Exploring the Influence of Predation Risks on Oldowan Tool Use in South Africa

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Newly described Oldowan stone tools from Swartkrans Member 1 Lower Bank have highlighted important differences in raw material use and knapping methods when compared to Sterkfontein Member 5 East. This variability has been correlated to contrasting habitats surrounding these caves and the presence of carnivores, suggesting that ecological factors may have influenced tool manufacturing in the Early Pleistocene. However, the strength of behavioral ecological interpretations rests upon the identification of adaptive advantages in employing specific reduction strategies. Knapping experiments are used to compare the flaking efficiency of bipolar and freehand reduction, which measures the rate at which these methods convert core mass into cutting edge length. Results suggest that bipolar knapping is an efficient means of producing useable flakes, and its use at Swartkrans potentially reflects adaptations to limiting predation risks.

Keywords: bipolar knapping; flaking efficiency; Oldowan; behavioral ecology; experimental archaeology

Introduction

The analysis of Oldowan reduction sequences has provided important perspective on the technical competencies of early hominin toolmakers (Delagnes and Roche 2005; Stout et al. 2010; de Lumley et al. 2018). Examining the provisioning and management of raw materials has played a critical role in this research (Stout et al. 2005; Braun et al. 2008a, 2008b, 2009). Oldowan hominins unequivocally selected raw materials for their structural and mechanical qualities, reflecting a practical knowledge of their use in subsistence activities (Braun et al. 2009; Caruana and Mtshali 2018). More recently, the interplay between material use and knapping methods has gained attention in Oldowan research (Diez-Martín et al. 2011; Gurtov and Eren 2014; Gurtov, Buchanan, and Eren 2015; Byrne et al. 2016). This has focused on the identification of bipolar and freehand stigma in flake assemblages and comparing the flaking efficiency of these knapping methods. The use of bipolar and freehand have been shown to effect flake morphologies and cutting edge length in specific lithological mediums (Eren, Diez-Martín, and Domínguez-Rodrigo 2013; de la Peña and Wadley 2014; Morgan et al. 2015; Pargeter and de la Peña 2017). However, few raw material types have been tested within these parameters in reference to Oldowan toolmaking (see Gurtov and Eren 2014; Gurtov, Buchanan, and Eren 2015; Sánchez-Yustos, Garriga, and Martinez 2017).

The application of knapping methods in younger archaeological periods is often correlated to aspects of flaking efficiency, expediency, and population mobility (de la Peña and Wadley 2014; Jeske 2014; Pargeter and de la Peña 2017; Pargeter and Eren 2017; Pargeter, de la Peña, and Eren 2018). However, in Oldowan research, the employment of freehand versus bipolar knapping is largely considered a response to fracture properties of raw materials (Toth 1985; Barsky et al. 2011). The most well documented example being the use of bipolar knapping to reduce xenomorphic (vein) quartz (Harris et al. 1987; Kuman and Field 2009; Barsky et al. 2011; Gurtov and Eren 2014). The anisotropic structure of this material is known to inhibit conchoidal fracture, and the axial compression mechanics of bipolar knapping is thought to improve flake formation (Knight 1993; Driscoll 2011). Moreover, bipolar is solely associated with vein quartz reduction at some Oldowan sites, which has generated interest in the "quartz-bipolar relationship" (Diez-Martín et al. 2011; Gurtov and Eren 2014; Gurtov, Buchanan, and Eren 2015; Rodríguez-Álvarez 2016). This research has shown that bipolar reduction offered technological advantages beyond mitigating fracture mechanics, such as increased flaking expediency.

However, bipolar knapping was not restricted to vein quartz reduction during the Oldowan period, albeit examples of its application to other raw materials remain rare (e.g. Roche et al. 2018). This has recently been highlighted in an analysis of the Swartkrans Member 1 Lower Bank (SWT-1) lithic assemblage from South Africa (Kuman et al. 2018). Kuman and colleagues (2018) described new materials from this sedimentary unit, demonstrating important differences in raw material use and knapping methods when compared to the coetaneous Sterkfontein Member 5 East (STK-5) assemblage (Kuman and Field 2009). Given these sites are in close geographic proximity (ca. 1.07 km apart) and had equal access to local raw material sources, these aspects of technological variability warrant further investigation.

While many factors may have contributed to the assemblage-level variability between SWT-1 and STK-5, archaeological analyses most frequently consider: 1) site formation (differences in natural accumulation processes) (e.g. Kuman 2003); 2) technological skill (differences in hominin toolmaking capacities) (e.g. Roche et al. 1999); and/or ,3) ecology (environmental constraints on tool use) (e.g. Plummer 2004). Although testing these scenarios remains challenging, past research has suggested that differences between the SWT-1 and STK-5 assemblages may relate to the ecological conditions near the respective cave entrances of these sites. In particular, large-bodied carnivores have played an important role in the accumulation of fossil assemblages at Swartkrans, and some hominin remains show definitive evidence of predation (e.g. SK 54), attesting to the dangers of the southern African landscape during the Early Pleistocene (Brain 1974, 1981). Hominin-carnivore competition for meat resources and predation risks have been suggested to be important influences on Oldowan tool use and variability (Blumenschine et al. 2008, 2012). Therefore, ecological differences between SWT-1 and STK-5, specifically predation risks, may have played a significant role in shaping lithic production strategies at Swartkrans.

However, behavioral ecological interpretations require the identification of adaptive advantages, in this case resulting from technological strategies that might have reduced predation risks. To investigate this, a knapping experiment was designed to examine differences between bipolar versus freehand knapping in reducing quartz, quartzite, and chert materials, which predominate the SWT-1 and STK-5 assemblages. Flake assemblages were compared in terms of flaking efficiency, measured as ratios of cutting edge length to flake mass and flake perimeter, as well as total mass loss in cores. Given the potential differences in environmental settings, it is possible that contrasts in knapping methods at Swartkrans and Sterkfontein provided technological advantages relating to cutting edge production. Such advantages may have been critical for mitigating potential hominin-carnivore interactions and would provide support for behavioral ecological interpretations of lithic variability between these sites.

Sites, Assemblages, and Technological Variability

Sterkfontein and Swartkrans caves are located within the Blaauwbank River Valley, which is now incorporated into the UNESCO Fossil Hominid Sites of South Africa (locally designated "The Cradle of Humankind") (Figure 1). They have been excavated since the mid 1930s and represent the largest early hominin- and Oldowan-bearing sites in southern Africa (Caruana and Stratford 2019). The entrances to these caves were likely avens that acted as catchments for allochthonous sediments, as well as bone and lithic materials through slopewash and other erosional and taphonomic processes.

The STK-5 deposit has been dated to 2.18 ± 0.21 mya through cosmogenic burial (Granger et al. 2015), although previous research using electron spin resonance (ESR) generated a younger date of 1.32 ± 0.08 mya (Herries and Shaw 2011). Uranium-led dating on bounding flowstones has restricted the age of Member 1 at Swartkrans to ca. 2.31 – 1.64 mya (Pickering et al. 2011), and cosmogenic burial ages have further refined the Lower Bank to 2.19 ± 0.08–1.8 ± 0.09 mya (Gibbon et al. 2014). While the uranium-led and cosmogenic ages suggest these deposits may overlap in time, it is difficult to determine the contemporaneity of hominin activities at these sites.

In terms of the assemblage sizes, STK-5 totals 3513 artifacts, and, combining the collections excavated by C. K. Brain and new materials reported in Kuman and colleagues (2018), there are now 2147 artifacts from SWT-1 (Table 1). The STK-5 assemblage has been studied for many years and is considered a type collection of the Oldowan industry in southern Africa (Kuman 1994a, 1998, 2007; Kuman and Clarke 2000; Kuman and Field 2009; Caruana 2017; Caruana and Mtshali 2018). Brain's work at Swartkrans amassed a small lithic assemblage from the Member 1 Lower Bank deposit (n = 298), although differences in sample size hindered meaningful comparisons with STK-5 (but see Field 1999). Kuman and colleagues' (2018) description of new lithic materials from SWT-1 (n = 1849) has now provided a more substantive means of investigating assemblage-level variability with STK-5.

In their report, Kuman and colleagues (2018) presented observational data highlighting significant differences between SWT-1 and STK-5, including raw material provisioning strategies and knapping methods. For raw materials, cortical surfaces of artifacts show that the Blaauwbank River gravel beds were a major collection source, each site positioned within ca. 500 m (Kuman 1994b; Kuman et al. 2018) (Figure 2). Despite the close proximity to the Blaauwbank gravels, Kuman and colleagues' (2018) analysis of cortical surfaces on artifacts suggest a portion of the SWT-1 materials were collected from the local landscape. By comparison, cortical surfaces from the STK-5 artifacts show that materials were predominantly collected from the gravels (Kuman and Field 2009).

Furthermore, Kuman and colleagues (2018) have confirmed differences in raw material profiles from STK-5 and SWT-1, where the latter displays a higher diversity of rock types (Table 1). Vein quartz predominates both lithic collections, comprising 90.5% of STK-5 and 61.3% of SWT-1 artifacts, which was likely selected for its durability in subsistence activities (Caruana and Mtshali 2018). However, the SWT-1 assemblage includes higher frequencies of chert, quartzite, diabase, shale, and sandstone materials (Table 1). Kuman and colleagues (2018) also suggested that the STK-5 assemblage shows a greater selective preference for raw materials quality, although further petrographic studies are needed to confirm this observation. Overall, the SWT-1 assemblage portrays a more expedient strategy of toolstone procurement, which seemingly lacks the degree of toolstone preference and selectivity observed at other Oldowan sites (e.g. Stout et al. 2005; Delagnes and Roche 2005; Kuman and Field 2009).

Another important point of technological variability between STK-5 and SWT-1 is a higher proportion of bipolar knapping present within the latter assemblage (Kuman and Field 2009; Kuman et al. 2018). When combining totals for typological categories that Kuman and colleagues (2018) used to identify bipolar knapping traits (i.e. cores, flakes, and chunks), 24% of these materials show signs of this reduction method. Within the STK-5 assemblage, only three bipolar cores have been identified (Kuman and Field 2009). Interestingly, the bipolar method was also applied across a larger spectrum of raw materials within SWT-1, while it is strictly associated with quartz reduction in STK-5 (Kuman and Field 2009; Kuman et al. 2018). Past studies have also proposed differences in core reduction strategies, highlighting that SWT-1 includes high proportions of casual and bipolar cores with less than three flake scars (Clark 1993; Field 1999). The STK-5 assemblage is dominated by multifacial cores types, showing greater rotation and exploitation of flaking surfaces, which suggests that raw materials were more intensely reduced at Sterkfontein (Kuman and Clarke 2000; Kuman and Field 2009).

Based on the comparisons above, the Oldowan assemblage from the Lower Bank infill at Swartkrans seems less organized and more expedient. In fact, past studies have referred to the SWT-1 lithic materials as a casual assemblage, based on the frequency of minimally-exploited cores (Clark 1993; Field 1999). If taken at face value, the connotations of this reference parallel those ascribed to bipolar knapping in the past. Researchers have argued that bipolar knapping is uncontrolled and therefore reflects less technological skill (Goodyear 1993; Odell 2000). Similarly, the lack of raw material preference and expedient reduction strategies insinuate that the Swartkrans hominins may have been less skilled when compared to the Sterkfontein toolmakers.

However, most researchers examining variability between SWT-1 and STK-5 have acknowledged potential environmental influences that may have constrained lithic production strategies (Clark 1993; Field 1999; Caruana 2017; Caruana and Mtshali 2018; Kuman et al. 2018). This implies that a behavioral ecological framework can be used to interpret technological variability. However, the application of behavioral ecological theory in this instance has not been supported by arguments for adaptive advantages associated with specific production systems (see below). Thus, the explanatory strength of behavioral ecological interpretations concerning variation between STW-1 and STK-5 relies on what technological advantages (if any) different knapping methods may have provided Oldowan toolmakers.

Environment, Behavior, and Oldowan Toolmaking

Behavioral ecological interpretations of Oldowan tool use have been widely published in recent years, which correlates variability in toolmaking modalities to environmental settings, including toolstone availability, subsistence strategies, and other factors (Rogers, Harris, and Feibel 1994; Stout et al. 2005; Braun et al. 2008a, 2008b; Plummer et al. 2009). This interpretive framework examines the environmental determinates of behavior in terms of increasing fitness, which often entails aspects of inter- and intra-specific competition or cooperation in accessing resources (Krebs and Davies 2008). From this perspective, behaviors are seen as carrying some adaptive benefit in mitigating specific ecological challenges.

Investigating behavioral ecological aspects of Oldowan tool use first requires insight into the environmental settings of sites to highlight local ecologies and potential subsistence challenges. Isotopic analyses of fossil materials and frequencies of animal communities are used to reconstruct climatic and habitat settings, which provide the contextual basis for examining the behavioral correlates of lithic production strategies (Wynn 2004; van der Merwe et al. 2003; Ségalen, Lee-Thorp, and Cerling 2007; Reynolds and Kibii 2011). Aspects of raw material provisioning and reduction intensity are then correlated to environmental constraints on the availability of toolstone, transport distances, and subsistence practices, which ultimately shape the organization of lithic manufacturing processes (Kuhn 1994, 2004; Braun et al. 2008a, 2008b, 2009; Malinsky-Buller, Ekshtain, and Hovers 2014; Vidal-Cordasco et al. 2017). From this perspective, variability in lithic assemblages reflects behavioral adaptations to local environmental conditions.

More recently, theories relating to hominin-carnivore interactions have also been proposed as a driving factor in the evolution of hominin cognition and behavior (Blumenschine 1986, 1988, 1995; Brantingham 1998; Brain 2001; Pobiner and Blumenschine 2003; Blumenschine et al. 2008, 2012; Thompson et al. 2019; Faurby et al. 2020). These studies suggest that as early hominin taxa became increasingly reliant on meat and fat resources, they began to encroach on the carnivore paleoguild, which led to increased competition for access to animal carcasses. Cutmarks and percussion damage identified on bovid fossils from Oldowan sites corroborate the increasing interests of early hominins in the acquisition of animal protein (see Domínguez-Rodrigo et al. 2005; Pickering et al. 2008). However, carnivore damage on Early Pleistocene hominin fossils in both East (e.g. OH 8 and OH 35) (Njau and Blumenschine 2012) and South (e.g. SK 54) (Brain 1969, 1974) Africa attest to the dangers of predation potentially associated with competition for such resources. Thus, it is possible that aspects of hominin cognition, tool use, and social cooperation became more complex over time, in part, to mitigate subsistence challenges surrounding access to animal protein (Thompson et al. 2019).

Blumenschine and colleagues (2008, 2012) have examined the composition of Oldowan assemblages from Olduvai Gorge Bed I and lowermost Bed II from a behavioral ecological perspective, which revealed two important patterns structuring toolmaking and use. In terms of raw material composition, they found that the distance from toolstone sources to archaeological sites was inversely correlated to raw material frequencies. This insight led Blumenschine and colleagues (2008, 2012) to propose a distance decay model for predicting toolstone use within Oldowan assemblages from Olduvai Gorge, demonstrating that Oldowan hominins selected toolstone based on its local availability.

Further, Blumenschine (1986, 1988, 1995) analyzed taphonomic markings on bovid long bones from Bed I assemblages (e.g. FLK Zinj) to investigate the timing of animal carcass access by Oldowan hominins. He proposed that hominins scavenged felid kills, which has been a matter of debate, and it is possible that they instead actively hunted (see Domínguez-Rodrigo et al. 2014). Nonetheless, this body of research created a behavioral ecological framework to contextualize Oldowan toolmaking and use which recognized the importance of raw material availability and carnivore competition in interpreting hominin behavior. From this perspective, variability in lithic production strategies is related to landscape-scale features and subsistence practices.

In South Africa, Brain (1968, 1969, 1993, 2001) was the first to recognize the potential impact of hominin-carnivore interactions on human evolution in this region. He proposed that hominid intelligence may have been an ecological adaptation to carnivore predation, with specific reference to early fire use (Brain 1981, 2001). Brain (2001) suggested that early hominins used fire intentionally to cook meat at Swartkrans Member 3, although this technology possibly evolved as a protective mechanism against predation by large-bodied felids (Brain

2001). Brain’s hypothesis was partly formulated through his analysis of the tooth marks on the SK 54 hominin calvarium, which were likely made by a leopard and were definitive evidence of carnivore predation (Brain 1968, 1969, 1974).

As such, Brain (2001) proposed a behavioral ecological interpretation for the evolution of technology at Swartkrans. This outlined the potential adaptive advantages of technological behaviors surrounding fire-making and use, specifically in protecting hominins from predation by large-bodied carnivores. To build a similar interpretive framework for examining Oldowan tool production, the paleoenvironments of Swartkrans and Sterkfontein caves are discussed in brief. This will provide important context for building a behavioral ecological framework to interpret technological variability between SWT-1 and STK-5.

The paleoecology of Swartkrans and Sterkfontein

The environmental record of Swartkrans Member 1 has been reconstructed through analyses of faunal community composition and isotopic data extracted from fossil teeth (Lee-Thorp, Thackeray, and Van der Merwe 2000; Avery 2001; Lee-Thorp, Sponheimer, and Luyt 2007). These studies have largely described the Member 1 environment as a mosaic of savannah woodland and open grasslands. The presence of water-dependent species (*Hippopotamus* sp. and *Aonyx capensis* [African clawless otter]) in the Lower Bank fossil assemblage, though, indicate standing water, possibly marsh-like conditions, close to the cave entrance(s) (Watson 1993).

Furthermore, large-bodied carnivores are fairly well represented within the Lower Bank assemblage, including felid (e.g. *Panthera leo* and *P. pardus*; NISP = 50) and hyaenid (e.g. *Chasmaporthetes nitidula*; NISP = 25) species that would have posed predation and competitive threats to early hominins (Watson 1993; de Ruiter 2003). In fact, Pickering and colleagues

(2008) argued that leopards were consistently present throughout Member 1 times at Swartkrans. Neuman (1993) found that carnivore tooth marks (n = 66), punctures (n = 12), and chewed edges (n = 53) were prevalent on bovid fossils from the Lower Bank deposit, which suggests that predation and consumption behaviors by carnivores played a major role in the accumulation of the SWT-1 fossil assemblage (see Pickering et al. 2008). Cutmarks (n = 10) and percussion marks (n = 3) found on bovid limb bones from Member 1 also attest to the scavenging activities of Oldowan hominins at this site and possible interspecific competition for animal carcasses (Pickering et al. 2008).

In comparison, the STK-5 fossil assemblage suggests different environmental settings. Carbon isotope analyses indicate a moderately wooded environment near the cave entrance(s) (Luyt and Lee-Thorp 2003). Large-bodied carnivore fossils are less abundant within this assemblage when compared to Swartkrans Member 1 (Pickering 1999). Only 13 felid (cf. *P. leo*) and six hyaenid (sp. indet.) specimens are found in the STK-5 assemblage, although carnivoran bone modifications (142 chewed and 32 digested specimens) are comparable (Pickering 1999; O’Regan 2007). However, Pickering’s (1999) taphonomic assessment of the STK-5 fossil assemblage strongly supported a death trap scenario, where animal bones accumulated in the cave system through falling down aven shafts, which he substantiated through skeletal part representation and bone breakage patterns. Lastly, no cutmarks or percussion damage on fossil bones have been reported within this assemblage.

The potentially wetter conditions near Swartkrans may have attracted bovids, and consequently large-bodied carnivores, or the surrounds were possibly an ambush site for carnivores that then carried and consumed kills near the cave entrance(s). Nonetheless, carnivore activities would have provided opportunities for early hominins to scavenge animal carcass

(Blumenschine et al. 2012; Thompson et al. 2019). Despite the hazards of predation, Swartkrans may have been a desirable place for early hominins to acquire meat resources. On the other hand, it has also been suggested that the higher elevation of Sterkfontein and its potential rocky outcrops limited carnivore activities and occupation (Kuman and Clarke 2000; Kuman et al. 2018). Kuman and colleagues (2018) further argued that the intense working of cores and a higher presence of knapping debris in the STK-5 assemblage suggest that hominins spent more time at this site.

Building a framework for behavioral ecological interpretations of the SWT-1 assemblage

Following Brain's (2001) hypothesis, it is possible that the differences in lithic production strategies observed within the SWT-1 assemblage may represent adaptive responses to potential carnivore encounters. In particular, the use of bipolar knapping and expedient methods of raw material procurement and reduction possibly reflect a need to limit time spent on site. The compromise in toolstone preference and reduction intensity may be part of an avoidance strategy to lower risks of predation while scavenging animal carcasses. In this sense, the casual nature of SWT-1 may represent adaptations to local ecological risks.

While the bipolar technique has been considered to be a less skillful means of toolmaking, recent experimental research has suggested potential advantages in both flaking expediency and efficiency (Jeske 2014; Pargeter and de la Peña 2017; Pargeter and Eren 2017; Pargeter, de la Peña, and Eren 2018). In fact, Gurtov and Eren (2014) recently found that the use of bipolar knapping to reduce Naibor Soit quartz/quartzite materials found in Bed I assemblages from Olduvai Gorge increased the expediency of producing sharp-edged flakes. This was measured as the number of useable flakes produced per gram of core per second in experimental settings. While they found no significant increases in cutting edge to mass ratios (i.e. flaking efficiency), they highlighted strategic advantages of bipolar knapping beyond mitigating raw material constraints.

The effects of knapping methods on raw materials from the Blaaubank River Valley have not been rigorously explored in similar experimental settings. To date, few studies have compared experimental results of bipolar and freehand knapping on flake morphologies in the context of Oldowan flaking (see Diez-Martín et al. 2011; Gurtov and Eren 2014; Gurtov, Buchanan, and Eren 2015; Byrne et al. 2016). The quality and fracture mechanics of raw materials are central to the production of cutting edges in flakes, which are affected by the formation histories of toolstone sources that vary across geographical regions. Therefore, it is necessary to test the response of raw material to flaking strategies on a site-by-site basis using local materials. With respect to the STK-5 and SWT-1 assemblages, any technological gains in cutting edge length resulting from bipolar and freehand knapping may correlate to the ecological risks of carnivore encounters. Finding relationships between these factors may provide further support for behavioral ecological interpretations of Oldowan variability in this region.

Materials and Methods

To explore potential advantages of bipolar knapping across raw materials utilized within the SWT-1 and STK-5 assemblages, a knapping experiment was designed to compare the effects of reduction methods on cutting edge production. Both bipolar and freehand methods were used to reduce vein quartz (n = 20), quartzite (n = 20), and chert (n = 20) cores collected from areas surrounding Swartkrans Hill. Ten nodules from each material group were reduced through the two respective knapping methods, and all flakes with useable edges over 2 cm in length were collected and measured. A useable edge was defined by its edge angle (≤ 50°), which relates to cutting proficiency (Prasciunas 2007).

The experiment was carried out by the author, who has nine years of knapping experience, using basalt hammerstones and dolerite anvils, due to their hardness. Freehand knapping was carried out by consistently holding cores at oblique angles relative to percussive strikes, while bipolar cores were orientated parallel, with the bottom of the core always anchored to the anvil to utilize compression mechanics (Diez-Martín et al. 2011; Hiscock 2015). The following measurements were taken for each flake product using digital calipers to the nearest 0.01 mm: maximum dimension, length, width, thickness, and platform width and depth. A goniometer was used to measure cutting edge angle to the nearest degree. Both total flake perimeter (excluding platform width) and cutting edge length were measured in ImageJ software. Cores were then measured according to maximum length, width, and thickness. Weight for both flakes and cores were measured with a digital scale to the nearest 0.1 g.

Quantitative methods were used to compare both flake and core assemblages. Flaking experiments typically produce relatively large sample sizes ($n > 100$), which in some cases can confound statistical tests through over-powering effects. A power test was conducted to understand the effect size (d) between groups and the power of tests while α (significance level) was held constant at 0.05. High statistical power relative to low effect sizes between samples may produce significant results where there are none (i.e. Type I error) (Marshall 2007). To reduce the probability of Type I errors, a subsampling strategy was employed, which ensured the robustness of statistical comparisons. A subsample of 20 flakes from each raw material group from bipolar ($n = 60$) and freehand ($n = 60$) flake assemblages were randomly chosen and tested (Pargeter and de la Peña 2017; Pargeter, de la Peña, and Eren 2018).

Flakes were first grouped as aggregate assemblages by knapping method. The ratio of cutting edge (mm) to mass (g) (CE/M) was compared, although mass was first transformed using an exponent of 2/3 to standardize its rate of increase to cutting edge measurements (Mackay 2008; Lin et al. 2013). Secondly, the ratio of cutting edge to flake perimeter (mm) (CE/FP) was used to investigate what percentage of flake perimeters produced through bipolar and freehand knapping were useable. Flakes were then grouped according to knapping method and raw materials (i.e. quartz-bipolar, freehand-chert, etc.) to examine any potential lithological effects on these results.

To compare cores, initial and ending weights were measured to understand how much mass core was lost throughout the reduction experiments. Cutting edge measurements were then totaled for all flakes from individual cores, and the resulting sums were compared with the total loss of core mass (initial mass–ending mass) (CE/CM) (Prasciunas 2007; Eren, Greenspan, and Sampson 2008). Mass measurements were also transformed using an exponent of 2/3 to equalize variance with cutting edge measurements. This comparison essentially tested the success rate of knapping methods to convert the mass lost during reduction into useable tool edge.

Mann-Whitney U tests were used to compare bipolar and freehand flake and core samples to account for the non-normally distributed data. All tests were performed in SPSS 25.

Results

A total of 640 useable flakes were generated during reduction experiments (343 bipolar and 297 freehand), which are summarized in Table 2 by knapping method and raw material groups (Figure 3). Using the entire flake sample to compare CE/M, a power test revealed a low effect size (d = 0.3) and high statistical power (0.99), which produced a significant result in a Mann-

Whitney U test ($p < 0.0001$). This was interpreted as a Type I error, as the small effect size suggests no significant difference between samples, despite the p-value result. When comparing the subsampled groups ($n = 120$), a power test revealed more favorable conditions ($d = 0.5$, $power = 0.8$). As such, the results of the subsampled comparisons are interpreted here as more robust. Statistical results for all comparisons of subsampled groups are reported in Table 3.

When flakes were sampled as aggregates of knapping methods, no significant differences in CE/M were detected, although a marginal difference in the percentage of usable tool edge along flake perimeters (CE/FP) was found, suggesting that bipolar knapping produced flakes with slightly more CE/FP ratios (Figure 4). However, the CE/FP results are only just below significance levels and thus do not represent major differences in cutting edge production rates. When divided by knapping method and raw material, no significant differences were detected in either CE/M or CE/FP ratios (Figures 5, 6). Raw material comparisons show some marginal differences in chert samples, where bipolar chert flakes show slightly higher ranges in CE/M. Lastly, no statistical differences between core assemblages were detected for CE/CM when grouped by knapping methods (Figure 7). Overall, these results suggest that bipolar and freehand knapping are equally efficient in producing useable cutting edges and limiting core waste through reduction sequences.

Behavioral Ecology and Bipolar Reduction at Swartkrans

The results above highlight that using both bipolar and freehand knapping to reduce raw materials from the Blaauwbank River Valley are equally efficient methods of producing useable flakes. These results echo those reported in Gurtov and Eren (2014), which also demonstrated that bipolar and freehand flaking produce similar amounts of cutting edge per gram of core. This further confirms that bipolar knapping does not reflect unskilled knapping and instead is a viable means of producing useable flake tools for subsistence activities. Bipolar knapping also does not waste greater amounts of core volume, which has been demonstrated for other material types (Diez-Martín et al. 2011).

Furthermore, Gurtov and Eren’s (2014) experiments showed that bipolar knapping is more time efficient and produced more useable flakes per second when compared to freehand knapping. This has significant implications when considering the lithic production strategies that characterize the SWT-1 assemblage. Early hominins at Swartkrans collected a wide variety of raw materials from both river gravels and the local landscape, suggesting a more expedient form of provisioning. Bipolar knapping was then used to reduce these materials, which seemingly was not an exhaustive process when compared to STK-5. Thus, the “causal” system of toolmaking at Swartkrans more accurately reflects expedient methods of toolstone sourcing and reduction, which may have provided advantages in limiting the time needed to produce tools for carrying out subsistence activities.

Contextualizing these interpretations within the paleoecology of Swartkrans suggests correlations between toolmaking strategies and ecological challenges. The potential increase in flaking expediency through bipolar knapping implies a technological advantage in reducing the time needed to flake raw materials that were collected the near the cave. Swartkrans was potentially hazardous, due to the presence of large-bodied carnivores, yet offered access to meat resources for early hominin scavengers. Through the lens of behavioral ecological theory, it is possible that expedient methods of procuring raw materials and producing tools, in part, mitigated predation risks and potentially lessened the chances of competition for access to animal carcasses. As such, the lithic production strategies characterizing the SWT-1 assemblage may reflect behavioral adaptations to the ecological pressures of carnivore competition and predation.

Lastly, recent assessments of Oldowan localities in East Africa, including Gona (ca. 2.6 mya) (Stout et al. 2010), Lokalalei (ca. 2.34 mya) (Delagnes and Roche 2005), and Melka Kunture (ca. 2–1.4 mya) (Gallotti and Mussi 2015) have supported techno-economic and socio-cognitive frameworks for interpreting differences in raw material use, typological frequencies, and reduction strategies. These viewpoints highlight aspects of skill, cognition, and social learning underlying lithic technologies, which emphasize the agency of toolmaking groups and individuals, in terms of decision-making and the social transmission of information as underlying causes of technological variability. However, such frameworks downplay the role of ecology as a deterministic factor of toolmaking and use (de la Torre and Mora 2009). Yet the results of this study, and others that seeks to understand technological behaviors within a larger ecological framework, suggest that behavioral ecological interpretations can offer important insights into the sources of variability within Oldowan assemblages (see Blumenschine 1986, 1988, 1995; Blumenschine et al. 2008, 2012). As such, this highlights the need to develop integrative approaches towards examining the sources of technological variability that incorporate cognitive, social, and ecological perspectives.

Conclusion

The results of this experimental research corroborate behavioral ecological interpretations of technological variability between STK-5 and SWT-1. The threat of competition and predation by large-bodied carnivores possibly inspired a more expedient form of lithic production at Swartkrans which did not focus on raw material selectivity or the careful management of reduction processes. Instead, toolmakers at this site employed a more rapid means of collecting materials and producing sharp-edged flakes through bipolar reduction, which was an equally efficient means of reduction as freehand knapping. Furthermore, this production strategy potentially decreased the time needed to create tools and butcher animal carcasses, while also limiting the risks of encountering large-bodied felids and hyaenids at Swartkrans.

However, other factors, including site formation and differences in hominin taxa and skill levels, may have also contributed to variability between SWT-1 and STK-5, although there is less support for these scenarios. Modelling the accumulation of lithic materials in these cave systems suggests uniform site formation processes across archaeological sites (Kuman 2007). Lithic knapping most likely took place near the openings of cave systems, and slopewash processes incorporated portions of discarded artifacts into active infills (Kuman 2003, 2007). While these assemblages are not complete, erosional forces were not likely to have biased the frequency of tool types in any significant manner beyond artifact size. Thus, the frequencies of raw materials, cores, and flakes are representative of the original assemblage composition.

Furthermore, at least three hominin species were extant during Oldowan times in southern Africa, including *Australopithecus sediba* (Malapa; see Figure 1) (Berger et al. 2010), *Paranthropus robustus*, and early *Homo* sp. (Watson 1993; Grine 2005; Pickering et al. 2012). Recently, the earliest *Homo erectus* was recovered from Drimolen, which dates to 2.04–1.95 mya (Herries et al. 2020). Fossil evidence of both early *Homo* and *P. robustus* are found in the SWT Member 1 Lower Bank deposit and only *P. robustus* in STK Member 5 East (Kuman and Clarke 2000). While there is overwhelming support for early *Homo* (cf. *H. habilis*) as an Oldowan toolmaker, the hand bones of *P. robustus* and *Au. sediba* would not have restricted these species from making and using tools (Susman 1991; Kivell et al. 2011). Without any capacity to attribute Oldowan assemblages directly to hominin species in South Africa, an argument for hominin technological skill driving variability in lithic assemblages cannot be tested. However, this scenario cannot be ruled out as a possibility.

Experimental evidence for technological advantages associated with bipolar reduction, especially when applied across a variety of raw materials, suggests that behavioral ecological interpretations can account for the differences between the STK-5 and SWT-1 lithic assemblages. The potential risks of carnivore competition and predation at Swartkrans may have prompted a nuanced lithic production system. The expedient collection of raw materials and use of bipolar knapping presented potential advantages in mitigating the challenges of contending with large-bodied carnivores for access to animal carcasses. This has important implications for understanding the evolution of early Pleistocene technology in southern Africa and the behavioral ecology of hominin populations. The results presented above suggest that the Oldowan hominins of South Africa were discerning of ecological challenges on this landscape and adapted toolmaking strategies to increase their access to animal protein and chances of survival.

Geolocation Information

Swartkrans Hill (Lat: 26° 1'2.44"S; Lon: 27° 43'25.06"E) is located in the Cradle of Humankindboundary in the Gauteng Province of South Africa.

Conflict of Interest Statement

The author declares no conflict of interest.

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Author Biography

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Figure Captions

Figure 1: A) Map of South Africa showing the geographic position of the UNESCO Fossil Hominid Sites of South Africa World Heritage Site (a.k.a. “Cradle of Humankind”) (black box). B) Outline of the “Cradle” region and locations of major paleoanthropological cave sites (BF = Bolt’s Farm; CP = Cooper’s; DN = Drimolen; GD = Gondolin; GV = Gladysvale; HG = Haasgat; KR = Kromdraai; ML = Malapa; RS = Rising Star).

Figure 2: Topographic map of the Blaaubank River Valley rendered from lidar data. Elevation in meters above sea level.

Figure 3: Experimental flakes (ventral to dorsal [left to right] views). Freehand flakes: A) chert, C) quartzite, and E) vein quartz; and bipolar flakes: B) chert, D) quartzite, and F) vein quartz.

Figure 4: Flaking efficiency comparison. A) Boxplot of cutting edge to mass ratios in flakes grouped by knapping methods. B) Boxplot of the percentage of useable cutting edges ($\leq 50^{o}$) produced per flake perimeter grouped by knapping methods.

Figure 5: Boxplots of cutting edge to mass ratios in flakes grouped by knapping methods and raw materials.

Figure 6: Boxplot of the percentage of useable cutting edges ($\leq 50^{o}$) produced per flake perimeter grouped by knapping methods and raw materials.

Figure 7: Boxplot of the amount of cutting edge produced per gram of core lost in lithic knapping.

Table 1: Artifact typology of the Swartkrans Member 1 Lower Bank Oldowan assemblage. Totals amalgamate artifact frequencies from Field (1999) and Kuman and colleagues (2018) (Congl = Conglomerate).

	Quartz	Quartz Congl	Chert	Chert Congl	Quartzite	Diabase	Shale/ Mudstone	Sandstone	Total	%
CORES									**93**	4.3%
Bipolar	**25**	**1**	**4**		**5**				**35**	1.63%
Casual	**3**		**3**		**4**				**10**	0.47%
Single Platform	**1**				**2**				**3**	0.14%
Bifacial	**2**		**1**		**3**				**6**	0.28%
Multifacial	**13**		**2**		**6**	**1**			**22**	1.02%
Subradial	**2**				**1**				**3**	0.14%
Subspheroids	**3**								**3**	0.14%
Core Fragments	**9**				**2**				**11**	0.51%
FLAKE TYPES									**277**	12.9%
Complete	**117**	**1**	**95**	**1**	**23**	**1**	**1**		**239**	11.13%
Incomplete	**66**		**74**		**8**				**148**	6.89%
Fragments	**102**		**67**		**5**		**1**		**175**	8.15%
FORMAL TOOLS									**15**	0.7%
Notched Scrapers	**2**			**1**	**2**				**5**	0.23%
Steep Scrapers	**3**								**3**	0.14%
Scaled Piece	**1**								**1**	0.05%
Scraper Notch					**1**				**1**	0.05%
Misc. Pieces	**5**								**5**	0.23%
OTHER									**267**	12.4%
Chunks	**180**		**14**		**5**		**1**	**1**	**201**	9.36%
Split Chunk	**1**								**1**	0.05%
Hammerstones					**5**				**5**	0.23%
Battered Cobbles/Anvils	**1**				**2**				**3**	0.14%
Possible Battered Cobble					**5**				**5**	0.23%

Manuports	**4**		**3**		**41**	**3**	**1**		**52**	2.42%
DEBRIS									**1210**	56.4%
<20mm	**772**		**403**		**15**	**20**				
TOTAL	**1312**	**2**	**666**	**2**	**135**	**25**	**4**	**1**	**2147**	100%
Raw Material %	**61.3%**	**0.1%**	**31.1%**	**0.09%**	**6.3%**	**1.2%**	**0.2%**	**0.05%**		

Table 2: Descriptive statistics of experimental flakes produced by bipolar and freehand knapping by raw material (Max Dim = Maximum Dimension; S.D. = Standard Deviation).

	Max Dim	**Length**	**Width**	**Thickness**	**Mass**	**Cutting Edge**	**Perimeter**
BIPOLAR							
Quartz (n = 79)							
Mean	44.26	39.34	31.53	16.84	24.55	70.34	110.21
Median	42.59	38.37	31.51	16.07	18.60	64.48	109.60
S.D.	15.36	13.45	11.05	7.33	28.56	32.97	36.15
Range	73.10	65.01	50.24	30.03	187.10	166.87	173.94
Minimum	21.14	18.86	11.94	5.63	1.60	22.14	54.62
Maximum	94.24	83.87	62.18	35.66	188.70	189.01	228.56
Quartzite (n = 96)							
Mean	56.64	48.46	41.49	17.59	52.32	101.44	138.42
Median	54.89	48.35	40.43	14.96	31.85	91.80	134.42
S.D.	16.32	13.84	15.41	7.71	67.13	42.33	39.71
Range	75.32	62.21	77.96	36.08	463.00	212.07	173.44
Minimum	31.29	26.91	8.61	1.40	2.90	33.15	80.13
Maximum	106.61	89.12	86.57	37.48	465.90	245.22	253.57
Chert (n = 168)							

Mean	47.33	44.11	32.18	12.42	23.42	92.31	120.39
Median	43.26	41.25	27.35	10.73	8.85	80.00	108.64
S.D.	18.21	16.78	15.25	6.19	33.41	42.24	45.95
Range	94.62	83.77	82.77	30.37	199.40	218.79	217.10
Minimum	21.78	20.30	12.03	2.77	1.10	23.88	58.52
Maximum	116.40	104.07	94.80	33.14	200.50	242.67	275.62
FREEHAND							
Quartz (n = 70)							
Mean	48.66	44.42	37.07	16.37	33.19	86.16	125.91
Median	44.84	40.80	32.69	14.69	16.50	84.92	116.10
S.D.	13.16	12.30	12.23	6.82	31.85	39.85	35.17
Range	50.63	48.98	46.66	32.07	142.90	174.06	134.82
Minimum	26.37	21.52	18.07	5.99	3.20	20.51	68.86
Maximum	77.00	70.50	64.73	38.06	146.10	194.57	203.68
Quartzite (n = 92)							
Mean	56.88	51.79	40.78	19.44	52.52	96.46	144.35
Median	52.71	50.17	38.69	15.67	27.25	93.42	132.98
S.D.	20.13	18.62	16.05	11.13	64.76	38.48	51.44
Range	82.54	75.11	78.93	47.79	331.30	186.12	205.57
Minimum	25.77	23.45	10.13	4.49	1.20	19.60	57.03
Maximum	108.31	98.56	89.06	52.28	332.50	205.72	262.60
Chert (n = 135)							
Mean	53.29	47.14	38.23	13.78	30.78	82.46	132.51
Median	49.62	43.65	31.56	11.78	13.50	74.77	121.78
S.D.	18.84	16.05	17.77	6.83	37.99	40.45	45.33
Range	87.32	71.44	69.79	38.57	207.30	219.59	198.43
Minimum	22.54	18.30	16.02	3.39	1.60	22.57	59.56
Maximum	109.86	89.74	85.81	41.96	208.90	242.16	257.99

Table 3: Mann-Whitney U test results.

	N	**Mean Rank**	**Sum of Ranks**	**U**	**Z**	**P-value (2-tailed)**
GROUPED BY KNAPPING METHODS						

CE/M	Bipolar	60	63.32	3799	1631	-0.89	0.3751
	Freehand	60	57.68	3461			
	Total	120					
CE/FP	Bipolar	60	66.87	4012	1418	-2.01	0.0449
	Freehand	60	54.13	3248			
	Total	120					
GROUPED BY RAW MATERIALS							
Quartz	Bipolar	20	20.75	415	195	-0.14	0.8924
CE/M	Freehand	20	20.25	405			
	Total	40					
Quartz	Bipolar	20	21.35	427	183	-0.46	0.6456
CE/FP	Freehand	20	19.65	393			
	Total	40					
Quartzite	Bipolar	20	18.925	378.5	168.5	-0.85	0.3941
CE/M	Freehand	20	22.075	441.5			
	Total	40					
Quartzite	Bipolar	20	22.65	453	157	-1.16	0.2443
CE/FP	Freehand	20	18.35	367			
	Total	40					
Chert	Bipolar	20	23.9	478	132	-1.84	0.0659
CE/M	Freehand	20	17.1	342			
	Total	40					
Chert	Bipolar	20	23.3	466	144	-1.52	0.1296
CE/FP	Freehand	20	17.7	354			
	Total	40					
CUTTING EDGE TO CORE MASS							
CE/CM	Bipolar	30	34.2	1026	339	-1.64	0.1008
	Freehand	30	26.8	804			
	Total	60					