]

	Core angle, nearest 5 degrees
Mann-Whitney U	6679.500
Wilcoxon W	25789.500
Z	-4.110
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Exterior Platform Angle, Gona v. Human[a]

	Core angle, nearest 5 degrees
Mann-Whitney U	10529.000
Wilcoxon W	29639.000
Z	-4.498
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Discussion

The human sample showed significantly more acute external platform ("core") angles than the bonobo and Gona samples. This suggests that the human subjects had superior cognitive abilities to recognize and exploit acute core edges in the production of flakes relative to the bonobos and Gona hominins. Interestingly, although the mean angles for the bonobo and Gona samples were similar, it is clear that the Gona hominins were more skilled stone knappers, producing flakes similar in overall morphology to the human sample and reducing cores much more efficiently and heavily than the bonobo toolmakers.

41. Flakes: Interior Platform Angle ("Bulb Angle")

Rationale

This angle, measured with a goniometer, is formed between the striking platform (at the point of percussion) and the ventral surface on the bulb of percussion. For most raw materials (including those in this study), most interior platform angles are greater than 90°: a bulb of percussion with a higher angle (e.g. 130°) would suggest a prominent bulb of percussion, while a lower angle (e.g. 95°, would suggest a more diffuse bulb of percussion. Certain raw materials, however, such as some limestones (not part of this study), probably a factor of their softness and the physics of fracture, tend to produce acute interior platform angles and obtuse exterior platform angles. (Sahnouni *et al*., 1997).

Results

The bonobo sample and the least obtuse interior platform angles (~98 degrees), with the human sample intermediate (~106 degrees) and the Gona sample the most obtuse (~108 degrees). Statistical testing indicated that the bonobo sample differed significantly from both the Gona and human samples at the .00 confidence level, but that the Gona and human sample did not differ significantly at the .05 confidence level.

Flakes: Interior Platform (Bulb) Angle by Tool-maker

Bulb angle, nearest 5 degrees

Tool-maker	Mean	N	Std. Deviation
bonobo	97.56	133	17.961
gona	108.45	153	12.540
human	106.33	226	16.241
Total	104.68	512	16.276

Test Statistics: Flake Bulb Angle, Bonobo v. Gona[a]

	Bulb angle, nearest 5 degrees
Mann-Whitney U	6620.500
Wilcoxon W	15531.500
Z	-5.121
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Bulb Angle, Bonobo v. Human[a]

	Bulb angle, nearest 5 degrees
Mann-Whitney U	10795.500
Wilcoxon W	19706.500
Z	-4.477
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Flake Bulb Angle, Gona v. Human[a]

	Bulb angle, nearest 5 degrees
Mann-Whitney U	16442.500
Wilcoxon W	42093.500
Z	-.814
Asymp. Sig. (2-tailed)	.416

a. Grouping Variable: Toolmkrcod

Discussion

Exactly why the bonobo internal (bulb) platform angles are different from the Gona and human sample is not clear. Perhaps lower hammerstone impact velocities applied closer to core edges, produce less pronounced bulbs of percussion and therefore, less obtuse platform angles than flakes produced by higher impact velocities further from the core edges. Controlled experiments with these raw materials should resolve this question.

42. Flakes: Percentage Dorsal Cortex ("Cortex Index")

Rationale

The amount of dorsal cortex on flakes (estimated as a percentage) can, like flake types, give indications of what stages of cobble reduction are represented in the debitage and how heavily reduced cobbles were. A mean "cortex index" for each assemblage can then be arrived at and assessed.

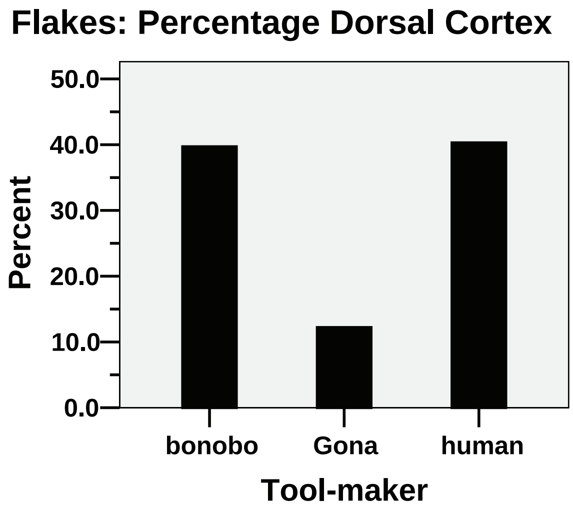
Results

The mean percentage of dorsal cortex on flakes in the bonobo and human sample were almost identical (~40%). The cortex index for Gona was much less (~12%), over three times less cortex on average than the experimental samples. Statistical testing showed that the Gona sample differed significantly from the bonobo and human sample at the .00 confidence level, but the bonobo and human sample were not significantly different at the .05 confidence level.

Flakes: Percentage of Dorsal Cortex by Tool-maker

Percentage of cortex

Tool-maker	Mean	N	Std. Deviation
bonobo	39.70	158	39.300
gona	12.20	166	20.600
human	40.30	244	35.500
Total	31.90	568	35.200



Test Statistics: Percentage of Dorsal Cortex on Flakes, Bonobo v. Gona[a]

	Percentage of cortex
Mann-Whitney U	7544.00
Wilcoxon W	21405.000
Z	-6.963
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Test Statistics: Percentage of Dorsal Cortex on Flakes, Bonobo v. Human[a]

	Percentage of cortex
Mann-Whitney U	18720.000
Wilcoxon W	31281.000
Z	-.495
Asymp. Sig. (2-tailed)	.621

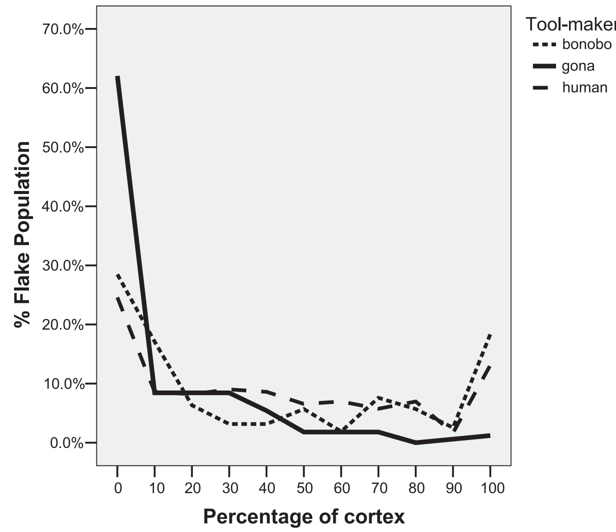
a. Grouping Variable: Toolmkrcod

Test Statistics: Percentage of Dorsal Cortex on Flakes, Gona v. Human[a]

	Percentage of cortex
Mann-Whitney U	10300.000
Wilcoxon W	24161.000
Z	-8.743
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Toolmkrcod

Percentage of Dorsal Cortex by Tool-maker



Discussion

This "cortex index" of mean percentage of dorsal cortex is an important way of assessing whether complete or partial reduction of Oldowan cobble cores took place at an archaeological site. Interestingly, the bonobo and human samples (representing complete reduction of cobble cores) had essentially the identical cortex index (40%), even though the human cores were reduced about 16 % more than the bonobo cores and produced 1.6 times as many whole flakes and 2.2 times as much overall debitage compared to the bonobo cores. It would appear that reducing cobbles by about 30% (bonobo cores) or by about 46% (human cores) can both yield the same cortex index.

The Gona flakes, on the other hand, tell a very different story. The astonishingly low cortex index of about 12% is a clear sign that significant numbers of flakes retaining significant cortex are missing from the archaeological sites. Even though the Gona cores (cobbles reduced about 64%) are somewhat more reduced than the human cores (about 17% more) and markedly more reduced than the bonobo cores (about 34% more), the fact that the Gona cores are more reduced and later stages of flaking are preferentially represented, this cannot explain the cortex index discrepancy: there should still be more cortex represented on the Gona flakes.

It would appear that, on average, perhaps half of the reduction of Gona cores took place off-site, and that subsequent flaking took place at the archaeological sites. But even these later stages of flaking of these Oldowan cobble cores should produce higher cortex indices than that seen at the Gona sites: the Gona cores were discarded with, on average, about 54% of their surfaces still retaining cortex (compared to 75% for bonobos and 62% for the human sample). As discussed previously, the most parsimonious explanation is that out of the debitage produced by later stages of reduction hominins selected larger, sharper flakes (and fragments) and subsequently transported them off-site. These larger flakes would tend to have higher percentages of cortex on their dorsal surfaces, so removing appreciable amounts of these flakes would markedly reduce the cortex index, as is seen at the Gona EG sites.

The fact that many large cortical flakes are missing from the sites, and that the majority of remaining flakes have little or no cortex, makes refitting much more difficult. Cortex in refitting studies is analogous to the straight-edged border pieces in a jigsaw puzzle; refitting Gona artifactual materials back together is comparable to doing a jigsaw puzzle lacking almost all border pieces as well as many other internal pieces; there will by definition be many gaps in the puzzle no matter how much one perseveres.

The human later stage flakes had a very similar mean percentages of dorsal cortex compared to the Gona hominin flake sample (~16% and ~12%, respectively). Statistical testing showed no significant difference between these two populations at the .05 confidence level.

Flakes: Percentage of Dorsal Cortex, Gona v. Human Later Stages

Percentage of cortex

Tool-maker	Mean	N	Std. Deviation
gona	12.23	166	20.638
humanlat	16.25	104	35.367
Total	13.78	270	27.277

Test Statistics: Flakes, Percentage of Dorsal Cortex, Gona v. Human Later Stages[a]

	Percentage of cortex
Mann-Whitney U	8188.000
Wilcoxon W	22049.000
Z	-.804
Asymp. Sig. (2-tailed)	.421

a. Grouping Variable: Toolmkrcod

If we remove the larger, sharper flakes from the later stage population of human flakes, the percentage of cortex goes down even further, with a mean virtually identical to that of the Gona sites (12.2%). This data is presented in the tables below.

Flakes: Percentage of Dorsal Cortex with Larger, Sharper Flakes Removed

Percentage of cortex

Tool-maker	Mean	N	Std. Deviation
gona	12.23	166	20.638
Human later stages with removal	12.22	63	40.259
Total	12.23	229	27.367

Test Statistics: Dorsal Cortex Percent, Gona v. Human Later Stages with Removal[a]

	Percentage of cortex
Mann-Whitney U	4604.500
Wilcoxon W	6620.500
Z	-1.647
Asymp. Sig. (2-tailed)	.100

a. Grouping Variable: Toolmkrcod

The percentage of dorsal cortex can be a powerful indicator of stages of cobble reduction represented at Oldowan sites. Cortex indices of less than 20% strongly suggest that only later stages of cobble reduction are represented (unless very large cobbles are being very heavily reduced). The very low cortical index at the Gona EG sites appears to represent later stages of flaking (also indicated by the flake types at these sites), very likely lowered even more by off-site transport of useful, also more highly cortical, flakes. Once again, this pattern strongly suggests a more complex tool-making and tool-using behavioral pattern than many palaeoanthropologists have probably suspected. An appreciation of this complexity is only possible when the archaeological assemblages are compared to experimentally-generated ones.

Summary

This study has had two major foci: 1) an examination of the stone tool-making skills of our nearest living relatives of the genus *Pan*, and 2) an examination of the stone tool-making skills and tool-related behaviors of the early hominins (possibly *A. garhi*) that produced the Gona EG sites some 2.6 Ma. This was accomplished through a 3-way comparison of the stone tool-making products of bonobos, of early hominin tool-makers at Gona (Ethiopia), and, as a point of reference, of modern humans.

This comparison entailed detailed analysis of 42 different attributes observable in the artifacts produced by these three species—looking at characteristics of their overall artifact assemblages, their cores, and their flakes. The process of this comparison has also provided a valuable, critical examination of these attributes of analysis themselves—many of which are commonly used by archaeologists, others less commonly so—in order to see what kinds of information and insights they can yield regarding tool-making behaviors and, overall, which ones are most useful in assessing tool-making skill. The experimental approach presented here thus shows a methodology that can be used to assess tool-making skills in Oldowan assemblages. With good control over raw material type, this approach can be applied across time, using objective criteria of flaked stone artifact attributes.

The major results and findings of this study can be summarized in three major categories:

Ape Stone Tool-making

1. We have established, in an experimental setting, a tradition of stone tool-making and tool-using in African apes, *Pan paniscus*.
2. This tradition, begun in 1990, has recently become transgenerational, with offspring of one of our two original subjects now beginning to flake stone.
3. The transmission of these skills now has a strong cultural component within the bonobo social group.
4. This experimental program is on-going and is providing valuable information regarding the initial acquisition and long-term development of stone tool-making skills among apes, and may provide insight into development of stone tool-making proficiency among early stone tool-making ancestors.
5. The two adult bonobos have become adept at making stone tools and producing conchoidally-flaked artifacts with many similarities to Oldowan cores and flakes, although their overall stone assemblages remain demonstrably different in many attributes from Oldowan assemblages.
6. The bonobo stone tool-making products can be used as a valuable frame of reference for evaluating artifacts at Early Stone Age sites.

Artifact Attribute Patterns

1. Out of eleven attributes deemed to be a function of knapping skill, the patterns at Gona were very similar to those in the human sample in six attributes, intermediate and significantly different from the human and bonobo patterns in two attributes, and intermediate but not significantly different from the bonobos in three other attributes.
    a. The Gona sample tended to cluster with the human sample in these skill-related attributes:
        i. Assemblage composition
        ii. Core types
        iii. Number of flake scars on cores
        iv. Flake shape (parallel v. divergent)
        v. Flake breadth/length (endstruck v. sidestruck)
        vi. Overall quality of flaking
    b. The Gona sample was intermediate between and significantly different from the human and the bonobo samples in two other skill-related attributes:
        i. Core edge battering
        ii. Ratio of core largest scar/core maximum dimension
    c. The Gona sample was intermediate between the human and bonobo samples, but not significantly different from the bonobo sample, in three other skill-related attributes:
        i. Core edge angle (the Gona mean was less than, but not significantly different from, the bonobo mean)
        ii. Flake edge angle (exterior platform angle) (the Gona mean was intermediate but not significantly different from the bonobo mean)
        iii. Flake platform battering (again, the Gona mean was intermediate but not significantly different from the bonobo mean)
2. For two other attributes (flake weight and maximum dimension), the Gona and the bonobo samples clustered, but each apparently had low values for these attributes for different reasons:
    a. The bonobo sample showed lower weights and maximum dimension as a function of lower skill
    b. The Gona sample showed lower flake weight and smaller maximum dimension of flakes as a function of later stages of flaking and highly reduced cores.
3. In ten other attributes deemed to be related to stage of core reduction, the Gona sample differed significantly from the two experimental samples (the bonobo and the human 50% reduction samples) largely as a function of later stage of flaking being preferentially represented at the Gona sites. The human 50% reduction sample tended to be intermediate in most of these attributes, with values between the Gona and bonobo samples, as the human cores in this sample were intermediate in their degree of reduction. Comparison of the human 50% reduction sample with the Gona assemblage highlights the relatively high degree of reduction at these early, 2.6 million year old Gona sites. (In the human later stages sample, these attributes tended to become much closer to the Gona values). The attributes related to degree of reduction which distinguished the Gona sample included:
    a. Invasiveness of flaking
    b. Percentage of circumference flaked
    c. Core weight
    d. Core maximum dimension
    e. Core breadth
    f. Modified breadth/length ratios
    g. Percentage of original cobble
    h. Percentage of surface cortex on core
    i. Number of flake dorsal scars
    j. Percentage of flake dorsal cortex

Early Archaeological Sites at Gona

1. The Gona archaeological sites at 2.6 Ma show a remarkable level of skill in flaking stone (with regard to efficiently reducing cobbles and producing usable flakes), in many ways more similar to the pattern produced by modern humans than by the experienced bonobo tool-makers;
2. The dominant flaking mode of both the Gona hominins and the bonobos entailed the unifacial reduction of lava cobbles. This suggests that unifacial reduction was a simple yet efficient way of detaching flakes from a cobble core. The Gona hominins appear to have preferentially selected absolutely thinner cobbles than the experimental samples; thinner, discoidal cobbles would have been easier to reduce, producing more debitage per core
3. Gona hominins reduced their cores much more heavily than the bonobo sample, with more invasive flake scars and less remaining cortex on cobble cores, suggesting that the prehistoric hominins were more skilled at removing numerous flakes from cores.
4. The Gona artifact assemblages suggests that hominins transported partially flaked cores to the archaeological sites, heavily reduced the cores at the sites, and carried away from the sites many of the more useful, larger and sharper flakes. The removal of these useful flakes is a strong indication that such flakes were an important part of the Gona hominins' technological repertory. This also suggests that much of the tool-using behavior of these hominins occurred "off-site," perhaps in part associated with animal carcass processing on the landscape, as indicated by cut-marked bones found in the same stratigraphic level.
5. Regarding the attributes related to skill, the fact that the Gona sample tended either to cluster strongly with the modern human sample or to be intermediate between the human and bonobo samples, suggests that:
   a. Gona hominins were remarkably skilled knappers;
   b. The early stone tool-makers at Gona had a sound cognitive understanding of the principles of stone fracture;
   c. The Gona tool-makers had the biomechanical abilities to impart well-directed, forceful hammerstone blows when detaching flakes.
6. Based upon the ratio of split to whole flakes, Gona hominins appear to be intermediate between bonobos and modern humans in the hammerstone forces generated in detaching flakes.
7. Bonobos produced more end choppers, while the Gona hominins produced more side choppers, almost certainly due to the Gona hominins' ability to reduce cobbles more extensively than the bonobos (i.e., with continued flaking, an end chopper will usually grade into a side chopper).
8. The Gona hominins were selective in their acquisition of raw material, obtaining higher proportions of stone cobbles with excellent-to-good flaking qualities (fine-grained and isotropic) than are found on average in the nearby river gravels. This selection was probably facilitated by testing the cobbles at the gravels by removing flakes to examine the internal characteristics of the potential core. Such selectivity for better-quality raw materials has also been independently reported from Gona sites (Stout ***et al***., 2005). In choosing raw materials for the experiments reported here, approximately 1 in 50 (or 2%) of the cobbles within the Gona conglomerates were deemed suitable for flaking based upon their superficial qualities. Testing of cobbles by Gona hominins at the gravel sources would have tended to enhance this selectivity even more.

Criteria for Assessing Skill

Based upon the study presented here, criteria for assessing higher levels of skill from Oldowan assemblages would include the following attributes for cores and debitage:

Cores

1. More side choppers versus end choppers (in general, more heavily reduced cores)
2. More flake scars per core
3. More reduced cores/less cortex on cores
4. More acute edge angles on cores
5. More invasive flaking on cores
6. Less edge battering on cores
7. Higher "quality of flaking"

Debitage

1. More debitage per core
2. Longer (and thicker) flakes relative to breadth
3. Larger, heavier flakes
4. Less platform battering/stepping
5. More parallel-sided flakes, less divergent flakes
6. More acute exterior platform angle
7. Lower percentage of cortex on flakes
8. Higher ratio of split to whole flakes
9. Fewer fragments, more whole flakes and broken flakes

In applying some of these criteria, particularly those that are also related to the degree of core reduction (e.g., amount of core cortex, number of flake scars, amount of debitage), it would be best to proceed cautiously with regard to an assignment of lower level of skill to the assemblage, as an individual site may not always indicate maximum ability of the hominin tool-makers but may also vary according to special circumstances (for instance, there may be lesser degree of core reduction at some sites very near raw material sources). A "lower skill" assessment of an assemblage should preferably involve diverse, multiple criteria within any one assemblage and, ideally, should also refer to region-wide artifact patterns to take into account maximum skill levels in a particular area in a general time period and factor out possible site-specific idiosyncrasies, such as raw material differences that can impact flaking qualities. Indication of high level of skill according to multiple attributes, however, would support greater stone tool-making proficiency and skill among the prehistoric tool-makers.

Conclusion

In sum, the Gona EG sites show that by 2.6 Ma the earliest known stone tool-making hominins, possibly *Australopithecus garhi*, had already evolved the cognitive and biomechanical capabilities to efficiently flake stone and produce sharp-edged flakes and fragments with stone percussors. This new behavior pattern, which appears to be roughly contemporaneous with cut-marked bones from the Middle Awash, may mark a major adaptive shift towards more carnivorous behavior through scavenging and/or hunting larger mammals.

In addition to a high degree of skill in stone tool-making, relatively complex tool-related behaviors among the Gona hominins are also indicated by this study, involving testing cobbles at gravel sources, substantially reducing cores prior to bringing them to these sites, and subsequently transporting numbers of flakes away from the sites, most probably for use at some other location(s). Thus, the Gona patterns do not suggest purely expedient tool-making and tool-using behaviors: these artifact assemblages do not appear to represent immediate responses to immediate, local opportunities but instead appear to involve some degree of planning, perhaps anticipation of future needs, and spatial displacement of different phases of tool-making and tool-using in different locations in the landscape.

The modern bonobo subjects were able to flake stone in a manner that would clearly be recognized as artifactual in a prehistoric context. However, the lithic assemblage produced thus far by the bonobos, despite showing some similarities to early Oldowan artifacts (e.g. chopper-dominated), exhibits important differences from Oldowan archaeological occurrences in Africa. While some individual flakes or cores may resemble Oldowan assemblages, the overall bonobo artifact assemblage shows marked differences in a number of features. If such a bonobo assemblage were discovered in a prehistoric context, with so many distinct differences from early Oldowan artifact assemblage in so many attributes, particularly ones associated with skill, it might be assigned to a "Pre-Oldowan" stage of technology.

Thus, this bonobo-generated sample may give clues regarding possible earlier, yet-to-be-discovered archaeological sites produced by early hominins. On the other hand, early hominins may have developed their cognitive and biomechanical capabilities prior to the need to flake stone, and the early Gona sites may in fact represent the earliest stages of hominin flaked stone technology. Future fieldwork and analysis should shed light on this question.

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Appendix 1a. Assemblage attributes: results of statistical tests.

Attrib. No.	ASSEMBLAGE	Test	All (3-way)	Arch v. Exp	B v. G	B v. H	G v. H	Out-lier?	Group(s)?	All signif. differ at .05 level?	Gradient?
1	Assemblage Composition (Lithic Class)	Chi-Square			0.000	0.000	0.788	B	G+H	n	n
2a	Debitage Breakdown	Chi-Square			0.000	0.000	0.000	n	n	y	n
2b	Whole v. Split Flake Proportions	Chi-Square	0.000		0.000	0.000	0.000	n	n	y	B→G→H
3	Rock Type (exp/arch, cores)	Chi-Square		0.057	NA	NA	NA	NA	~(G+Exp)	NA	NA
4	Raw Material Quality (exp/arch, cores)	Chi-Square		0.200	NA	NA	NA	NA	G+Exp	NA	NA

B=bonobos, G=Gona, H=humans
Exp=Experimental (B+H), Arch=Gona
NA=not applicable

Appendix 1b. Assemblage attributes: comments on overall patterns and results.

Attrib. No.	ASSEMBLAGE	COMMENT
1	Assemblage Composition (Lithic Class)	Bonobos outlier with much higher core %, lower flake and fragment percents
2a	Debitage Breakdown	Bonobos high flake %
2b	Whole v. Split Flake Proportions	Split flakes: Humans highest, Gona intermediate, bonobos lowest
3	Rock Type (exp/arch, cores)	Experimental and archaeological rock types similar
4	Raw Material Quality (exp/arch, cores)	Experimental and archaeological rock quality similar

Exp=Experimental (B+H), Arch=Gona

Appendix 2a. Core attributes: results of statistical tests.

Attrib. No.	CORES	Test	All (3-way)	Arch v. Exp	B v. G	B v. H	G v. H	Out-lier?	Group(s)?	All signif. differ at .05 level?	Gradient?
5	Cores: Original Form	None			0.045	0.198	0.003	G	B+H	n	
6	Cores: Flaking Mode	Chi-Square			0.253				B+G		
7	Cores: Invasiveness	Chi-Square			0.000	0.009	0.04	n	n	y	B→H→G
8	Cores: % Circumference	Mann-Whitney			0.000	0.000	0.092	B	~(G+H)	n	B→H→G
9a	Cores: Quality of Flaking (4 categories)	Chi-Square	0.000		0.075	0.000	0.003	H	n	n	B→G→H
9b	Cores: Quality of Flaking (2 categories)	Chi-Square	0.003		0.009	0.003	0.902	B	G+H	n	B→G→H
10	Cores: Edge Battering/Stepping	Chi-Square			0.011	0.000	0.000	n	n	y	B→G→H
11	Cores: Modified Leakey Type	Chi-Square	0.000		0.000	0.000	0.029	n	n	y	
11(b)	Cores: Modified Leakey Type (End v. Side Ch.)	Chi-Square			0.000	0.000	0.173	n	G+H	n	B→H→G
12	Cores: Weight	Mann-Whitney			0.000	0.000	0.000	n	n	y	G→H→B
13	Cores: Maximum Dimension (L)	Mann-Whitney			0.000	0.000	0.000	n	n	y	G→H→B
14	Cores: Breadth	Mann-Whitney			0.000	0.000	0.000	n	n	y	G→H→B
15	Cores: Thickness	Mann-Whitney			0.001	0.824	0.000	G	B+H	n	G→B→H
16	Cores: B/L Ratio	Mann-Whitney			0.175	0.394	0.026	n	G+B, B+H	n	G→B→H
17	Cores: Modified B/L Ratio	Mann-Whitney			0.000	0.000	0.079	B	~(H+G)	n	B→H→G
18	Cores: Th/B Ratio	Mann-Whitney			0.099	0.007	0.484	(~B)	~(G+H)	n	B→G→H
19	Cores: Max D of Largest Scar	Mann-Whitney			0.004	0.936	0.001	G	H+B	n	G→H→B
20	Cores: Largest Scar/Maximum D	Mann-Whitney			0.121	0.003	0.098	n	B+G, G+H	n	B→G→H
21	Cores: % Original Clast	Mann-Whitney			0.000	0.000	0.000	n	n	y	G→H→B
22	Cores: # Flake Scars	Mann-Whitney			0.000	0.000	0.965	B	G+H	n	B→H→G
23	Cores: Step/Scar Ratio	Mann-Whitney			0.204	0.302	0.007	n	G+B, B+H	n	G→B→H
23(b)†	Cores: Step/Scar Ratio, Gona v. Human Later†	Mann-Whitney					0.893†		G+H later†		
24	Cores: Edge Angle	Mann-Whitney			0.213	0.000	0.000	H	G+B	n	H→G→B
25	Cores: % Cortex	Mann-Whitney			0.000	0.000	0.045	n	n	y	G→H→B

B=bonobos, G=Gona, H=humans
†=Human later stages of reduction

Appendix 2b. Core attributes: comments on overall patterns and results.

Attrib. No.	CORES	COMMENT
5	Cores: Original Form	Mostly cobbles for all; Gona more indeterminate forms, as more reduced
6	Cores: Flaking Mode	Bonobos v. Gona comparison: Bonobos + Gona, no significant difference
7	Cores: Invasiveness	Gradient B→H→G, all differ, humans 50% reduction sample intermediate
8	Cores: % Circumference	Gradient B→H→G, humans 50% reduction sample intermediate, bonobos ~outlier
9a	Cores: Quality of Flaking (4 categories)	Gradient, Gona intermediate (but many cells < 5)
9b	Cores: Quality of Flaking (2 categories)	Bonobos outlier, G + H higher quality, Gona intermediate
10	Cores: Edge Battering/Stepping	Bonobos high, Gona intermediate, humans low
11	Cores: Modified Leakey Type	Bonobos very high end % choppers, Gona, humans very high % side
11(b)	Cores: Modified Leakey Type (End v. Side Ch.)	Bonobos very high end % choppers, Gona, humans very high % side
12	Cores: Weight	All differ: Gona low, humans intermediate, bonobos high
13	Cores: Maximum Dimension (L)	All differ: Gona low, Humans intermediate, bonobos high
14	Cores: Breadth	All differ: Gona low, humans intermediate, bonobos high
15	Cores: Thickness	Gona outlier (thinner), B + H group (thicker)
16	Cores: B/L Ratio	Gona ratio < human; bonobos intermediate
17	Cores: Modified B/L Ratio	Bonobos lowest (end choppers); Humans + Gona higher, more reduced (side choppers)
18	Cores: Th/B Ratio	Bonobos lowest, Gona intermediate, humans highest
19	Cores: Max D of Largest Scar	Gona outlier, smallest ratio (more reduced cores); H 50% control sample + B group
20	Cores: Largest Scar/Maximum D	Gona intermediate, B (lowest) + H (highest) extremes differ
21	Cores: % Original Clast	All differ: Gona lowest, human 50% reduction sample intermediate, bonobos highest
22	Cores: # Flake Scars	Bonobo lowest, outlier, humans + Gona group, higher
23	Cores: Step/Scar Ratio	Bonobo intermediate; Gona + human 50% reduction control sample extremes differ
23(b)†	Cores: Step/Scar Ratio, Gona v. Human Later†	No significant difference between Gona and human later stages sample
24	Cores: Edge Angle	Human lowest, outlier; Gona intermediate, groups with bonobos
25	Cores: % Cortex	All differ; Gona lowest (more reduced), bonobo highest (least reduced)

B=bonobos, G=Gona, H=humans
†=Human later stages of reduction

Appendix 3a. Flake attributes: results of statistical tests.

Attrib. No.	FLAKES	Test	All (3-way)	Arch v. Exp	B v. G	B v. H	G v. H	Out-lier?	Group(s)?	All signif. differ at .05 level?	Gradient?
26	Flakes: Flake Types 1-6	Chi-Square			0.000	0.031	0.000	n	n	y	y
	Flakes: Flake Types 1-6	Kolmog.-Smirnov			0.000	0.136	0.004	G	B+H	n	y
27	Flakes: Location of Cortex										
28	Flakes: Scar Pattern										
29	Flakes: Flake Shape	Chi-Square	.000		0.000	0.000	0.035	n	n	y	
29(b)	Flakes: Flake Shape, parallel v. divergent	Chi-Square	.000		.002	.000	.387	y	G+H	n	n
30	Flakes: Platform Battering/Stepping	Chi-Square			0.789	0.000	0.003	H	B+G	n	H→G→B
31	Flakes: Weight	Mann-Whitney			0.288	0.000	0.000	H	B+G	n	G→B→H
32	Flakes: Maximum Dimension	Mann-Whitney			0.112	0.000	0.000	H	B+G	n	G→B→H
33	Flakes: Thickness	Mann-Whitney			0.000	0.000	0.112	n	n	n	B→G→H
34	Flakes: B/L Ratio	Mann-Whitney			0.000	0.000	0.079	B	G+H	n	H→G→B
35	Flakes: Th/B Ratio	Mann-Whitney			0.000	0.000	0.000	n	n	y	B→H→G
36	Flakes: Platform Th/Platform B Ratio	Mann-Whitney			0.000	0.002	0.001	n	n	y	B→H→G
37	Flakes: No. Platform Scars (Types 1-6)	Mann-Whitney			0.957	0.022	0.018	H	B+G	n	(B+G)→H
37(b)	Flakes: No. Platform Scars (Types 4-6)	Mann-Whitney			0.558	0.018	0.100	(~H)	~(B+G)	n	H→G→B
38	Flakes: No. Dorsal Scars, All Flakes	Mann-Whitney			0.000	0.397	0.000	G	B+H	n	B→H→G
39	Flakes: Step & Hinge/Scar Ratio	Mann-Whitney			0.000	0.340	0.002	G	B+H	n	G→H→B
39(b)†	Flakes: Step & Hinge/Scar Ratio, Gona v. Human Later Stages†	Mann-Whitney					0.447†		G+H†		H→G→B
40	Flakes: Core Angle (Ext. Plat. Ang.)	Mann-Whitney			0.180	0.000	0.000	H	B+G	n	B→H→G
41	Flakes: Bulb Angle (Int. Plat. Ang.)	Mann-Whitney			0.000	0.000	0.416	B	H+G	n	G→(B+H)
42	Flakes: % Dorsal Cortex (“cortex index”)	Mann-Whitney			0.000	0.621	0.000	G	B+H	n	
42(b)†	Flakes: % Dorsal Cortex (“cortex index”), Gona v. Human Later Stages†	Mann-Whitney					0.421†		G+H†		
42(c)†	Flakes: % Dorsal Cortex (“cortex index”), Gona v. Human Later Stages† w/removal	Mann-Whitney					0.100†		G+H†		

B=bonobos, G=Gona, H=humans
†=Human later stages of reduction

Appendix 3b. Flake attributes: comments on overall patterns and results.

Attrib. No.	FLAKES	COMMENT
26	Flakes: Flake Types 1-6	All samples differ
	Flakes: Flake Types 1-6	B + H group (high types 2, 3 and 1, H also 5); Gona differs in higher % types 3 and 6
27	Flakes: Location of Cortex	Gona: low % with all cortex, high % with no cortex (later stages, heavily reduced)
28	Flakes: Scar Pattern	All: mainly simple pattern; bonobo relatively high in plain, Gona in opposed
29	Flakes: Flake Shape	All differ, bonobos high oval + divergent; Gona and humans high parallel + convergent
29(b)	Flakes: Flake Shape, parallel v. divergent	Gona and humans group, more parallel flakes; bonobos more divergent flakes
30	Flakes: Platform Battering/Stepping	Humans lowest, outlier, Gona intermediate; bonobos highest
31	Flakes: Weight	Human flakes heaviest; Gona lightest (small, later stages), bonobo intermediate
32	Flakes: Maximum Dimension	Human flakes largest; Gona smallest (later stages), bonobo intermediate
33	Flakes: Thickness	Bonobo flakes thinnest, Gona intermediate, humans thickest
34	Flakes: B/L Ratio	Bonobo flakes sidestruck; gona and human more endstruck
35	Flakes: Th/B Ratio	Bonobo flakes thinnest, Gona flakes thickest relative to breadth
36	Flakes: Platform Th/Platform B Ratio	Bonobo flake platforms thinnest, Gona flakes thickest, relative to platform breadth
37	Flakes: No. Platform Scars (Types 1-6)	Bonobo and Gona group, low number, humans highest
37(b)	Flakes: No. Platform Scars (Types 4-6)	Humans lowest, Gonas and bonobos high
38	Flakes: No. Dorsal Scars, All Flakes	Bonobos lowest, group with humans; Gona highest
39	Flakes: Step & Hinge/Scar Ratio	Gona lowest, humans intermediate, bonobos highest
39(b)†	Flakes: Step & Hinge/Scar Ratio, Gona v. Human Later Stages†	Human later stage flakes and Gona nearly identical in step & hinge/scar ratio
40	Flakes: Core Angle (Ext. Plat. Ang.)	Human sample smallest angle; Gona intermediate; bonobos highest
41	Flakes: Bulb Angle (Int. Plat. Ang.)	Bonobo sample smallest angle; humans and Gona larger, group
42	Flakes: % Dorsal Cortex ("cortex index")	Gona very low % cortex (later stages); humans 50% reduction + bonobos much higher
42(b)†	Flakes: % Dorsal Cortex ("cortex index"), Gona v. Human Later Stages†	Human later stage flakes and Gona very similar in cortex index
42(c)†	Flakes: % Dorsal Cortex ("cortex index"), Gona v. Human Later Stages† w/removal	Human later stage flakes with removal and Gona nearly identical in cortex index

B=bonobos, =Gona, H=humans
†=Human later stages of reduction

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