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The origins of stone tool reduction and the transition to knapping: An experimental approach

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ABSTRACT

A reassessment of many of the archaeological assemblages older than two million years has resulted in a general consensus that the earliest Oldowan artifacts were made by skilled toolmakers who had a clear understanding of the fracturing mechanics of different toolstone materials. This has led several researchers to propose a simpler lithic reduction stage that occurred prior to 2.6 Ma. Three lithic reduction techniques that are within the behavioral repertoire of our closest living relatives in the genus *Pan* are proposed as potential intermediate stages between the percussion behaviors of the last common ancestor of chimpanzees and humans and the skilled knapping of the Oldowan toolmakers. These include direct and indirect projectile percussion and bipolar flaking techniques. Measures of productivity, expediency, and efficiency were obtained and compared between these three reduction techniques and novice freehand knapping in order to better understand some of the factors that influenced how early hominins with little to no understanding of lithic fracturing mechanics achieved sharp flake tools. The provisional results of this proof-of-concept experiment indicate that, of these four conditions, dropping or throwing a large hammer stone on a brittle core is the most efficient way to exploit a core, while bipolar flaking is the most expedient method; however, novice freehand knapping creates the most productive flakes with large, sharp cutting edges. Thus, the transition to knapping in the late Pliocene may have been due to a shifting emphasis on productive toolmaking over expediency or efficiency.

1. Introduction

Since the initial discoveries in the 1970s of Oldowan assemblages that pre-date 2 Ma, such as those from Omo (Chavaillon, 1970, 1976; Merrick, 1976; Merrick et al., 1973) and Gona (Corvinus, 1975; Corvinus and Roche, 1980), archaeologists had argued that late Pliocene stone tools represent the earliest and simplest attempts at lithic reduction by hominins (Leakey, 1971; Wynn, 1981). Over several millennia, this "pre-Oldowan" stage underwent cumulative technological improvements to become the classic Oldowan of the lower Pleistocene (Leakey, 1971). The discovery of technologically sophisticated stone tools from Gona, dated to 2.6–2.5 Ma (Semaw et al., 1997), and reassessments of many of the late Pliocene assemblages (Ludwig and Harris, 1998; Semaw, 2000; de la Torre, 2004; Delagnes and Roche, 2005; Stout et al., 2005; Toth et al., 2006; Braun et al., 2009), however, have led to the realization that the oldest stone tool artifacts demonstrate selectivity of raw materials and technological complexity just as sophisticated as the early Pleistocene Oldowan assemblages. This demonstrable skill exceeds that of modern non-human apes (Toth et al., 2006; de la Torre, 2010). The sudden complexity at 2.6 Ma in the archaeological record implies an evolutionary leap, not only in technology, but also in cognition, which defies traditional ideas of Darwinian gradualism. This has led several researchers to propose that hominins had been modifying stone tools prior to 2.6 Ma and that older artifacts will be found that represent a previous technological phase when hominins recognized the benefits of sharp tools but were unaware of the mechanisms of knapping (Semaw et al., 1997; Dennell, 1998; Panger et al., 2002). Panger et al. (2002: 243) argue that "the available direct evidence of tool use in the archaeological record potentially underestimates the origin of hominin tool use by millions of years." There is indirect, albeit controversial and not conclusive, evidence for modified stone tool use prior to 2.6 Ma: faunal bones dating to 3.4 Ma bear cut marks incised by sharp-edged stone tools (McPherron et al., 2010; but see Domínguez-Rodrigo et al., 2010, 2011).

What would this previous technological stage look like? Humans' closest primate relatives provide the best evidence for alternative lithic reduction techniques to freehand knapping that hominins could have employed, which would have required little to no knowledge of conchoidal fracture. Conchoidal fracture produces flakes with a distinct bulb of percussion and concentric ripples, giving them the resemblance of a unionid shell. While it is usually associated with controlled knapping, conchoidal fracture can also occur unintentionally (Cotterell and Kamminga, 1987).

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Percussive behaviors using ‘power tools,’ those tools whose functionality requires forceful action (Whiten et al., 2009), are not unique to humans and their ancestors; the *Pan* clade also exhibits percussive technology behaviors using power tools that are culturally transmitted. For example, in the wild, *Pan troglodytes* has been witnessed to club prey, potential threats, and competitors with woody materials (Whiten et al., 2009), stab sharp sticks into tree holes to wound prey (Pruetz and Bertolani, 2007), and some groups in West Africa are known to use the anvil-and-hammer technique to crack nuts (Nishida, 1987; McGrew, 1992, 2004; Matsuzawa, 1994; Boesch and Boesch-Aschermann, 2000; Matsuzawa et al., 2001; Biro et al., 2003, 2006). Chimpanzees usually carry out this task by sitting in front of an anvil and striking the nut with a hammer in one or both hands. This nut-cracking behavior has been noted to be very similar and possibly even a precursor to knapping and bipolar flaking percussion (Sugiyama and Koman, 1979; Wynn and McGrew, 1989; Joulian, 1996; Marchant and McGrew, 2005; Wynn et al., 2011). Bipolar flaking involves placing a core atop an anvil and striking it repeatedly in a perpendicular plane, producing two opposing points of impact on either end of the core (Kobayashi, 1975; Barham, 1987; Cotterell and Kamminga, 1987; Jeske and Lurie, 1993; Zaidner, 2013). The common ancestor of chimpanzees and humans likely employed percussive technology similar to that of modern chimpanzees to obtain food items, which could have led to the discovery of the utility of sharp stone flakes.

There are currently no recorded cases of chimpanzees making intentional stone flakes in the wild, but several experimental studies have explored the potential knapping behaviors of modern bonobos in captivity (*Pan paniscus*; Toth et al., 1993; Schick et al., 1999; Roffmann et al., 2012). Kanzi, the first bonobo to be studied, was encouraged to produce flakes by striking a hammer stone held in one hand against the edge of a core held in the other hand. Overall, Kanzi had difficulty producing enough force to consistently produce successful flakes, and he did not seem to grasp the idea of finding acute angles on the edge of the core. Kanzi also discovered on his own that throwing the core against a hard floor (i.e. direct projectile percussion) could produce multiple flakes upon impact, which led him to shift to this technique as his primary method of making flakes over freehand knapping. He also invented the method of throwing one cobble against another on the ground (i.e. indirect projectile percussion), which could effectively create flakes from both stones. These throwing methods allowed him to “impart a much greater impact force between the stones than by hand-held percussion” (Toth et al., 1993: 86). Roffmann et al. (2012) have found that bonobos trained in freehand knapping continue to demonstrate preferences for hammering and aimed throwing techniques over knapping to extract food rewards hidden in wooden logs. Aimed stone throwing has also been observed among wild chimpanzees (Beatty, 1951; Goodall, 1964; Boesch and Boesch, 1990; Whiten et al., 2001; Nishida et al. 2009).

Parsimony supports the hypothesis that early hominins probably had similar cognitive and anatomical knapping restrictions to modern *Pan* (Wynn and Mcgrew, 1989; Tocheri et al., 2008; Wynn et al., 2011). It seems unlikely that hominins would have initially discovered the process of making sharp flakes through freehand knapping and even more unlikely that they would have become such highly skilled knappers rapidly and independently across populations in East and South Africa. In fact, there is currently no evidence for wild chimpanzees smashing a rock or wooden implement against a nut or fruit held in their other hand. Chimpanzees are known to adapt their tools to the level of risk presented by a situation (Humle and Matsuzawa, 2002); therefore, it is likely that they assess the risk of hammering a heavy item into one's own hand to be too high for the potential reward and thus rely on other safer techniques. A more likely scenario for the discovery of lithic reduction involves early hominins, perhaps *Australopithecus*, discovering that hitting a brittle rock atop an anvil, or the anvil itself, with a hammer stone produces sharp tools useful for foraging activities (Sugiyama and Koman, 1979; Wynn and McGrew, 1989; Marchant and McGrew, 2005; Wynn et al., 2011). Likewise, the same could have been discovered by throwing a brittle rock directly against an anvil or by throwing a hammer stone at a brittle rock. These behaviors are all within the realm of the last common ancestor's behavioral repertoire and would not require the necessary cognition or skill to understand and initiate purposeful conchoidal fracture. And, as Bril et al. (2012) have pointed out, throwing techniques allow chimpanzees to produce greater kinetic energy upon the point of contact than they would be able to achieve with the knapping gesture. Thus, a hominin with a comparable anatomy to a chimpanzee could in theory produce flakes more efficiently and expediently by throwing than by hammering or knapping techniques.

When deciding on how to break a rock to obtain sharp tools, a variety of factors likely played into a hominin's decision-making process, including the productivity or functionality of the tools resulting from the reduction technique, how quickly and easily they could be obtained, how efficient the technique was at preserving raw material and the individual's energy, and the level of risk of each method presented to the toolmaker. To investigate this problem further, a proof-of-concept experiment was devised to compare these factors between four different lithic reduction techniques using medium to large cores (Fig. 1 and Supplementary material): 1) novice freehand knapping, where blows dealt by a hammer stone in the dominant hand are directed towards the edge of a core setting either in the less dominant hand or on the thigh; 2) bipolar flaking, where a hammer stone held uni- or bimanually is used to strike a core setting on top of a stone anvil; 3) direct projectile percussion, where a core is thrown directly at a stone anvil; and 4) indirect projectile percussion, where a hammer stone is thrown at a core setting on a stone anvil. This paper contributes to a broader understanding of the benefits and drawbacks of freehand knapping and alternative hammering and throwing methods that may have been available to hominins during the Plio-Pleistocene.

2. Methods

2.1. Experimental design and procedure

The experiment was comprised of four different lithic reduction conditions carried out by novices: freehand knapping, bipolar flaking, direct projectile percussion, and indirect projectile percussion. A total of 40 nodules of Burlington chert, in the form of large to medium chunks and pre-made spalls, were procured for the study. Chert was used as a raw material to make Oldowan tools at times (Kimbel et al., 1996; Kimura, 1997; Goldman-Neuman and Hovers, 2012), though it should be noted that the chert used in this study is local to parts of the Midwestern United States. The average mass of the cores used in each condition was similar (ANOVA, $F = 0.734$, $p = 0.539$). Two individuals with no previous experience in flintknapping or breaking rocks (1 male, 1 female) participated in each condition, each person breaking 5 cores per condition. Individuals with no prior experience fracturing stones were included in this study rather than trained or expert individuals because they better approximate the skill level of an early hominin that would have had little experience or knowledge of lithic fracturing mechanics. An a priori power analysis was performed for sample size determination, based on data from a pilot study. With $\alpha = 0.05$ and power $= 0.80$, the maximum projected sample size needed for variables measuring expediency and efficiency was 9 cores per experimental condition (Soper, 2014). Therefore, a sample size of 10 rocks per condition should be sufficient to detect a significant effect between the different reduction techniques for variables measuring expediency and efficiency. Due to the restrictions of this study, productivity could not be adequately powered (see Section 2.2 for more information on expediency, efficiency, and productivity).

All participants were healthy adults between 22 and 29 years of age. The participants who took part in the bipolar and throwing conditions were different from those in the flintknapping condition because it