Journal of Archaeological Science (1999) **26,** 821–832
Article No. jasc.1998.0350, available online at http://www.idealibrary.com on IDEAL

Continuing Investigations into the Stone Tool-making and Tool-using Capabilities of a Bonobo (*Pan paniscus*)

Kathy D. Schick, Nicholas Toth and Gary Garufi

Department of Anthropology and Center for Research into the Anthropological Foundations of Technology (CRAFT), Indiana University, Bloomington, IN 47405, U.S.A.

E. Sue Savage-Rumbaugh, Duane Rumbaugh and Rose Sevcik

Language Research Center and Departments of Biology and Psychology, Georgia State University, Atlanta, GA 30303, U.S.A.

(*Received 9 October 1997, revised manuscript accepted 9 September 1998*)

A long-term collaborative study by palaeolithic archaeologists and cognitive psychologists has continued in its investigations into the stone tool-making and tool-using abilities of a captive bonobo (a 180 pound male, named Kanzi, aged 12 years at the time of experiments reported here). A major focus of this study has been examination of the lithic reduction strategy over time and detailed analysis of the artefacts Kanzi has produced in 2 years of experimentation since our original report. Kanzi has exhibited marked improvement in his stone-working skills, although to date the artefacts he has produced still contrast with early hominid-produced artefacts in a number of attributes. Statistical analysis revealed that Kanzi is clearly preferentially selecting larger, heavier pieces of debitage (flakes and fragments) for use as tools.

Keywords: BONOBO, CHIMPANZEE, EXPERIMENTAL ARCHAEOLOGY, OLDOWAN, PRIMATE TECHNOLOGY, STONE TOOLS, TECHNOLOGY.

An anthropoid ape, if he could take a dispassionate view of his own case, would admit that though he could form an artful plan to plunder a garden—though he could use stones for fighting or for breaking nuts, yet the thought of fashioning a stone into a tool was quite beyond his scope.
Charles Darwin, The Descent of Man, 1871

Introduction

An interesting and controversial problem in palaeoanthropology concerns the evolution of cognitive abilities and motor skills of early prehistoric tool-making hominids. A number of investigations and syntheses have focused upon possible evidence of the abilities of Early Stone Age hominids from the Plio-Pleistocene based upon early stone artefacts (e.g., Oakley, 1981; Gowlett, 1984; Toth, 1985; Foley, 1987; Wynn, 1988; 1989; Isaac, 1989; McGrew, 1989; McGrew, 1992; Berthelet & Chavaillon, 1993; Davidson & Noble, 1993; Gibson & Ingold, 1993; Harris & Capaldo, 1993; Kibunjia, 1994; Schick & Toth, 1993; Toth & Schick, 1986, 1993; Mithen, 1996; Semaw *et al.*, 1996).

Although many, perhaps most, manifestations of hominid intelligence and cognition would be likely to have little or no visibility in the prehistoric record, flaked stone artefacts provide potential information regarding the problem-solving and decision-making abilities of these early tool-makers. Flaked stone technology can also potentially be used as a basis for comparing and contrasting these abilities in prehistoric hominids, modern humans, and modern non-human primates.

Evidence of primate (especially chimpanzee) tool behaviour in the wild has been documented in detail (e.g., Goodall & Hamburg, 1974; Telecki, 1974; Sugiyama & Koman, 1979; Beck, 1980; Boesch & Boesch, 1981, 1983, 1984, 1990; Goodall, 1986; Kortland, 1986; Wrangham, 1987; Marchant & McGrew, 1991; McGrew, 1989, 1991, 1992, 1993; McGrew & Marchant, 1992; Nishida, 1973, 1990; Sugiyama, 1993). However, flaked stone technologies are absent in any known wild primate population.

In a pioneering study by Wright (1972), a captive orangutan named Abang was trained to detach a flake from a pre-shaped flint core that was strapped to a wooden plank to stabilize the core, using a stone cobble as a percussor (hammerstone). This flake was subsequently used to cut through a cord to gain access to a box that held a food reward inside. The

0305–4403/99/070821+12 $30.00/0

experiment was terminated after the first successful attempt. Wright concluded from this experiment that prehistoric australopithecines would have almost certainly possessed the cognitive and motor skills to make simple flaked stone tools as well. Wright's study provided an inspiration and a starting point for the research reported here.

In the spring of 1990, a long-term, multidisciplinary study was initiated to investigate the potential stone tool-making and tool-using abilities of a captive bonobo (*Pan paniscus*). The subject, Kanzi, was then a 9-year-old, 150 pound male well-known for his communication skills (Savage-Rumbaugh, 1986, 1991; Savage-Rumbaugh *et al.*, 1986; Savage-Rumbaugh & Rumbaugh, 1993; Savage-Rumbaugh & Lewis, 1994). Kanzi is a member of a rare and endangered species of ape (born in captivity) and highly accomplished in the comprehension of human speech and even the syntax of novel sentences of request uttered to him in highly controlled conditions. His productive competence, conservatively estimated, approximates to that of a 1- to $1\frac{1}{2}$-year-old human child.

The basic results of that first year of investigation have been previously reported (Toth *et al.*, 1993). Our approach was to model stone tool-making and tool-using by direct example, and then to provide Kanzi with unmodified stone to flake on his own. The initial goal for Kanzi was to cut through a cord to open a box containing a desired food item. Subsequently, we also built containers in the form of drums with thick, transparent membranes/drumheads that needed to be slit through to acquire the food items inside.

Over the following 2 years, Kanzi continued to flake stone periodically (as the overall research schedule and circumstances permitted), and his success in flaking stone continued to improve. One especially interesting development in this experimental study was Kanzi's innovation of a flaking technique that had not been shown to him by the researchers: by throwing a stone on a hard surface, and subsequently by throwing one stone against another. Kanzi's success in fracturing stone by throwing seems to be a function of the greater force of impact allowed by throwing as well as possible biomechanical constraints of his hands and upper limbs when holding the hammerstone in one hand and core in the other. Throwing one cobble against another became his technique of preference during the time reported here. He would normally position the core on the ground about 1 m away from his feet and was quite accurate at throwing, often hitting the core on his first attempt.

Methodology

In this report we focus upon the level of Kanzi's stone-working skills after 3 years of knapping experience (an estimated 120 h of tool-making and tool-using experience). In this study one major objective was to investigate and quantify how extensively and skillfully Kanzi could flake stone in the manufacture of usable cutting tools. For this purpose, extended experiments were conducted, in each of which Kanzi initiated core reduction and continued flaking the same core through successive trials. These experiments are representative of Kanzi's ability to flake stone at the time of this study (Figures 1(a)–(c)).

Eleven detailed experiments in cobble reduction were conducted with Kanzi in the analysis reported here. For each experiment, an unmodified chert or agate cobble was made available to Kanzi as well as a more spherical quartzite or lava cobble that could be used as a hammerstone or anvil. The chert and agate cobbles all exhibited angles from which flakes could be detached by hard-hammer percussion, although they presented a range of flaking di culty.

For each of the 11 experimental reductions, a reward box with a food item inside was made available. The reward box was constructed of strong plastic with a clear Mylar top through which the reward could be viewed by Kanzi, and the box was mounted on a metal platform. A hinged door at one end of the box was held shut with a thick nylon cord. The food item inside (fruit, sweets, or beverages) could be obtained by cutting through the nylon cord with a sharp stone tool and opening the door.

Each experiment consisted of multiple trials (minimum of 5, maximum of 17) flaking a single core (Table 1). Nine of these experiments each started with an unmodified chert cobble and a hammerstone and consisted of five successive trials in cobble reduction to produce usable flakes. The remaining two experiments, involving agate cobbles, were extended beyond five trials to explore Kanzi's further reduction of a core.

A trial began when Kanzi was given access to the cobbles and the reward box (as described above), and it ended when he had successfully flaked the stone and used one or more of the sharp artefacts produced (usually larger flakes) to cut through the cord, open the box, and obtain the food item. After each trial, all debitage (flakes and fragments) was removed from the experimental area, leaving only the core and hammer/anvil for further flaking activity in subsequent trials.

Results

E orts were made to encourage Kanzi to flake stone using hand-held, direct percussion with a stone hammer, a tool-making technique believed to have been predominant in the Early Stone Age based upon experimental replicative research and detailed technological analysis of prehistoric artefact assemblages (Jones, 1981; Toth, 1982, 1985; Schick & Toth, 1993). As previously reported (Toth *et al.*, 1993), Kanzi unexpectedly initiated his own favoured technique for flaking stone: throwing one cobble against a hard

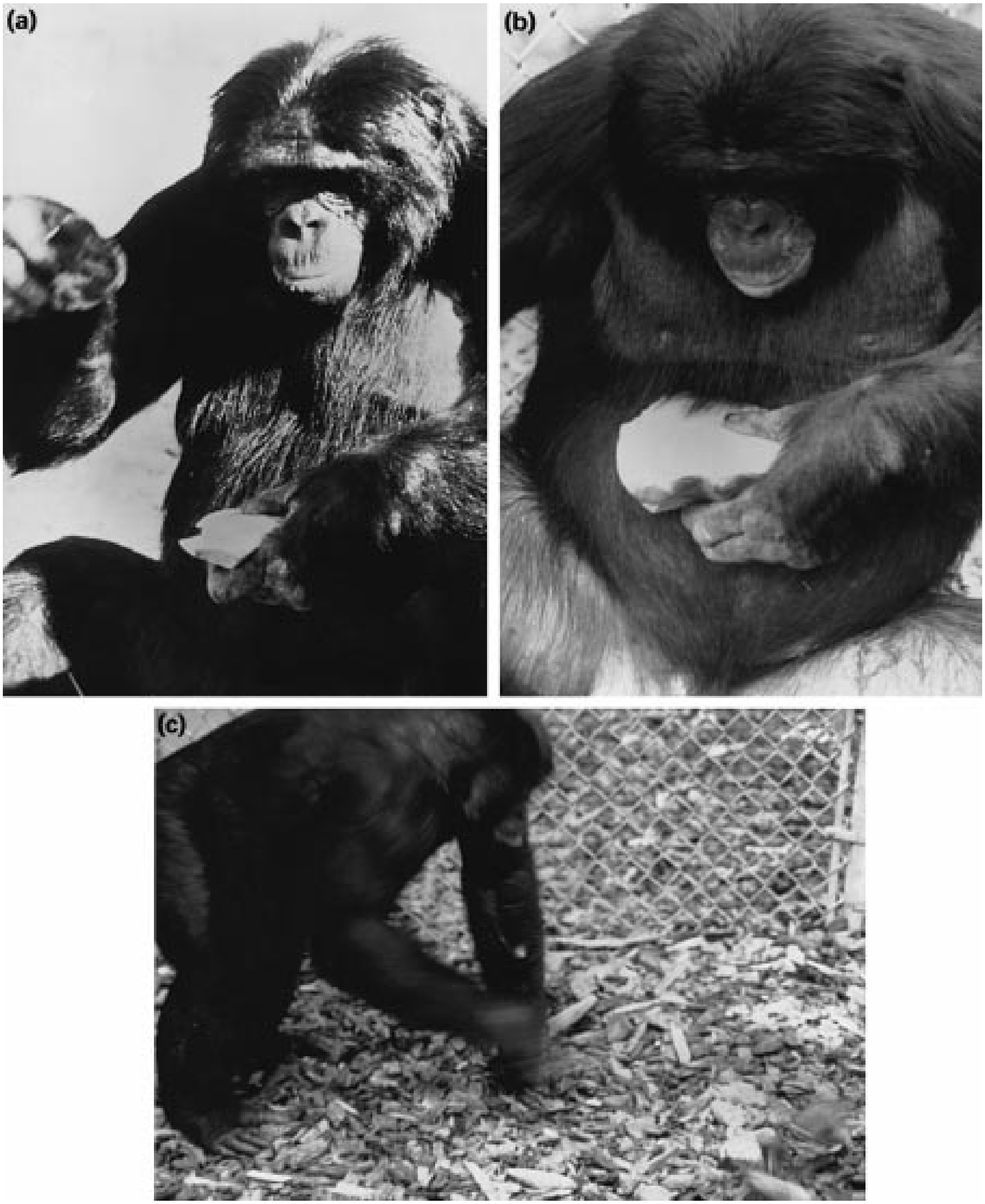


Figure 1. (a) Kanzi flaking by hand-held, hard-hammer percussion; (b) Kanzi inspecting a cobble before flaking; (c) Kanzi throwing one cobble against another to initiate fracture. The thrown cobble has just rebounded o the stationery cobble after impact, and can be seen as a blur in the bottom right. The great majority of artefacts described here were produced by this technique.

surface or against another cobble in order to initiate fracture. He first learned this technique indoors when he discovered he could produce flakes by throwing a cobble against a hard tile floor, and then he transferred this technique to throwing one rock against another when outdoors. This technique of throwing (either a hammerstone against a core, or a core against an anvil) was the primary technique that Kanzi employed in this

Table 1. Synopsis of extended reduction experiments involving multiple trials with the same core

Exe #	Raw material	# TR	Final form	Final core wt (g)	Final DEB wt (g)	Final # cores	Final # RET	Final # FL	Final # FRAG	# used	Total artefacts #
1	CHERT	5	CORE	1619	342	1		4	10	7	15
2	CHERT	5	CORE	1071	737	1		12	8	10	21
3	CHERT	5	CORE	604	726	1		5	20	8	26
4	CHERT	5	CORES	a) 229 b) 330	332	2		6	16	10	24
5	CHERT	5	MODIF	(74)*	958	0	1	26	12	17	39
6	CHERT	5	CHUNK	(137)*	899	0		9	15	12	24
7	CHERT	5	CORE	1037	991	1		9	21	11	31
8	CHERT	5	CORES	a) 422 b) 272	798	2		2	20	6	24
9	CHERT	5	CORES	a) 214 b) 340	890	2		10	5	6	17
10	AGATE	15	CORE	431	903	1	1	9	39	22	50
11	AGATE	17	CORE	727	545	1	1	9	12	14	23
	TOTALS	77		7286 (7497)*	8121	12	3	101	178	123	294

The number of resultant cores was based upon the typological designation of the artefact on technological grounds if it were found in an archaeological assemblage.
Flakes and fragments greater or equal to 2 cm maximum dimension are considered here.
TR = number of trials per experiment; DEB = debitage; RET = retouched/modified pieces; FL = flakes; FRAG = fragments.
*Total weight of cores including those that, though technically cores, would not normally be recognized as such in classification of an archaeological assemblage.

experimental study. In his use of the throwing technique, Kanzi appears able to impart much greater force to initiate stone fracture than he does in flaking a hand-held core, and this may help explain his strong preference for throwing in tool-making. Thus, the results presented here represent characteristics of artefacts produced by Kanzi almost exclusively through throwing rather than hand-held percussion.

The results of these 11 experiments are treated here as an archaeological assemblage for analytical purposes. All flaked stone artefacts greater or equal to 2 cm are classified and described qualitatively and quantitatively below.

Major artefact classes

A total of 294 artefacts were produced in this experimental round. This includes 12 cores, three retouched pieces, 101 whole flakes, and 178 other types of fragments such as snapped and split flakes, angular fragments, and chunks (Table 1). Representative examples of artefacts produced by Kanzi in this round of experimentation are illustrated in Figure 2. Overall technological breakdown of his flaking products are shown in Figure 3.

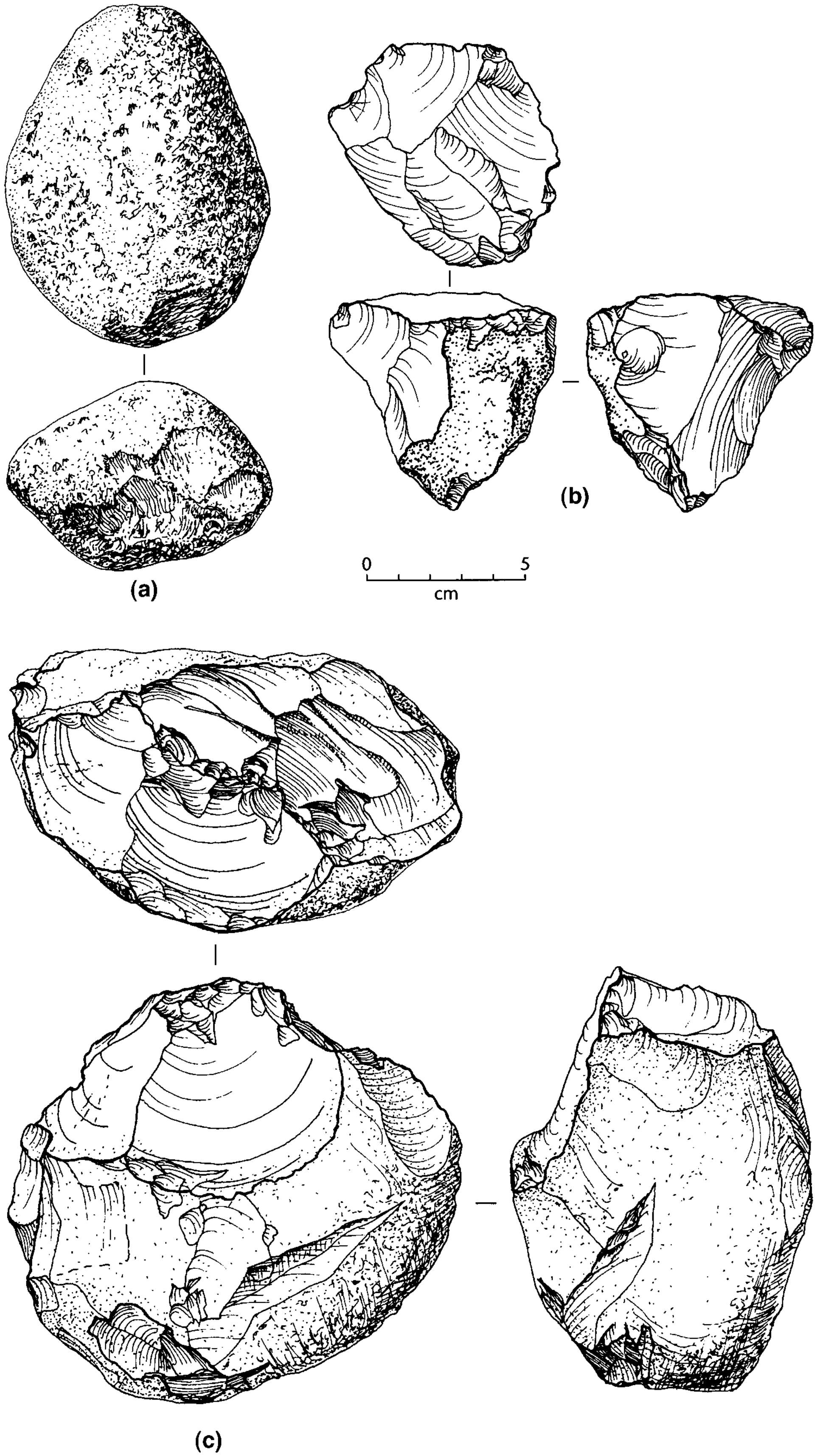
Cores

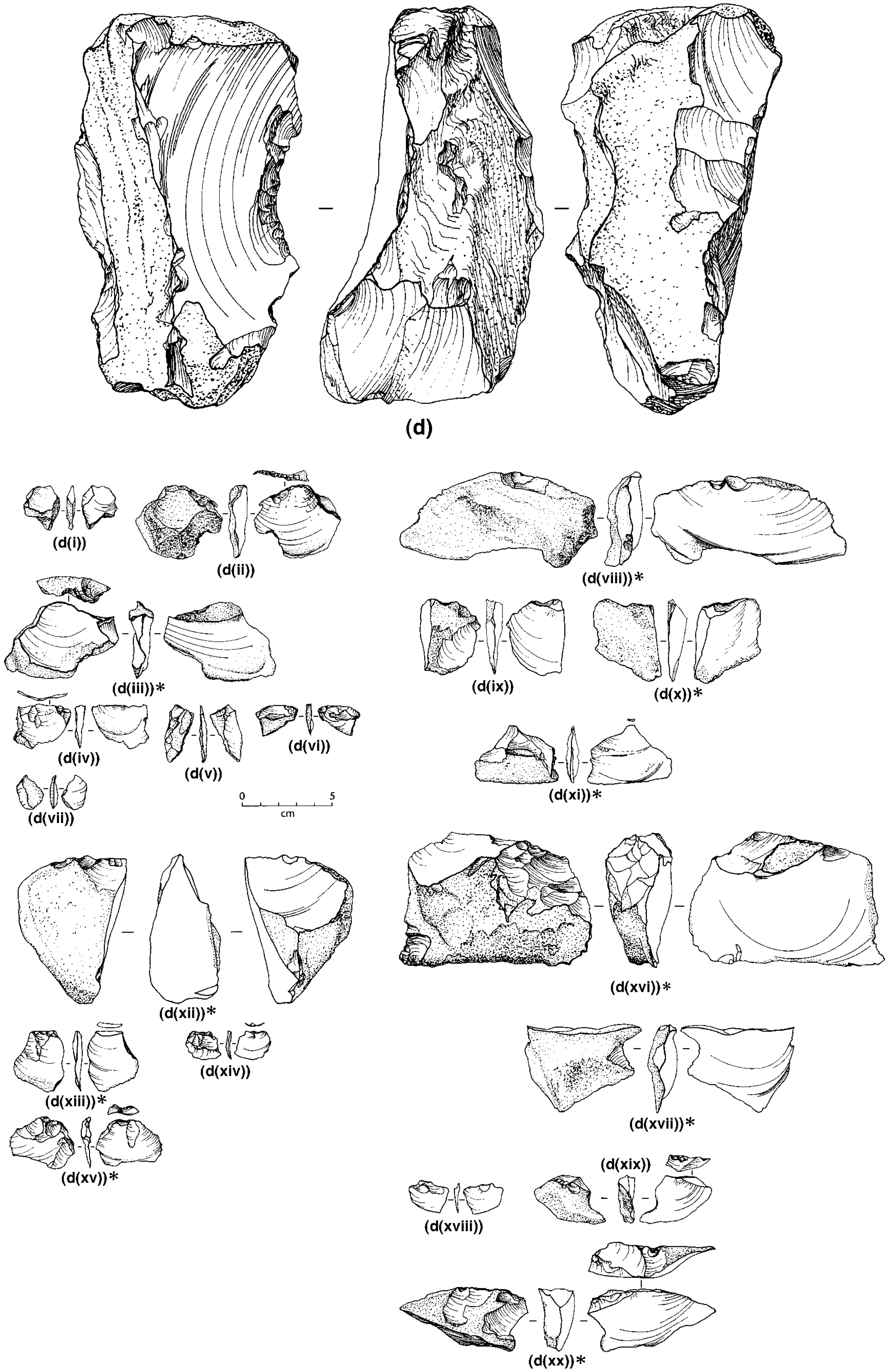
Twelve flaked stone artefacts classified as cores were produced by Kanzi in these experiments (Figure 4 & 5). These cores tend to be technological very simple, primarily produced by throwing. Flaking along core edges tends to exhibit primarily a pattern of unifacial flaking, or a combination of unifacial flaking and some bifacial flaking along an edge. Cores whose edges are predominantly bifacially flaked are not common.

The cores were classified as: eight casual cores (66·7%), or minimally modified cores (called "modified cobbles and blocks" in Mary Leakey's typology and "formless cores" in Glynn Isaac's) (Leakey, 1971; Isaac, 1977) that are hard to assign to any formal typological category. Following Leakey's (1971) typology for Olduvai Gorge, the remaining cores would be classified as three choppers (two bifacial end choppers, and one two-edged bifacial side chopper); and one heavy-duty scraper (Table 2). [Attributes for the two core remnants that would be assigned to typological categories other than cores (a "modified piece" and a "chunk") are shown in Table 3.]

The final core forms produced by Kanzi, of course, represent the morphological end products at the termination of the experimental series in producing flakes with each particular cobble. These cores are generally characterized by a high degree of variability in the degree of reduction and the invasiveness of the flake scars. There is, for instance, a great deal of variation in the number of flake scars, the proportion of cortex remaining, and the mean ratio of the largest flake scar to the size of the core (Table 4). There are few step or hinge fractures on these cores. Unlike Kanzi's earlier cores, which were primarily produced by freehand percussion with a hammerstone, these cores produced by throwing show much less battering along core edges and some bolder, more invasive flake scars.

Interestingly, there was little direct evidence in the morphology or fracture patterning of the cores that


(a)
(b)
(c)
0
5
cm


(d)
(d(i))
(d(ii))
(d(iii))*
(d(iv))
(d(v))
(d(vi))
(d(vii))
0 5
cm
(d(viii))*
(d(ix))
(d(x))*
(d(xi))*
(d(xii))*
(d(xiii))*
(d(xiv))
(d(xv))*
(d(xvi))*
(d(xvii))*
(d(xviii))
(d(xix))
(d(xx))*

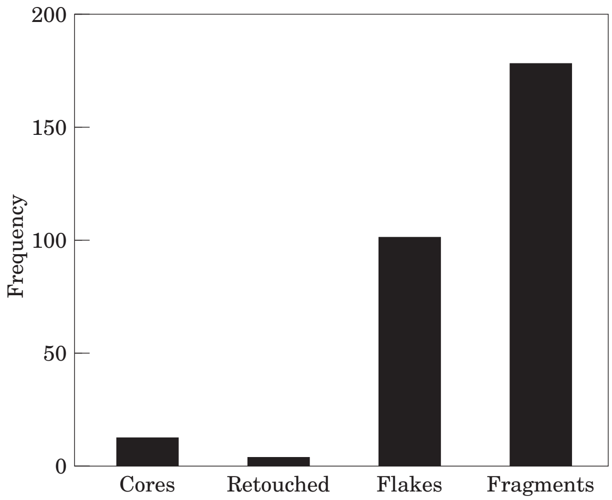


Figure 3. General technological breakdown of the flaked artefacts produced by Kanzi.

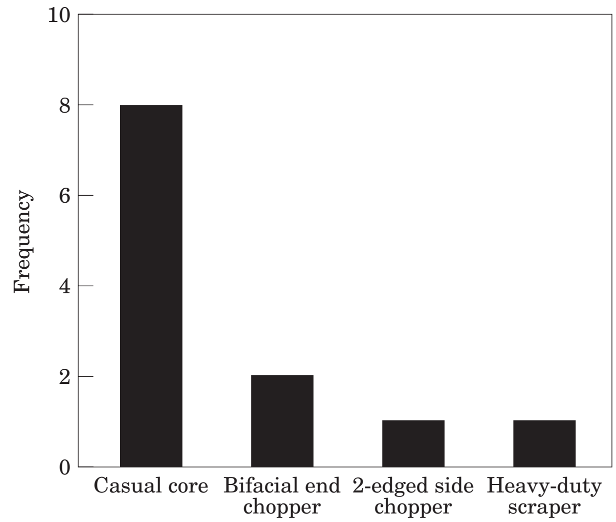


Figure 5. Breakdown of core types produced by Kanzi.

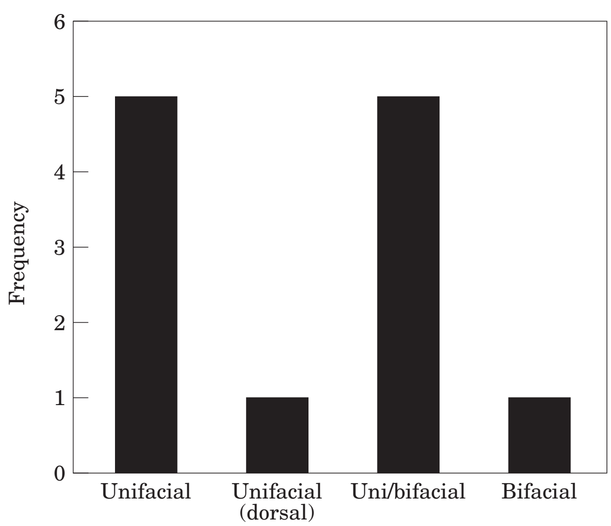


Figure 4. Breakdown of the modes of flaking on cores produced by Kanzi. Note that most cores exhibit either unifacial flaking or a combination of unifacial and bifacial flaking.

would suggest that they were produced by throwing rather than hand-held, hard-hammer percussion. Some notable exceptions to this include two cores that showed incipient cones of percussions several centimetres away from the edge, suggesting a less controlled percussion blow associated with a throwing technique. Also, heavily used hammerstones thrown by Kanzi show much battering over their surfaces (as opposed to more localized battering by freehand percussion) and usually were used until they split in half. These split quartzite hammers did show fracture typical of throwing, including a pronounced point of crushing and a flat release surface with a sheared cone of percussion.

In addition to the artefacts classified as cores, three artefacts were classified as ‘‘retouched/modified pieces’’ as well. These were fragments that exhibited very casual and sporadic chipping along an edge. These pieces would not fit into a formal typological ‘‘tool’’ category, but would tend to be called ‘‘utilized’’ or ‘‘modified’’ in an archaeological assemblage.

Kanzi has not shown any signs of intentially modifying or retouching edges of flakes and fragments to intentially re-sharpen or modify them. In one round of experimentation Kanzi was presented with a set of large flakes that had had superb cutting edges; these edges had, however, been blunted against a stone grinder by the experimenters to make them functionally useless before giving them to Kanzi. He did not attempt to modify these edges with a hammerstone, but simply tried to cut with them, to no avail.

Figure 2. Examples of the artefacts produced by Kanzi. (a) A heavily-used quartzite hammerstone used by Kanzi for throwing and hand-held, direct percussion. Note the battering over much of the surface of the percussor. (b) A chert core produced by Kanzi by throwing, a bifacial end chopper starting to grade into a polyhedron. Note the extensive flaking of the upper face, seen in the top illustration. (c) A large chert core, classified as a bifacial side chopper, produced by Kanzi by throwing. (This specimen was not included in the analysis reported here as it was not part of the controlled reduction experiments, but rather the casual, informal experiments.) Note the similarity to a typical Oldowan chopper-core. (d) A large chert core classified as a two-edged side chopper, produced by Kanzi by throwing. Sequential debitage struck from this core is shown in illustrations (d(i))–(d(xx)). Each flake and fragment actually selected by Kanzi and used for cutting is annotated with an asterisk. Note that used pieces of debitage (tools) tend to be appreciably larger on average than unused debitage. Also note the distinct striking platforms, dorsal scar patterns, and overall size of the debitage.

Table 2. Attributes for technological cores produced in the extended trial experiments

Exp. #	Core wt (g)	Orig. Fm	L (mm)	Br (mm)	Th (mm)	MaxS (mm)	#S >2cm	% Cort	Edge Ang	Mode	Type
1	1619	C	161	131	82	92	8	80	65	U/B	Casual core
2	1071	C	165	94	71	125	10	50	60	U/B	2-edged side chopper
3	604	C	102	74	80	64	9	60	85	U/B	Bifacial end chopper
4a	229	I	101	40	63	63	3	65	90	U	Casual core
4b	330	I	90	68	41	50	3	20	70	U(d)	Casual core
7	1037	C	134	92	86	96	9	60	80	U/B	Casual core
8a	422	C	105	83	66	80	3	80	80	U	Casual core
8b	272	C	78	70	63	70	12	30	75	B	Bifacial end chopper
9a	340	F	111	80	44	44	4	20	80	U	Casual core
9b	214	F	93	81	40	82	7	45	85	U	Casual core
10	431	C	99	84	60	68	9	40	80	U/B	Casual core
11	727	C	102	100	60	68	8	75	85	U	Heavy duty scraper

Orig. Fm=original form; C=cobble; I=indeterminate; F=flake or flake fragment; MaxS=maximum dimension of largest flake scar on core; #S=number of flake scars on core; %Cort=percentage of cortex remaining on core; Edge Ang=minimum edge angle along core; Mode=flaking mode on core; U=unifacial, B=bifacial, U/B=partially unifacial and partially bifacial, d=flaking on dorsal surface of piece. Measured attributes are for the final core forms.

Table 3. Attributes for resultant core or core fragment in two experiments that, on technological grounds, would be placed in other typological categories if found in an archaeological assamblage

Exp #	Wt (g)	L (mm)	Br (mm)	Th (mm)	Type
5	74	66	61	31	Modified piece
6	137	104	42	50	Chunk

Table 4. Mean characteristics of the set of cores produced by Kanzi in this experiment

Core attribute	Mean/ . .	Range
Mean weight	608·0 g (. .=432·9)	[214–1619 g]
Mean maximum dimension	11·2 cm (. .=2·7)	[7·8–16·5 cm]
Mean flake scar number	7·1 (. .=3·1)	[3–12]
Mean amount remaining cortex	52·1% (. .=21·6)	[20–80%]
Mean minimum edge angle	77·9° (. .=8·9)	[60–90°]
Mean scar size/core size ratio	0·68 (. .=0·14)	[0·40–0·90]

Flakes

A total of 101 whole flakes were produced in this experimental assemblage. The flakes are typical of those normally produced by hard-hammer percussion without any intentional platform preparation, with thick striking platforms and prominent bulbs of percussion (Table 5). Because of the amount of force that Kanzi could produce by throwing, some of these flakes are substantial in size (greater than 10 cm in maximum dimension). Flakes were divided into six major types based upon presence and absence of cortex on the striking platform and dorsal surface (Toth, 1985) (Figure 6).

Table 5. Mean characteristics of the set of flakes produced by Kanzi in the experiments

Flake attribute	Mean/ . .	Range
Mean flake maximum dimension	5·30 cm (. .=2·59)	[2·0–13·1 cm]
Mean flake weight	42·5 g (. .=75·1)	[0·5–381 g]
Mean flake length	4·19 cm (. .=2·17)	[1·2–9·8 cm]
Mean breadth/length ratio	1·2 (. .=0·3)	[0·5–2·4]
Mean thickness/breadth ratio	0·3 (. .=0·1)	[0·1–0·7]
Mean # platform scars	1·2 (. .=1·3)	[0–6]
Mean # dorsal scars	2·1 (. .=2·1)	[0–11]
Mean platform core angle	89·7° (. .=18·0)	[50–125°]
Mean platform bulb angle	110·8° (. .=17·6)	[55–145°]

Platform "core angle"=exterior platform angle between platform and dorsal surface; platform "bulb angle"=interior platform angle between platform and ventral surface at bulb.

These were:

Type I: Cortical platform, all cortex dorsal surface;
Type II: Cortical platform, partial cortex dorsal surface;
Type III: Cortical platform, non-cortical dorsal surface;
Type IV: Non-cortical platform, all cortex dorsal surface;
Type V: Non-cortical platform, partial cortex dorsal surface;
Type VI: Non-cortical platform, non-cortical dorsal surface.

Eighty-eight flakes could be assigned to one of these six flake types (the others being indeterminate, usually with shattered or punctiform platforms; Table 6). Kanzi's flakes indicate both unifacial flaking of cobble cores (cortical platforms, types I–III) and especially bifacial flaking of cores (non-cortical striking platforms, types IV–VI). The overall flake distribution is

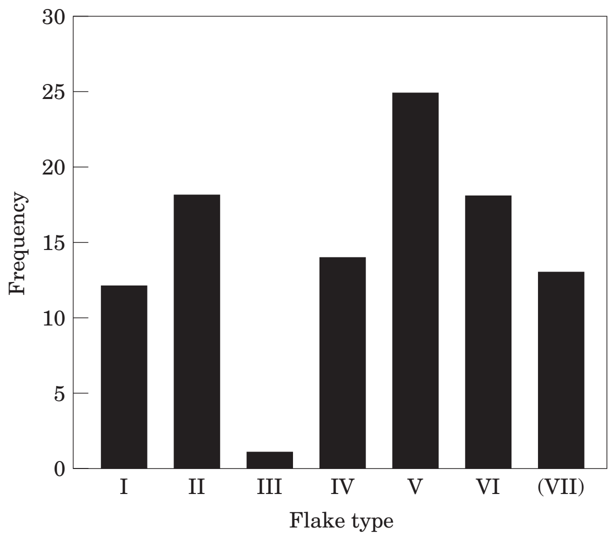


Figure 6. Breakdown of flake types by Kanzi. (Type VII represent whole flakes that cannot be assigned to one of the other types, usually because their striking platforms are too small or punctiform to determine whether they are cortical or non-cortical.)

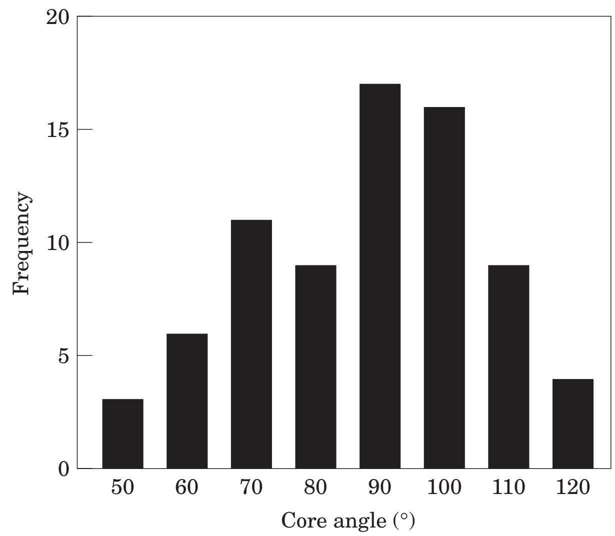


Figure 7. Breakdown of the exterior platform angles ("core angles") on whole flakes. Note that angles of 90° tend to be most common.

Table 6. Proportions of flake types among the whole flakes produced by Kanzi in the experiments

Type	*N*	%
Type I	12	(13·6)
Type II	18	(20·5)
Type III	2	(2·3)
Type IV	14	(15·9)
Type V	25	(28·4)
Type VI	17	(19·3)
Totals:	88	100·0

N=88 flakes attributable to flake types I–IV out of the flake population.
See text for description of flake types.
Note that 13 flakes were also classified as type VII or "indeterminate" flake type and are not included in this tabulation.

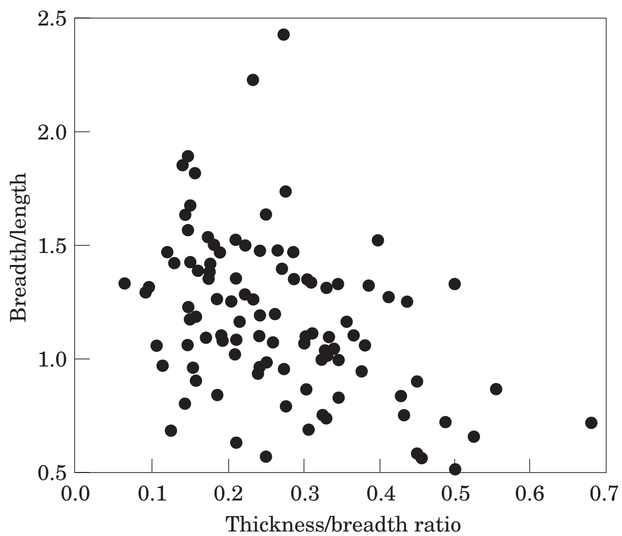


Figure 8. Distribution of whole flakes based on breadth/length and thickness/breadth ratios. Note that flakes tend to be side-struck.

generally consistent with the reduction of cobbles by hard-hammer percussion. An interesting pattern was the low frequency of type III flakes, showing that there was no prolonged unifacial flaking of cortical cobbles. This would be explained by Kanzi's preferential use of the throwing technique, which tends to randomize the precise point of the percussive blow on the core.

In general, Kanzi's flakes are characterized by thick striking platforms (average 1·04 cm), prominent bulbs of percussion with obtuse interior platform angles (average 110·8°, and steep exterior platform angles ("core angles"), averaging 89·7° (Figure 7). These flakes tend to be much larger (average 5·3 cm in maximum dimension and a maximum size of 13·1 cm) than those produced in the first round of experimentation, where the largest flake was only 5·0 cm in maximum dimension (Toth *et al.*, 1993). Flakes tend to be slightly side-struck (average breadth/length ratio is 1·2) (Figure 8), and have relatively few platform scars (average 1·2) (Figure 9) and few dorsal scars (average 2·1) (Figure 10).

Selectivity and tool use

Analysis of the flakes and fragments selected for tools by Kanzi for cutting activities clearly shows that he is preferentially selecting larger, heavier pieces (Figures 11 & 12). The mean maximum dimension of used pieces was 5·31 cm (*N*=123; . .=2·24 cm); for unused pieces the mean was 3·49 cm (*N*=156; . .= 1·90 cm). The mean weight of used pieces was 38·70 g (. .= 75·63 g); for unused pieces the mean was 16·67 g (. .=53·83 g).

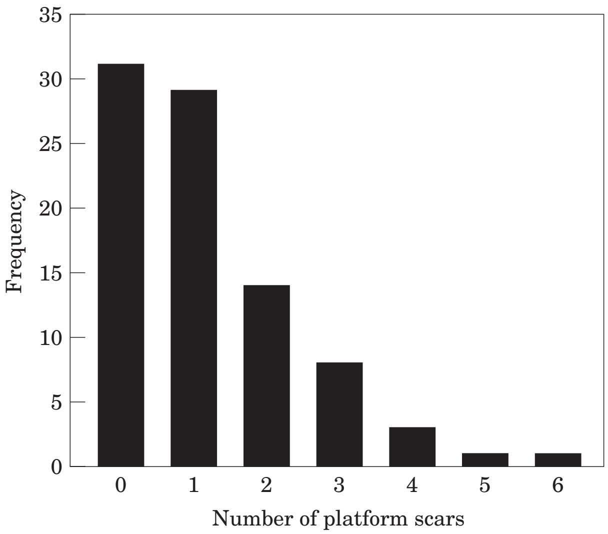


Figure 9. Breakdown of number of platform scars on whole flakes. Note that most flakes have either cortical platforms or plain, single platform scars.

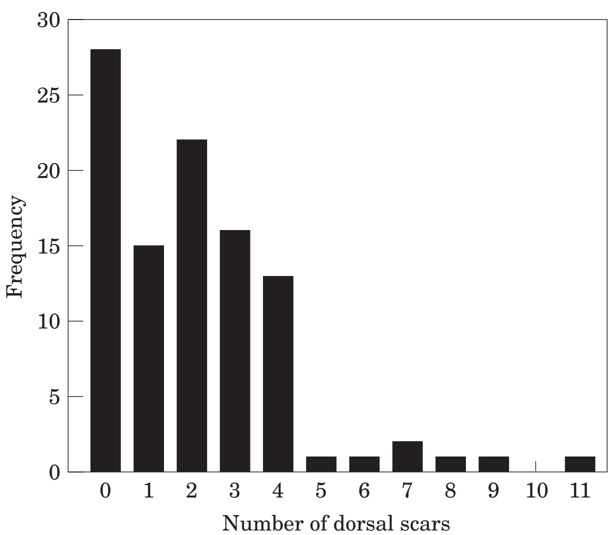


Figure 10. Breakdown of number of dorsal scars on whole flakes. Note the high number of flakes with total cortex on their surface (scars=0).

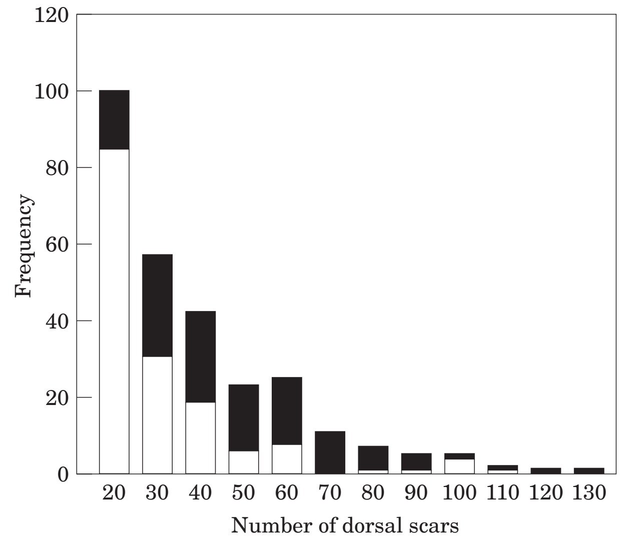


Figure 11. Breakdown of the size of debitage (flakes and fragments) produced by Kanzi. (Lower size cuto for this analysis is 20 mm, approximately the size of the smallest flake or fragment used by Kanzi.) Note that larger pieces tend to be preferentially used. □, Not used; ■, used.

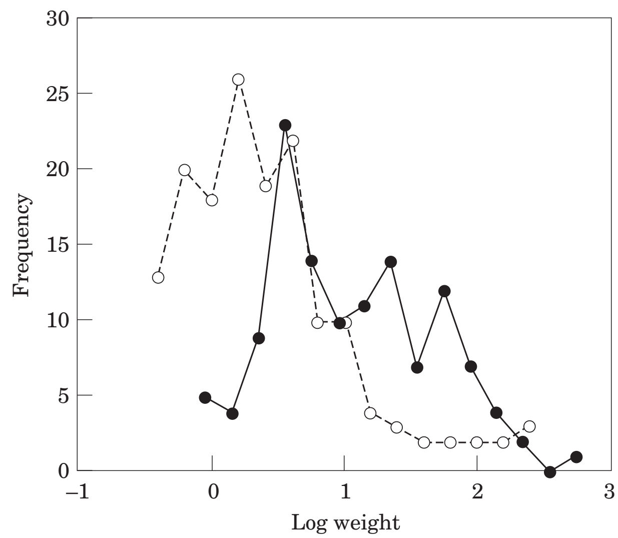


Figure 12. Breakdown of the debitage produced by Kanzi by weight. (Weights indicated on the log scale are as follows: − 1=0·1 g, 0=1 g 1=10 g, 2=100 g, 3=1000 g.) Used pieces are shown by the solid black circles. Note the preferential use of heavier pieces. ●, Used; ○, unused.

It is our impression that Kanzi also has a good sense of the potential usefulness of flakes and fragments as cutting tools. He would normally visually inspect a candidate for a cutting tool (Figure 1), and often put it in his mouth as well, apparently testing edges for sharpness with his tongue. As a crude guide to trying to assess edge sharpness, we measured the minimum edge angle of used and unused pieces with a goniometer. Interestingly, this revealed no statistical di erence (used pieces had mean edge angles of 50·49° (. .=14·51); unused pieces had a mean of 49·10° (. .=17·60). This gross measure of sharpness does not, however, consider the microscopic nature of the cutting edge nor the regularity of the edge, and thus is not a complete reflection of its cutting potential.

In any case, it does seem that Kanzi is clearly preferentially selecting larger, heavier pieces as tools. The mean weight of used pieces is over twice the weight of unused pieces. These larger pieces are easier to hold and on average would produce longer edges for cutting activities.

Discussion and conclusions

The results of this experimentation provides some baseline data on minimum levels of skill in flaking fine-grained siliceous materials by a non-human primate. Future work will expand this data base and will compare these experimentally-produced assemblages with those of early prehistoric archaeological assemblages to assess levels of skill and dexterity.

Kanzi's ability to produce usable flakes has improved markedly over the 3 years of this experimental program. He has learned to throw a hammerstone against a core to increase dramatically the impact force, and he has learned to aim the hammer throw near the edge of a core for more successful flake production. It appears, however, that he is still not exploiting acute angles to e ciently flake cores. This observation is born out in analysis of the core angle on flakes (the angle formed by the striking platform and the dorsal surface of the flake): these angles have a mean of 89·7°, essentially a right angle, the maximum angle which permits these raw materials to fracture. Modern and prehistoric hominid stone knappers normally recognize and exploit more acute angles on cores when using hard-hammer percussion and often produce flakes with exterior flake angles averaging around 80°. Thus, flakes produced by Kanzi in these experiments contrast with ones produced by early hominid tool-makers in their relatively steep core angles.

Kanzi's preference of throwing a hammerstone against a core seems to us to be a solution to his di culty in controlling a forceful, well-directed hammer blow to a core using conventional hand-held hammer percussion (and perhaps also to avoid the possibility of hitting his fingers when holding the core with a hand-held technique). This di culty is probably owing to Kanzi's biomechanical organization as a bonobo and his apparent lack of control when using a hand-held hammer and core.

Kanzi's innovation of throwing and its dramatic e ect on his tool-making e ciency has made us wonder whether very early lithic assemblages in East Africa (*c*. 2·6–2·0 million years ago) might be produced in part by throwing. Close analysis of such archaeological assemblages might yield clues as to whether this technique was common or not in early hominid tool-making behaviour.

Kanzi is clearly selecting larger and heavier flakes and fragments to be used for cutting activities, on average over twice as heavy as unused pieces. He also seems to be assessing sharpness of potential cutting edges by close visual examination as well as by putting the piece in his mouth and apparently testing with his tongue.

Continued experimentation will focus on the use of hand-held, hard-hammer percussion as the predominant flaking technique, as this appears to be the principal technique responsible for very early Palaeolithic occurrences at most African sites. This will provide a more direct comparison between the Early Stone Age archaeological record and experimental studies of flaking by apes. We also plan to give him more di cult materials to flake in the future, such as lavas, quartzes, and quartzites, so that more precise comparisons can be made between this experimental study and the early hominid archaeological record.

Adding more ape subjects to the study is beginning as well. Kanzi's half-sister Panbanisha (an 8-year-old bonobo) has recently started flaking stone, and her progress will be carefully monitored in the future and add to our comparative information. We are also planning to start investigations of common chimpanzees at the Language Research Centre as well.

Acknowledgements

The concept for this research originated at a conference organized by the Wenner-Gren Foundation for Anthropological Research on "Tools, Language, and Intelligence" held in Cascais, Portugal in 1990. Funding for this research came from grants from the Wenner-Gren Foundation for Anthropological Research, the Centre for Research into the Anthropological Foundations of Technology (CRAFT), at Indiana University, and the o ce of Research and the University Graduate School at Indiana University. Additional funding came from a grant from the National Institute of Health (Grant number NICHD06016) to the Language Research Centre, Atlanta (Georgia State University). Support also came from Georgia State University's College of Arts and Sciences. We would also like to thank Judy Sizemore and Tawanna Tookes at the Language Research Centre for their help.

References

Berthelet, A. & Chevaillon, J. (Eds) (1993). *The Use of Tools by Human and Non-Human Primates*. Oxford: Clarendon Press.

Beck, B. B. (1980). *Animal Tool Behaviour*. New York: Garland.

Boesch, C. & Boesch, H. (1981). Sex di erences in the use of hammers by wild chimpanzees: a preliminary report. *Journal of Human Evolution* **10,** 585–593.

Boesch, C. & Boesch, H. (1983). Optimization of nut-cracking with natural hammers by wild chimpanzees. *Behaviour* **83,** 265–286.

Boesch, C. & Boesch, H. (1984). Mental map in wild chimpanzees: an analysis of hammer transports for nut cracking. *Primates* **25,** 160–170.

Boesch, C. & Boesch, H. (1990). Tool use and tool making in wild chimpanzees. *Folia Primatologica* **54,** 86–99.

Davidson, I. & Noble, W. (1993). Tools and language in human evolution. In (K. R. Gibson & T. Ingold, Eds) *Tools, Language, and Cognition in Human Evolution*. Cambridge: Cambridge University Press, pp. 363–388.

Foley, R. A. (1987). *Another Unique Species*. Harlow, Essex: Longman.

Gibson, K. R. & Ingold, T. (Eds) (1993). *Tools, Language and Cognition in Human Evolution*. Cambridge: Cambridge University Press.

Goodall, J. (1986). *The Chimpanzees of Gombe: Patterns of Behaviour*. Cambridge, MA: Belknap.

Goodall, J. & Hamburg, D. A. (1974). Chimpanzee behaviour as a model for the behaviour of early man: new evidence on possible origins of human behaviour. *American Handbook of Psychiatry* **6,** 14–43.

Gowlett, J. A. J. (1984). Mental abilities of early man: a look at some hard evidence. In (R. Foley, Ed.) *Hominid Evolution and Community Ecology*. London: Academic Press, pp. 167–192.

Harris, J. W. K. & Capaldo, S. D. (1993). The earliest stone tools: their implications for an understanding of the activities and behaviour of late Pliocene hominids. In (A. Berthelet & J. Chavaillon, Eds) *The Use of Tools by Human and Non-Human Primates*. Oxford: Clarendon Press, pp. 196–220.

Isaac, G. Ll. (1977). *Olorgesailie*. Chicago IL: Chicago University Press.

Isaac, G. Ll. (1989). In (B. Isaac, Ed.) *The Archaeology of Human Origins: Papers by Glynn Isaac*. Cambridge: Cambridge University Press.

Jones, P. R. (1981). Experimental implement manufacture and use: a case study from Olduvai Gorge, Tanzania. *Philosophical Transactions of the Royal Society of London* **292,** 189–195.

Kibunjia, M. (1994). Pliocene archaeological occurrences in the Lake Turkana basin. *Journal of Human Evolution* **27,** 159–171.

Kortland, A. (1986). The use of stone tools by wild-living chimpanzees and earliest hominids. *Journal of Human Evolution* **15,** 77–132.

Leakey, M. D. (1971). *Olduvai Gorge, Volume 3, Excavations in Beds I and II, 1960–1963*. Cambridge: Cambridge University Press.

Marchant, L. F. & McGrew, W. C. (1991). Laterality in function of apes: a meta-analysis of methods. *Journal of Human Evolution* **21,** 425–438.

McGrew, W. C. (1989). Why is ape tool use so confusing? In (V. Standen & R. A. Foley, Eds) *Comparative Socioecology*. Oxford: Blackwell, 457–472.

McGrew, W. C. (1991). Chimpanzee material culture: what are its limits and why? In (R. A. Foley, Ed.) *The Origins of Human Behaviour.* London: Unwin Hyman.

McGrew, W. C. (1992). *Chimpanzee Material Culture: Inplications for Human Evolution*. Cambridge: Cambridge University Press.

McGrew, W. C. (1993). The intelligent use of tools; twenty propositions. In (K. R. Gibson & T. Ingold, Eds) *Tools, Language, and Cognition in Human Evolution*. Cambridge: Cambridge University Press.

McGrew, W. C. & Marchant, L. F. (1992). Chimpanzees, tools, and termites: hand preference or handedness? *Current Anthropology* **32,** 114–119.

Mithen, S. (1996). *The Prehistory of the Mind: The Cognitive Origins of Art, Religion and Science*. London: Thames and Hudson.

Nishida, T. (1973). The ant-gathering behaviour by the use of tools among wild chimpanzees in the Mahali Mountains. *Journal of Human Evolution* **2,** 357–370.

Nishida, T. (Ed) (1990). *The Chimpanzees of the Mahale Mountains*. Tokyo: University of Tokyo Press.

Oakley, K. P. (1981). Emergence of higher thought 3·0–0·2 Ma . *Philosophical Transactions of the Royal Society of London B* **292,** 205–211.

Savage-Rumbaugh, E. S. (1986). *Ape Language: From Conditioned Response to Symbol*. New York: Columbia University Press.

Savage-Rumbaugh, E. S. (1991). Language learning in a bonobo: how and why they learn. In (N. Krasnegor, D. M. Rumbaugh, M. Studdert-Kennedy & S. Scheifelbusch, Eds) *Biobehavioural Foundations of Language Development*. Hillsdale, NJ: Lawrence Earlbaum, pp. 209–233.

Savage-Rumbaugh, E. S. & Rumbaugh, D. M. (1993). The emergence of language. In (K. R. Gibson & T. Ingold, Eds) *Tools, Language, ad Coqnition in Human Evolution*. Cambridge: Cambridge University Press.

Savage-Rumbaugh, E. S. & Lewin, R. (1994). *Kanzi: The Ape at the Brink of the Human Mind*. New York: John Wiley & Sons.

Savage-Rumbaugh, E. S., McDonald, K., Sevcik, R. A., Hopkins, W. D. & Rubert, E. (1986). Spontaneous symbol acquisition and communicative use by pygmy chimpanzees (*Pan paniscus*). *Journal of Experimental Psychology* **115,** 211–235.

Savage-Rumbaugh, E. S., Sevcik, R. A., Brakke, K. E., Rumbaugh, D. M. & Greenfield, P. M. (1990). Symbols: their communicative use, comprehension, and combination by bonobos (*Pan paniscus*). In (C. Rovee-Collier & L. P. Lipsitt, Eds) *Advances in Infancy Research, Volume 6*. Norwood, NJ: ABLEX Publishing Corporation, pp. 221–278.

Schick, K. D. & Toth, N. (1993). *Making Silent Stones Speak: Human Evolution and the Dawn of Technology*. New York: Simon and Schuster.

Semaw, S., Renne, P., Harris, J. W. K., Feibel, C. S., Bernor, R. L., Fesseha, N. & Mowbray, K. (1996). 2·5-million-year-old stone tools from Gona, Ethiopia. *Nature* **385,** 333–338.

Sugiyama, Y. (1993). Local variations of tool and tool use among wild chimpanzee populations. In (A. Berthelet & J. Chavaillon, Eds) *The Use of Tools by Human and Non-Human Primates*. Oxford: Clarendon Press.

Sugiyama, Y. & Koman, J. (1979). Tool-using and -making behaviour in wild chimpanzees at Bossou, Guinea. *Primates* **20,** 513–524.

Telecki, G. (1974). Chimpanzee subsistence technology: materials and skills. *Journal of Human Evolution* **3,** 575–594.

Toth, N. P. (1982). *The stone technologies of early hominids at Koobi Fura, Kenya: an experimental approach.* Ph.D. Dissertation, Department of Anthropology, University of California, Berkeley.

Toth, N. (1985). The Oldowan reassessed: a close look at early stone artefacts. *Journal of Archaeological Science* **12,** 101–120.

Toth, N. & Schick, K. D. (1986). The first million years: the archaeology of protohuman culture. In (M. B. Schi er, Ed.) *Advances in Archaeological Method and Theory, Volume 9*. Orlando: Academic Press, pp. 1–96.

Toth, N. & Schick, K. D. (1993). Early stone industries and inferences regarding language and cognition. In (K. Gibson & T. Ingold, Eds) *Tools, Language, and Cognition in Human Evolution*. Cambridge: Cambridge University Press, pp. 346–362.

Toth, N., Schick, K. D., Savage-Rumbaugh, E. S., Sevcik, R. A. & Rumbaugh, D. M. (1993). Pan the tool-maker: investigations into the stone tool-making and tool-using capabilities of a bonobo (*Pan paniscus*). *Journal of Archaeological Science* **20**, 81–91.

Wrangham, R. W. (1987). The significance of African apes for reconstructing human evolution. In (W. G. Kinzey, Ed.) *The Evolution of Human Behaviour: Primate Models*. Albany: State University of New York Press.

Wright, R. V. (1972). Imitative learning of a flaked tool technology: the case of an orangutan. *Mankind* **8,** 296–306.

Wynn, T. G. (1988). Tools and the evolution of human intelligence. In (R. W. Byrne & A. Whiten, Eds) *Machiavellian Intelligence*. Oxford: Clarendon, pp. 271–284.

Wynn, T. G. (1989). *The Evolution of Spatial Competence*. Urbana: Universty of Illinois Press.

Wynn, T. G. & McGrew, W. C. (1989). An ape's view of the Oldowan. *Man* **24,** 383–398.