

THE ROLE OF VERBAL INTERACTION DURING EXPERIMENTAL BIFACIAL STONE TOOL MANUFACTURE

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Many researchers have hypothesized an analogous, and possibly evolutionary, relationship between Paleolithic stone tool manufacture and language. This study uses a unique design to investigate how spoken language may affect the transmission of learning to make stone tools and comes to surprising results that may have important implications for our views of this relationship. We conducted an experiment to test the effect of verbal communication on large core biface manufacture during the earliest stages of learning. Previously untrained flintknappers were assigned to two different communication conditions, one with and one without spoken language, and were instructed to replicate the bifaces produced by the same instructor. The attempted bifaces (total = 334) from the two groups were compared using an Elliptical Fourier analysis, the Flip Test, and a rating scale by an independent lithicist. We found no significant difference in the overall shape, symmetry, or other measures of skill among the two groups, using all three of these methods. Analysis of the 18,149 debitage elements from the experiment, however, revealed that the two groups set up their striking platforms in fundamentally different ways. The nonverbal group produced more efficient flakes than the verbal group, as evidenced by the significantly higher ratios of platform width to platform thickness and size to mass of the nonverbal subjects' flakes. These results indicate that verbal interaction is not a necessary component of the transmission of the overall shape, form, and symmetry of a biface in modern human novice subjects, and it can hinder the progress of verbal learners because of their tendency to over-imitate actions of the instructor that exceed their current skill set.

KEYWORDS: *experimental archaeology, skill transmission, flintknapping, emulation vs. imitation, language*

Human language has many important qualities, such as symbolism and hierarchical organization, which set it apart from non-human communication systems (Cheney and Seyfarth 1998; Hauser et al. 2002). Indeed, language is widely considered to be fundamental to the human species (Deacon 1997). Despite considerable research in multiple fields (Christiansen and Kirby 2003; Fitch 2000, 2005), it is unknown when or how this complex system of spoken communication evolved in the human lineage because of the lack of direct fossil evidence (Fitch 2000). Unfortunately, there are few, if any, reliable skeletal markers that can be used to infer the presence of speech or language (for a review of potential fossil cues to speech and language, see Fitch 2000, 2010). The archaeological record of the production of early stone tool technologies, despite inherent limitations (Buckley and Steele 2002), may offer an indirect window into the cognitive and linguistic capabilities of early humans due to the varying levels of skill required to produce different stone tools.

There is accumulating evidence for a praxic exaptation origin for language, meaning that the language neural network may have co-opted the structures and functions already in place for the distal manual motor network (Arbib 2005; Meister et al. 2003; Pulvermüller and Fadiga 2010; Rizzolatti and Craighero 2004; Stout and Chaminade 2012; Uomini and Meyer 2013; Wilkins and Wakefield 1995, 1996). Hierarchical activities involving sequential actions, like tool use and tool production, may have a developmental and evolutionary foundation in Broca's region of the brain (Greenfield 1991; Steele et al. 2012), which also participates in speech production. The Technological Hypothesis of Language Origin asserts that the language circuit in Broca's area of the brain is an exaptation of the original technological praxis network in that same region (Stout and Chaminade 2012). Although Broca's area traditionally has been thought to be an anatomically discrete region of the brain functionally specialized in the production of language, there is

now ample evidence for the overlap of distal manual motor functions in the homologue of Broca's area in non-human primates (Hepp-Reymond et al. 1994; Kurata and Tanji 1986; Rizzolatti et al. 1981, 1988; Tagliabattola et al. 2008) and Broca's area in a broad sense in modern humans (Heiser et al. 2003; Higuchi et al. 2009). Moreover, studies have also shown that the caudal region of Broca's area is activated during the replicative manufacture of Oldowan and Acheulian tools by modern humans (Stout and Chaminade 2007; Stout et al. 2008), and language and stone toolmaking cause common cerebral blood flow lateralization signatures (Uomini and Meyer 2013). Furthermore, it has been found that many aphasic patients also have imitation deficits and apraxia, which causes an inability to perform purposeful movements, such as tool use (Heilman and Valenstein 2002; Iacono and Wilson 2006; Kertesz and Hooper 1982; but see Papagno et al. 1993). These studies substantiate the idea that language and tool use depend on similar biological mechanisms for processing hierarchical information; however, further research is necessary to understand the potential functional relationship between tool manufacture and language in the brain.

If some aspects of language evolved by co-opting the praxis network in Broca's area, which, as already discussed, is known to be activated during the process of Paleolithic stone tool production, it is probable that language and tool manufacture continued to co-evolve, and the increasing complexity of language reinforced the increasing complexity and diversity of technology and vice versa (Ambrose 2001, 2010; Stout and Chaminade 2009). We are aware of only one study to date that has attempted to test the effect of verbal communication on the production of stone tools in modern humans (Ohnuma et al. 1997). In this study, Ohnuma et al. (1997) measured the rates and mean times of acquisition of successful Levallois flake production among a verbal and a nonverbal group (each group consisted of 10 university student subjects) over a period of eight hours in two days. Because these time and rate parameters did not differ significantly between the two groups, the authors concluded that spoken language was not necessary for Levallois flake production in earlier species of *Homo*.

While Ohnuma et al. (1997) admit their results are preliminary, they conclude that earlier human species did not need language based on modern *Homo sapiens* as a direct proxy for the

behavior and cognition of other species. The validity of the analogy between modern humans and earlier hominin species is a long standing debate within the field. Researchers have different perspectives on the usefulness of this analogy. For example, Davidson and Noble (1993) argue that chimpanzees are a better analog for pre-linguistic human ancestors than modern humans. On the other hand, while Toth and Schick (1993) admit that modern humans are not a perfect analog for early hominins in the late Pliocene and early Pleistocene, they argue that investigations into their toolmaking behaviors could prove to be quite valuable for interpreting the past. They suggest an experiment which involves teaching modern humans to make stone tools in two different ways, with verbal and nonverbal instruction, which "might prove to be very informative for inferring levels of communicative sophistication" of pre-anatomically modern hominins (Toth and Schick 1993: 357). While it is important to note that modern humans and their lineal ancestors have been evolving along their own trajectory for hundreds of thousands of years and undoubtedly adapting to different selective pressures since the early Pleistocene, the same can be said for modern apes, whose genes and behaviors are likely even more far removed from those of pre-*sapiens* hominins. We are more inclined to agree with Toth and Schick that modern humans and non-human apes can be informative for providing inferences about past hominin species; however, we are aware of the problems that such analogies present.

It is surprising that Ohnuma et al. (1997) report such rapid rates of acquisition of the Levallois technique (verbal mean = 301 minutes, nonverbal mean = 291 minutes) because it has been argued that "the *connaissance* and *savoir faire* of Levallois knappers clearly constitutes a stock of knowledge that one acquires with years of practice" (Wynn and Coolidge 2004: 474), which is probably why there are relatively few novice Levallois replicative studies. Those that exist report learning periods of months because of the high level of skill involved (Eren et al. 2011A, 2011B). Nonetheless, Moore (2010) argues that the Levallois is a much simpler technology than is often assumed. He argues that simple flake unit chaining can lead to results that resemble higher-order architecture and predetermination. Clearly, the complexity of the Levallois and the length of time it takes to acquire such a technique is an unresolved debate.

There is reason to believe that verbal instruction may play an important role during the

transmission of knowledge related to the bifacial reduction of stone tools. Stout (2002) points out that verbal interaction between apprentice and expert plays a large role in the learning process of modern bifacial adze making in Indonesian Irian Jaya, especially when communicating complex, technological concepts. Arguably, the transmission of this skill may be extremely difficult without verbal instruction. Therefore, we posit that the effect of verbal interaction on the production of stone tools can be tested. We propose that the transition from learning simple flake removal to bifacial flaking offers a more reliable test than the Levallois technique for the effect of verbal interaction on stone toolmaking. Bifacial reduction is a relatively complex cognitive task, requiring the coordination of ongoing hierarchically-organized action sequences (Stout and Chaminade 2009), but it can be acquired over a period of days, instead of months, of practice (Shea 2006). For these reasons, we should be able to see any effect verbal interaction has on the final products within the early stages of skill transmission.

To test the effect of verbal communication on the early stages of transmission of bifacial knapping in modern humans, we conducted an experiment in which participants with no prior flintknapping experience were differentially taught to make large bifacial cutting tools. We divided the randomly assigned participants into two trial groups; one group was taught how to flintknapping using spoken language, while the other group learned in a nonverbal environment. We predicted that we should see no difference in the resultant bifaces and debitage between the two groups if verbal interaction does not play an important role in the transmission of the complex action sequence of bifacial reduction.

MATERIALS AND METHODS

EXPERIMENTAL DESIGN AND PROCEDURE

The 24 participants were divided based on schedule availability into verbal (seven females and six males) and nonverbal (seven females and four males) groups in order to learn how to produce bifaces similar to those produced by an instructor. None of the participants had any prior flintknapping experience. The participants ranged from 18 to 25 years old, except for one outlier who was 46 years old. This study was approved by the Institutional Review Boards and Human Subjects Office at the University of Iowa (IRB ID#

201008790). All subjects gave written informed consent prior to the experiment. Participants were not compensated.

One of the authors (Woods), who has conducted replicative flintknapping for more than a decade, was the instructor for both groups. Both groups met with the instructor separately to practice flintknapping for one hour, once a week, for five weeks. Each session was video recorded and consisted of a quick demonstration, after which the instructor would circle the room assisting the participants. Each week, both groups had identical learning goals to meet, which progressed in order of difficulty from recognizing ideal angles and making flakes, to producing alternate, bifacial flaking, to shaping completed bifaces. In the verbal group, the goals to achieve each session and all attendant advice and information were conveyed via spoken communication, and by example. Participants in the nonverbal group received no spoken instructions at all; they had to infer the goals for each session based on observing and mimicking the instructor. All assistance to the nonverbal group was provided in the form of handling rocks, pointing, and knapping demonstration. Each participant's flaking debris was kept separate, and at the end of each session, each participant's cores and bifaces were collected along with his/her debitage. The debitage was then gently screened through a ¼ inch mesh, and all pieces which passed through the screen were discarded prior to labeling and analysis.

MATERIALS

Participants flaked two different raw materials depending on the week of the study. During the first four weeks, the participants were allowed unrestricted access to large plastic bins of heat-treated Burlington chert, a fine- to medium-grained stone that is easy to flake (Hoard and Anglen 2003). These rocks were provided to the participants largely without cortex in the form of large to medium chunks and pre-made spalls. During the final week, participants were each allowed to choose one piece from a selection of Pedernales flint from Texas. This flint was of higher quality than the Burlington chert, meaning there were fewer faults within the rock, but it was not heated and required more force to fracture.

BIFACE ASSESSMENT

All attempted bifaces (total $n = 334$) produced by the verbal and nonverbal groups were evaluated

and scored by an independent assessor, Dr. John Whittaker (Grinnell College, IA), who ranked them in terms of overall quality and the requisite skill attendant with production. Whittaker is an experienced lithic specialist with technical expertise in prehistoric technologies, flintknapping, and stone tool analysis (e.g., Whittaker 1994; Whittaker and Kaldahl 2001; Whittaker and McCall 2001). By design, he had no prior knowledge about the experiment, and all labels indicating that he was evaluating material from two different groups were masked. He ranked all cores produced from the experiment on a scale of 1 to 10, with 1 being representative of very poor quality and not even formally qualifying as a biface, and 10 being representative of the best bifaces within the sample.

Key qualities Whittaker used to categorize the bifaces included overall degree of shape symmetry, the degree to which the knapper made the edge bifacial, and the extent of corpus thickness. These measures reflect standardization of production because of their conformance to the bifaces produced by the instructor during demonstrations (Figure 1). Plan-view symmetry, regularity of form, and corpus thinness are regularly cited characteristics of stone tools that indicate high levels of skill (e.g., Bamforth and Finlay 2008; Root 2000; Whittaker 1987). The highest ranking bifaces were thus combinatorially thin, symmetrical, and bifacially worked. Whittaker also factored in an assessment of the number of edge flakes removed and the length of the bifacial edge for his final ranked scores. The higher ranked bifaces had long, straight bifacial edges and a relatively high number of successful edge flakes removed, while the lower ranked attempted bifaces reflected the original shape of the raw material with evidence for unsuccessful attempts to take off flakes and little to no bifacial edge (Figures 2 and 3). Whittaker was also asked to rank only the final session bifaces ($n = 24$) on a scale of 1 to 10, with a score of 1 representative of a core that does not even qualify as a biface and a score of 10 that is representative of skilled craftsmanship.

Because of the subjective characteristic of Whittaker's analysis of overall quality and attendant skill manifested by bifaces, we found it prudent to also conduct quantitative analyses on symmetry and plan-view shape to confirm some of Whittaker's measures. Symmetry in the archaeological record is associated with skilled craftsmanship and has also been linked with evolving cognition (Wynn 2002). The Flip Test was used to provide



FIGURE 1. An example of one of the bifaces produced by the instructor during the experiment which the participants were to try to imitate. This biface has an index of asymmetry score of 3.36.

a numerical measure of asymmetry for each biface produced from the last two sessions in the experiment (Hardaker and Dunn 2005). The Flip Test is an analytical method that flips the tool over its vertical axis and assesses the amount of deviation from perfect symmetry. Mathematically, this calculation is expressed as $500(A)/(H+W)^2$, where A is the number of asymmetrical pixels, H is the maximum height, and W is the maximum width of the tool. We excluded cores from prior sessions because the participants were not consistently producing bifaces until the fourth session; therefore, any measure of asymmetry would be meaningless.

The overall shape of the biface plan-views from the final two sessions was compared between the two groups by performing an Elliptical Fourier Analysis (EFA). EFA is a method used to describe the outline of a two-dimensional closed or open curve by fitting elliptical Fourier harmonics to an outline (Kuhl and Giardina 1982; Lestrel 2008). Each harmonic is described by four coefficients, which are derived from the x and y coordinates of a particular shape outline. The outline can be described in more detail with each additional harmonic. While EFA is able to describe complex shapes, it is also useful for identifying subtle differences among similar oval shapes (e.g., Seiffert and



FIGURE 2. Examples of relatively low-quality bifaces with ranked scores falling between 1–4 shown in facial view (a), and in side view (b).

Kappelman 2001). EFA is a common technique in biology and paleontology (e.g., Lestrel 2008; Renaud et al. 1996) and has recently been applied to lithic artifacts in the archaeological record (e.g., Iovita 2010; Iovita and McPherron 2011; Saragusti et al. 2005).

Measurements were derived from digital photographs of each biface, which were taken in plan-view at a 90° angle. EFA requires every object to be oriented in the same direction in the photograph, and as others have noted, this is a very

difficult task (Iovita and McPherron 2011; McPherron and Dibble 1999), especially when dealing with the products of novice flintknappers. All bifaces were oriented with the tip facing the left side of the picture. For those products that lacked a tip, the tool was oriented with the widest portion towards the right side of the picture. The shape outline was placed on a Cartesian grid, and points along the outline were given x and y coordinates (Hammer and Harper 2005). Using SHAPE software (Iwata and Ukai 2002), we extracted



FIGURE 3. Examples of relatively high-quality bifaces with ranked scores falling between 8–10 shown in facial view (a), and in side view (b).

the x and y coordinates by first using ChainCoder to record the contour of the objects as a chain-code (Freeman 1974) and then Chc2Nef to calculate the normalized elliptic Fourier descriptors from the chain-code. Finally, to describe the morphological features of the tools, we performed a Principal Component Analysis (PCA) of the normalized elliptic fourier descriptors.

DEBITAGE ANALYSIS

Following screening, all collected debitage elements (total count = 18,149 pieces) were labeled and analyzed. Each piece was weighed to the nearest tenth of a gram, measured for maximum thickness to the nearest millimeter, and allocated to a metric size category continuum

as defined by the smallest of a series of nested squares on centimeter graph paper into which the piece would completely fit (i.e., 1, 2, 3 cm²..., etc.). To discern any differences in skill at raw material selection between the groups, both raw material quality and the presence of faults were recorded for each debitage piece. As raw material quality can be very difficult and time consuming to quantify (Woods 2011), the quality of each debitage piece of material was simply coded either as “high”, “low”, or “mixed” (for analytic purposes “mixed” quality was considered “low”). The presence of faults as evidenced by cracks or surficial mineral staining on flat interior surfaces was noted. Each piece was coded as a flake (either proximal or distal), or nonflake debitage shatter (Andrefsky 2005). Proximal flakes were determined by the presence of an intact striking platform and a bulb of percussion, while distal flakes were determined by the presence of recognizable ventral and dorsal surfaces. We classified any angular pieces with no clear ventral or dorsal surfaces as nonflake debitage shatter. The maximum length and width of striking platforms were also collected. These measures provided a means to examine several aspects of flake and shatter dimensions, material quality, and platform setup as key factors in this analysis. All statistical analyses were performed using SPSS (IBM Corp., 2010) and NCSS (Hintze 2001).

RESULTS

While the use of two different raw materials was not ideal, it was, in the end, necessary. The 24 novices produced 114 kg of debitage over five weeks, not including the cores. By the final week, they exhausted the originally large stock of Burlington chert, and Pedernales flint had to be substituted from the instructor’s personal supply. No significant difference could be found between the volume of the flint nodules provided to both groups during the final week (*t*-test, $t = -0.991$, $p = 0.33$). Because both groups always had the same quantity and quality of stone at the same points in learning, and it has been argued that knapper skill may have more to do with successes and failures than stone quality (Eren et al., 2011b; Sharon 2008; but see Clark 1980), it is our interpretation that this shift in raw material had little effect on the results.

BIFACE ASSESSMENT

Analysis of the attempted bifaces produced in the course of this experiment reveals that access to

verbal instruction does not have a significant effect on the overall quality of the biface, including symmetry and shape. We evaluated the biface rankings from all sessions combined (total $n = 334$), as well as those from only the final flintknapping session (total $n = 24$) in order to assess biface quality in both trial groups throughout the experiment (aggregate), as well as for only those bifaces manufactured with the highest level of experience (final flintknapping session only). In terms of the aggregate sample comparisons, the total range of biface quality scores was similar for both groups, ranging from 1 to 10 in the nonverbal group and 1 to 9 in the verbal group. The nonverbal group had slightly higher mean and median quality scores (4.18 and 4.0 respectively) than the verbal group (3.94 and 3.5 respectively). In terms of the final flintknapping session sample comparisons, the total range of biface quality scores was reduced slightly from 2 to 8 in both groups, and the nonverbal group again had slightly higher mean and median quality scores (4.3 and 4.0 respectively) than the verbal group (3.29 and 3.0 respectively). Nonetheless, and most importantly, in both cases (the combined aggregate across all sessions, and the final session biface end-products), the verbal and nonverbal groups were not statistically significantly different from each other in their assessed biface quality scores (Table 1 and Figure 4).

The results of the Flip Test exhibit a similar pattern to the qualitative ranking analysis in that the nonverbal group produced lower mean scores of asymmetry (i.e., more symmetrical bifaces) than the verbal group. We found no significant difference in symmetry between the two distributions (Table 2). Index scores ranged from 28.52 to 1.99 in the entire sample of bifaces from the final two practice sessions ($n = 96$). Hardaker and Dunn (2005) provide a table to help interpret the Flip Test scores, with scores ranging from 1 (virtually perfect symmetry) to 6 and above (very low symmetry). Using this table as a guide, a score of 1.99 is considered to be a very high level of symmetry, representing an exceptionally skilled craftsman. Only about 26 percent of the specimens could be considered average to highly skilled work. The rest of the specimens are interpreted as having low to very low symmetry. There is a decrease in median asymmetry scores for both groups from the fourth to the fifth practice session, indicating an improvement in this specific skill over time (Figure 5).

TABLE 1. SUMMARY OF QUALITY SCORE RANKINGS FOR BIFACIAL CORE PRODUCTS

	Verbal			Nonverbal			Prob [†]
	n	Mean	SD	n	Mean	SD	
Aggregate end products	158	3.94	1.94	176	4.18	1.87	0.1537 ns
Final session end products	14	3.29	1.64	10	4.30	1.95	0.1634 ns

[†]Probability results for equal means via Mann–Whitney *U* tests following non-normal distributions with equal variances. ns, not significantly different. One subject assigned to the nonverbal group participated in all flintknapping sessions except the final session, and thus did not produce a final handaxe. Also, one subject in the verbal group accidentally snapped the final biface in two and subsequently bifacially flaked both halves. These two factors account for the slight difference in sample sizes reported for final session end products here, with the debitage sample sizes reported in Table 4.

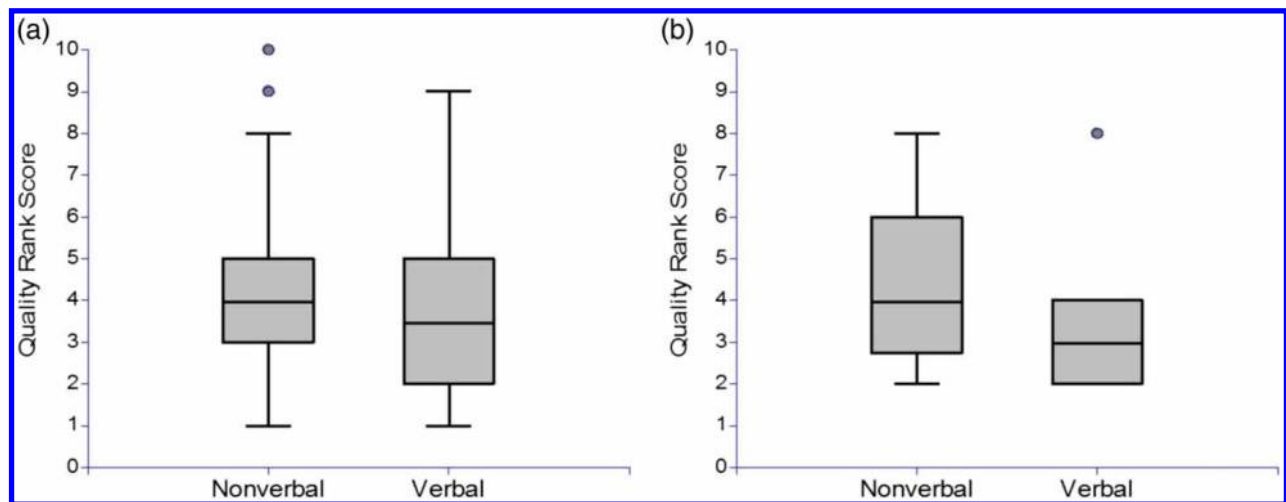


FIGURE 4. Boxplot distribution of (a) quality rank scores by group for the total aggregate number of bifaces from all five flintknapping sessions ($n = 334$), and (b) the scores for the final session bifaces only ($n = 24$). In both cases, the groups were not significantly different (see Table 1).

We found no significant differences in outline shape of the bifaces between the verbal and nonverbal groups for Principal Components 1–7 (see Table 3 for harmonic descriptions). The first seven elliptic fourier descriptors explain 93.5 percent of the total variance of shape. These results are in concordance with Whittaker’s qualitative analysis and the Flip Test. PC 8 (1.5 percent of total variance), which represents the degree of

base roundedness, was found to be statistically different between the verbal and nonverbal groups.

DEBITAGE ANALYSIS

Even though we found no significant difference in quality between the bifaces from the verbal and nonverbal groups, there is striking evidence from

TABLE 2. SUMMARY OF FLIP TEST

	Verbal			Nonverbal			Prob [†]
	n	Mean	SD	n	Mean	SD	
Week 4 Bifaces	29	9.57	5.22	43	7.68	4.66	0.060 ns
Week 5 Bifaces	14	7.91	4.32	10	7.78	5.3	0.371 ns
Total	43	9.03	4.96	53	7.7	4.73	0.090 ns

[†]Probability results for equal means via Mann–Whitney *U* tests following non-normal distributions with equal variances. ns, not significantly different.

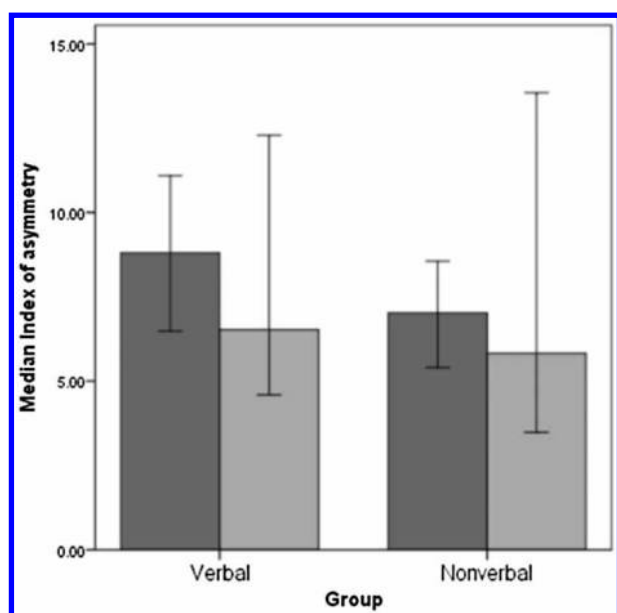


FIGURE 5. Median asymmetry index scores for the verbal and nonverbal groups from the fourth practice session (dark grey) to the fifth session (light grey). Error bars represent 95 percent confidence intervals.

the debitage analysis that the verbal environment affected the transmission of certain concepts. While both groups produced the same overall ratio of shatter to flakes, showed similar skill in selecting raw material as defined by the ratio of flakes to shatter produced on high or low quality stone, and broke nearly the same overall mass of rock over the duration of five weeks (verbal = 56,775.6 g, nonverbal = 56,991.4 g), the nonverbal group produced significantly more lithic debitage elements (nearly twice as many as the verbal group). Moreover, the verbal group set up significantly larger striking platform areas than the nonverbal group, resulting in significantly larger, more

massive flakes in terms of mass, flake size, and flake thickness (Table 4 and Figure 6).

Skill was measured by the ratio of platform width to platform thickness, the ratio of flake size to flake mass, and by the frequency of missed hits, as evidenced by incipient cones and crushed areas on the flakes and shatter. The nonverbal group's overall mean ratio for platform width to platform thickness was significantly higher than that of the verbal group (Table 4). As a result, the ratio for flake size to flake mass was also significantly higher in the nonverbal group (Figure 7). Increased platform width relative to platform thickness increases the ratio of surface area to flake thickness, thus making the flake more efficient (Dibble 1997). Learning differences were apparent between the two groups from the very first week and continued throughout the five sessions. This was most obvious in the ratio of flake size to flake mass. The nonverbal group ratio of size to mass was significantly higher ($p < 0.001$) than the verbal group for all five sessions (Figure 8). Moreover, the nonverbal group showed significant improvement between some individual sessions and overall (Games-Howell, $p < 0.001$), while the verbal group only showed significant improvement from Week 1 to Week 5 (Games-Howell, $p = 0.001$) but displayed no significant improvement between individual sessions. The overall number of incipient cones and crushed areas on the debitage was significantly higher for the verbal group than the nonverbal group. Incipient cones are caused by striking a platform with an angle of more than 90 degrees or by misestimating the amount of force required to fracture the stone (Whittaker 1994), and they usually occur at higher frequencies among less experienced flintknappers (Bamforth and Finlay 2008; Finlay 2008).

TABLE 3. SUMMARY OF PCA FROM ELLIPTICAL FOURIER ANALYSIS

	Description	Proportion of variance (%)	T Statistic	Prob [†]
PC1	Elongation	51.9	0.22	0.828 ns
PC2	Center width	19.6	0.857	0.400 ns
PC3	Tip width	10.1	1.275	0.216 ns
PC4	Base width	4.4	0.66	0.516 ns
PC5	Degree of Side A center-tip convexity	3.1	-0.661	0.516 ns
PC6	Degree of base convexity	2.5	1.003	0.327 ns
PC7	Degree of side B center-tip convexity	1.9	0.133	0.895 ns
PC8	Degree of base roundedness	1.5	2.166	0.041*

[†]Student's *t*-test. Significant at * $p < 0.05$; ns, not significantly different. The *t*-test is based on comparisons of the means for the individual PC scores for each component between the two trial groups.

TABLE 4. SUMMARY OF AGGREGATE DEBITAGE ANALYSIS

	Verbal (<i>n</i> = 13)		Nonverbal (<i>n</i> = 11)		Prob ¹
	Mean	S.D.	Mean	S.D.	
Total debitage elements (counts)	6,690	–	11,459	–	<0.00001 ***
Total debitage mass (kg)	56.78	–	56.99	–	0.9203 ns
Maximum flake thickness (mm)	6.58	1.36	5.10	0.61	0.0039 **
Flake mass (g) ²	7.45	3.42	4.35	1.22	0.0259 *
Flake size (cm ²) ²	3.35	0.42	2.94	0.18	0.0058 *
Platform area (mm ²)	95.33	37.08	62.16	16.69	0.0201 *
% Shatter	16.04	4.09	15.74	4.83	0.8708 ns
% Flakes	83.78	4.10	84.15	4.83	0.8399 ns
% Flakes on high quality stone	86.1	4.49	84.76	4.46	0.4751 ns
% Shatter on high quality stone	13.9	4.49	15.24	4.46	0.4754 ns
% Flakes on low quality stone	79.75	5.58	83.24	7.67	0.2102 ns
% Shatter on low quality stone	20.25	5.58	16.73	7.62	0.2056 ns
Ratio of pWidth to pThickness	4.05	2.78	4.15	2.65	<0.001 ***
Ratio of flake size to flake mass ²	3.11	4.19	4.17	4.83	<0.001 ***
Missed hits/hammer marks	0.22	0.895	0.14	0.776	<0.001 ***

¹Probability results for equal means via *t*-tests in the case of normal distributions and equal variances, the Kolmogorov–Smirnov test in the case of non-normal distributions and unequal variances, and the Mann–Whitney *U* test in the case of non-normal distributions and equal variances. For total debitage counts, the probability result is based on the exact binomial test for equal proportions. Significant at **p* < 0.05, ***p* < 0.005, ****p* < 0.001; ns = not significantly different.

²Trait for which an additional test (F-test on the ratios of the variances of the log-transformed traits between the verbal and nonverbal samples following Lewontin, 1996) was conducted to test the possibility that inherent skill differences among individuals between groups may have influenced these mean values (see discussion section). This procedure, which tests the null hypothesis of equal coefficients of variation as elaborated by Lewontin (1966) has advantages over the use of the standard coefficient of variation (SD/Mean). No statistically significant differences were found for the three variables of interest here (all resulting values ranged between *p* > 0.10–0.50).

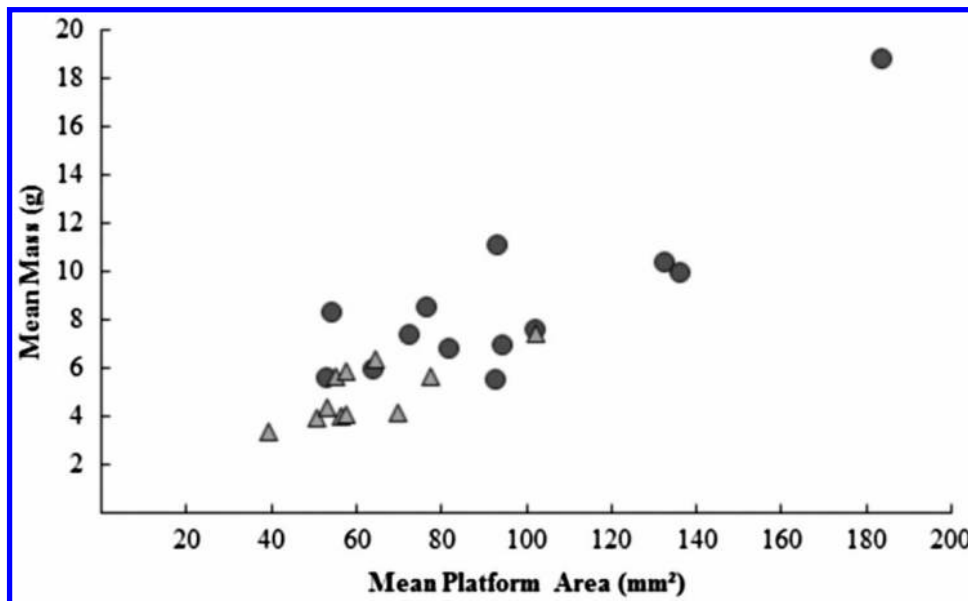


FIGURE 6. The relationship between the mean mass and mean platform area of flakes produced by participants in the verbal (circles) and nonverbal (triangles) groups. The groups are significantly different in both variables (see Table 2) whether or not the outlier for both variables in the upper right portion of the bivariate plot is retained. There is a significant positive correlation between the two variables when all the participants are included (*r* = 0.87; *p* < 0.001), as well as when the outlier is removed (*r* = 0.75; *p* < 0.001).

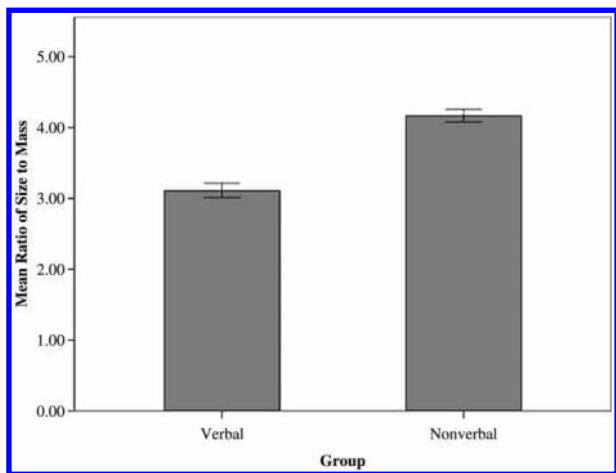


FIGURE 7. A comparison of the mean ratio of flake size to flake mass between the verbal and nonverbal groups, clearly demonstrating a significant difference between the two groups (error bars represent 95 percent confidence intervals). A higher ratio of size to mass is the result of a higher ratio of platform width to platform thickness.

DISCUSSION

The hypothesized prediction that a group of novice flintknappers in a spoken language-based learning environment will produce significantly different large core bifacial tools from a similar group deprived of spoken language is not valid. This leads us to the more general conclusion that the overall shape and form of the biface, and the concept of symmetry during stone tool reduction,

can be transmitted via verbal or nonverbal communication in modern human novices. This result supports other lines of evidence that toolmaking knowledge can be transmitted nonverbally (Coolidge and Wynn 2005; Dunbar 2003; Gardner 2002; Gatewood 1985; Keller and Keller 1996).

The attributes of biface quality we chose for comparison of the two groups (plan-view shape and symmetry, corpus thickness, and bifacial edge length) are often used to describe the standardization, and thus, the attendant skill required for production, of stone tools in the Lower Paleolithic archaeological record. It is now generally agreed upon that Acheulian handaxes increased in symmetry through time (Saragusti et al. 1998; Wynn 2002), and there was selection for increased symmetry, likely because it improved the efficiency and functionality of the tool (Lycett 2008; Mitchell 1996; but see Machin et al. 2007). While it is important to note how our measurements of skill relate to the archaeological record, we wish to stress that the participants in this study were not replicating specimens from the archaeological record. Instead, they were trying to replicate the large core bifaces produced by the instructor, which were consistently symmetrical, thin, and bifacially worked. Furthermore, these attributes were emphasized by the instructor as goals for the participants to try to meet, which is why these are the attributes of biface quality we sought to measure and compare between groups.

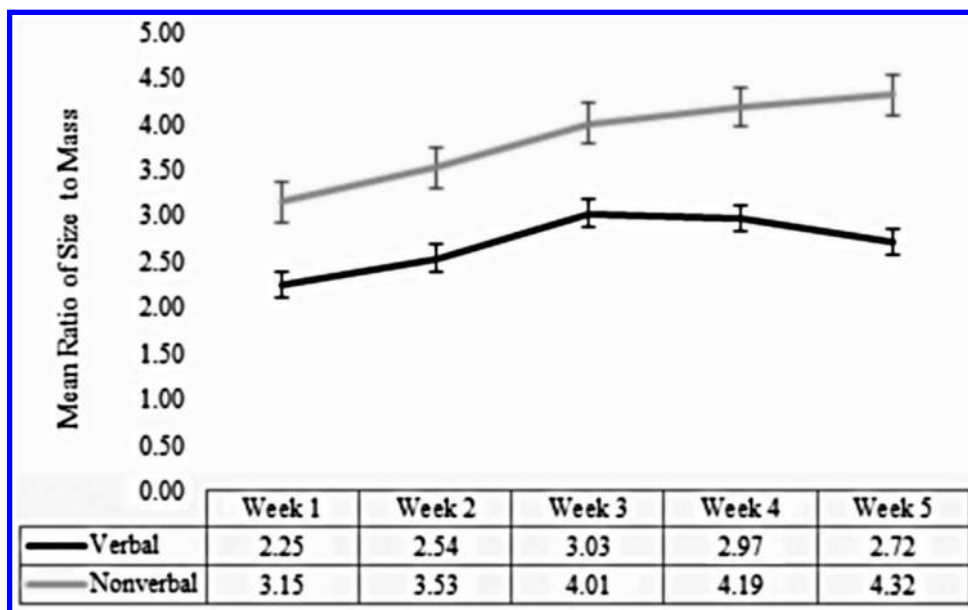


FIGURE 8. A comparison of the mean ratio of flake size to flake mass between the verbal and nonverbal groups from individual practice sessions.

Despite similarities in their final bifacial products, analysis of the debitage from this experiment revealed that the verbal and nonverbal groups flintknapped in fundamentally different ways. These differences were almost entirely the result of variation in how the two groups set up their striking platforms. The verbal group set up and utilized significantly larger striking platforms, which resulted in the production of significantly larger, more massive flakes than those produced by the nonverbal group. Platform size has previously been shown to correlate with flake size (Dibble 1997), which is consistent with our findings (Figure 6). The nonverbal group flakes, however, had significantly higher ratios of platform width to platform thickness and size to mass, which mean the participants in the nonverbal group produced arguably more efficient flakes in that they were both large and thin (Dibble 1997). The nonverbal group also showed marked improvement in flake efficiency week to week, while the verbal group showed only gradual improvement and some backsliding (Figure 8). While the verbal group produced larger flakes on average than the nonverbal group, they were also much thicker, signifying that the verbal flintknappers may have had less control over platform size. This result is further supported by their significantly higher frequency of incipient cones on the debitage, which means they had more failed attempts to remove flakes. On the other hand, the participants in the nonverbal group produced a much larger frequency of debitage than the verbal group, which may be the result of misjudgment of the amount of force required for flake detachment. This is a characteristic of novices attempting any kind of lithic reduction (Milne 2013; Shelley 1990). Participants in the verbal group were more economic in their core preparation, meaning they produced fewer flakes to reach the same end goal, which may be a sensitive marker of skill (Eren et al. 2011a).

These results indicate that bifacial knapping can be transmitted quite successfully in a nonverbal learning condition. In fact, the presence of verbal interaction during the transmission of bifacial knapping may actually hinder the novice's progress toward producing more efficient flakes, at least in the early phases of learning. It could be argued that the verbal group had less practice than the nonverbal group because they spent more time receiving instructions and asking questions and not striking platforms, and this could explain our results; however, from our analysis

of videotaped sessions, we found that the amount of time the instructor spent demonstrating and instructing (speaking or gesturing, depending on the group) did not significantly differ between the verbal and nonverbal groups (*t*-test, $t = 1.593$, $p = 0.162$). Thus, there must be another explanation for why novices who learned to flintknape nonverbally produced so many more flakes and showed more facility in managing platform dynamics.

The pattern that emerges from these data is the occurrence of more experimental flake detachment among nonverbal flintknapping novices to reach the goal of a symmetrical, large core biface, and the setup of more ambitious platforms among verbal flintknapping novices to reach the same goal. These results present an interesting parallel with current comparative and developmental psychology literature on the issues of emulation vs. imitative learning and their role in cultural transmission among human and non-human apes (see Whiten et al. 2009 for a review). Emulation refers to a process by which an observer learns from the results of a model's actions, rather than the details of the actions leading up to these results (Horner and Whiten 2005; Tomasello et al. 1987). In contrast, imitation is broadly defined as copying a model's behavior, both the methods and results (Horner and Whiten 2005), and when an observer reproduces the actions of a model with such high fidelity that the efficiency of the task is reduced, this phenomenon is known as over-imitation (Lyons et al. 2007; McGuigan et al. 2007, 2011). When interpreting the results of this experiment, it is apparent that the verbal participants more faithfully imitated the instructor, to the point of over-imitation, by devoting more time to setting up ambitious platforms that, in the end, were too difficult to execute at this early a stage of learning. Thus, their task efficiency was reduced, as is evidenced by their higher frequency of missed hits and thick flakes.

Over-imitation was first described in children, and it was thought that this blanket copying would decline with age. Quite surprisingly, it was discovered that over-imitation increases with age, and adults imitate causally irrelevant aspects of tool use with higher fidelity than young children (McGuigan et al. 2007, 2011; Nielsen and Tomaselli 2010). Our results support this pattern of over-imitation in adults; however, the fact that nonverbal instruction among flintknapping adults leads to emulation requires explanation. One possible explanation for the reduced imitative

learning amongst the nonverbal group is that ambitious platform preparation may not have been obvious to them as a goal to attempt to meet because of the absence of verbal interaction; therefore, they focused more on emulating the process to reach the goal of a large core biface by detaching small, thin flakes until they were satisfied that their product resembled those produced by the instructor. Through their experimentation, they learned from their mistakes and improved their flake production each week. As Tomasello et al. (1987: 182) note, sometimes “the most efficient strategy might be to simply observe the relation between the tool and the goal and then experiment with the specifics on one’s own.” Alternatively, Nielsen (2006) found that toddlers 18 months of age are more likely to imitate rather than emulate when the model is engaged and social compared to when the model is aloof. It is possible that the instructor in our experiment was perceived by the participants in the verbal group to be more engaged and social because of his verbal instructions, thus stimulating more imitation in the verbal group than the nonverbal group; however, the social account for over-imitation has come under some scrutiny by McGuigan et al. (2011), who found that televised models also produced patterns of over-imitation amongst children and adults.

Other researchers have also noted the important relationship between imitation and language. For example, Meltzoff (1988) and Tomasello (1999) have argued that imitation plays a crucial role in language acquisition. Multiple lines of evidence support that this link between imitation and language occurs at the neural level, which may have evolutionary implications (Heiser et al. 2003; Iacoboni et al. 1999; Thurm et al. 2007).

While the differences in debitage between the two groups are quite obvious, there are a few caveats to keep in mind. First, because of the constraints of raw material, the sample size used for this experiment is not ideal, and therefore, individual idiosyncrasies may have had an effect on the results. Our study design did not evaluate subjects for manual dexterity, and future work involving novice flintknappers should include a test of manual dexterity during the consideration of group assignment to ensure that one group does not consist of more naturally dexterous, or skilled individuals than the other group. However, there is no indication that the within-group degree of variation in key variables (e.g., flake size, flake mass, or the ratio of these

two variables) is significantly different between the two groups as would be expected if inherent skill differences existed between the verbal and nonverbal samples (see footnote 2 in Table 4). A second caveat to note is that the participants were allowed to flintknape only for a short amount of time. It is possible that with more practice and time, these differences might disappear; however, we argue that the results of this study nonetheless provide an important contribution to the understanding of the initial stages of learning and understanding of basic flintknapping concepts under varying communicative learning conditions. A final caveat is that we cannot ignore the fact that the participants in the nonverbal group are still inherent symbol-users who have been immersed in language all their lives. It is possible that their learning and thoughts were mediated by inner speech during the experiment (Vygotsky 1962).

CONCLUSIONS

In sum, we found that large bifacial cutting tools can be produced by novice flintknappers under verbal or nonverbal linguistic learning conditions. Thus, the presence of verbal interaction during the early stages of transmission of flintknapping concepts has little to no effect on the overall quality, shape, and symmetry of large core bifaces; however, verbal communication does appear to have a strong effect on debitage output. We assert that the difference in learning strategies is the result of emulation amongst the nonverbal novices and over-imitation amongst the verbal novices. The nonverbal participants showed the most improvement over time and produced more efficient flakes, but they generated nearly twice as many debitage elements as the verbal participants in the process. Although the results of this study speak specifically to the flintknapping learning behaviors of modern humans under varying linguistic conditions, some inferences could be made about the linguistic behaviors of earlier hominin species.

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