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Technology based evolution? A biometric test of the effects of handsize versus tool form on efficiency in an experimental cutting task

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ABSTRACT

The use of stone cutting tools opened a novel adaptive niche for hominins. Hence, it has been hypothesised that biomechanical adaptations evolved to maximise efficiency when using such tools. Here, we test experimentally whether biometric variation influences the efficiency of simple cutting tools ($n = 60$ participants). Grip strength and handsize were measured in each participant. 30 participants used flint flakes, while the other 30 used small (unhafted) steel blades. Variations in basic parameters of tool form (length, width, thickness, cutting edge length) were recorded for the 30 flint flakes. It was ensured that mean handsize and strength in each participant group were not significantly different to investigate the effect of tool variation. The experimental task required cutting through a 10 mm-diameter hessian rope. Cutting efficiency was measured using both 'Number of cutting strokes required' and 'Total time taken'. Results show that both efficiency measures were significantly correlated with handsize using all 60 participants. However, no significant differences were found between the flake and blade groups in terms of mean efficiency. Nor was any significant relationship found between tool form parameters and efficiency in the flint flake group. We stress that our results do not imply that tool form has no impact on tool efficiency, but rather that – all other things being equal – biometric variation has a statistically significant influence on efficiency variation when using simple cutting tools. These results demonstrate that biomechanical parameters related directly to efficiency of use, may plausibly have been subject to selection in the earliest stone tool-using hominins.

1. Introduction

1.1. Technology based evolution in the human hand?

> "To chip a flint into the rudest tool, or to form a barbed spear or hook from a bone, demands the use of a perfect hand". Charles Darwin (1871: 138) *Descent of Man*

The earliest deliberately manufactured stone tools appear in the stratigraphic record of East Africa from at least 2.6 MYA (Semaw, 2000; Semaw et al., 2003). These early stone tools are generally referred to as the 'Oldowan' or 'Mode 1' (Leakey, 1971; Schick and Toth, 2006; Shea, 2007). However, there are hints from indirect evidence that the 'appearance' of stone cutting tools in the archaeological record at this time may actually be the result of a more extended – but archaeologically intractable – period of stone tool use within a wider context of primate tool use (Braun, 2010; McPherron et al., 2010; Panger et al., 2002). Hence, the use of stone cutting tools has, for *at least* the last 2.6 MYA, been entangled in the story of human evolution (Semaw, 2000).

Chimpanzees (*Pan troglodytes*) are famed for being adept tool users in the wild (McGrew, 1992). However, the majority of tool use exhibited by extant chimpanzees occurs within the context of extractive foraging, whereby a tool is used to assist the extraction of edible matter (termites, honey, nuts, etc.) during bouts of feeding behaviour (McGrew, 1992). On the grounds of parsimony it is probable, therefore, that the manufacture and use of stone cutting tools ≥2.6 MYA emerged within the context of hominin feeding strategies (Isaac, 1971; Marchant and McGrew, 2005; van Schaik et al., 1999; Yamakoshi, 2001). Evidence to support this conjecture is available in the form of cutmarks on fauna associated with Oldowan artefacts (e.g. Blumenschine, 1986; Braun et al., 2010; Bunn, 1981; Domínguez-Rodrigo et al., 2005; Semaw et al., 2003; Potts & Shipman, 1981; Steele, 2010). Hence, the emergent use of stone cutting tools represents a novel feeding strategy, widely regarded as a key adaptation and intimately associated with many of the behavioural and anatomical features of later hominins (e.g. Braun et al., 2010; Bunn, 2007; Marchant and McGrew, 2005; Shipman and Walker, 1989; Stanford and Bunn, 2001).

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The use of manufactured stone tools (in particular their implicated association with increased levels of meat consumption) is frequently embroiled in debates concerning enlargement of the hominin brain (e.g. Aiello and Wheeler, 1995; Plummer, 2004; Shipman and Walker, 1989). However, there is also a long history of speculation concerning the evolution of human gripping and manipulatory capabilities, and the influence that stone tool use may have effected in this regard (e.g. Washburn, 1959). Indeed, considerations regarding a role for stone tools in the evolution of the human hand go back at least as far as Darwin's (1871) *Descent of Man*. Research over the last century, has confirmed the existence of a suite of features in the bones and musculature of the human hand and wrist associated with specific gripping and manipulatory capabilities, which are differentiated from those of other extant great apes (Landsmeer, 1962; Lewis, 1989; Marzke and Marzke, 2000; Marzke et al., 2010; Marzke and Wullstein, 1996; Napier, 1956, 1962; Straus, 1942; Susman and Creel, 1979; Tocheri et al., 2003, 2007). The wrist and hands of non-human apes are largely adapted for locomotion (Sarmiento, 1988), fuelling suggestions that at some point since humans split from the last common ancestor of living apes, the human hand evolved away from features adapted for locomotion toward alternative functions (Hamrick et al., 1998; Marzke, 1997; Niewoehner, 2001; Tocheri et al., 2008).

Many of the evolved (derived) properties of human hand morphology are associated with a powerful 'precision grip' (Napier, 1956). Precision gripping may be defined "as any grip that involves the thumb and one or more fingers, with or without the palm serving passively as a prop" (Marzke, 1997: 92). Strong precision gripping in humans is facilitated in large part by a well-developed flexor pollicus muscle in the forearm, which is "either rudimentary or absent" in non-human great apes (Straus, 1942: 228). This muscle inserts via a tendon at a cavity on the distal pollical phalanx (thumb tip) enabling strong flexion of the thumb tip (Marzke and Marzke, 2000). Other derived features include a longer thumb relative to finger digits (Napier, 1993). Such features enable strong 'pad-to-side' gripping whereby the thumb can firmly secure small objects against the side of the metacarpals, as would be the case during the use of Oldowan flake cutting tools (Marzke, 1997; Marzke and Shackley, 1986; see also Pickering and Hensley-Marschand, 2008). Electromyography (EMG) has confirmed that the flexor pollicus longus is heavily recruited during cutting and scraping activities performed with stone flakes (Hamrick et al., 1998). EMG studies have also shown that the flexor pollicus longus muscle is heavily recruited during hard hammer percussion in experimental studies of stone tool manufacture, further suggesting that a whole group of stone tool related behaviours initiated by the Oldowan might have influenced hand evolution in particular ways (Marzke et al., 1998). Indeed, although experiments using a trained bonobo chimpanzee (*Pan paniscus*) have demonstrated that the production and use of stone cutting flakes is within the manipulatory capacities of at least some non-human apes (Schick et al., 1999; Toth et al., 1993), it has also been noted that little downward force was applied during these experimental cutting actions, and that the wrist was largely kept immobile, with most of the force being provided by the shoulder (Ambrose, 2001: 1749).

In sum, there is substantive evidence on anatomical grounds that variations in the human hand and associated musculature have the potential to influence the efficiency of stone tool performance. However, to our knowledge, no previous study has tested directly the prediction that biometric variation between individuals (the fundamental basis of any selective hypothesis) significantly influences the efficiency of simple cutting tools when employed in cutting tasks. If engineered carefully, experiments can provide an effective means of testing archaeological hypotheses of this nature (Clarke, 1972: 54; Lycett and Chauhan, 2010: 5; Toth and Schick, 2009).

1.2. Experimental frameworks for stone tool use and efficiency assessment

There is a long history of experimenting with stone tool manufacture and use in order to inform archaeological endeavour (Johnson, 1978), although the quality of such experimentation in terms of providing quantifiable results that are directly comparable across situations, has varied widely. Most experimental studies using stone flakes have concentrated on demonstrating plausible functions, from the manufacture of wooden implements (Crabtree and Davis, 1968), all the way up to the practicalities of butchering adult elephants (Frison, 1989; Schick and Toth, 1993). Recently, there appears to have been something of a reinvigoration of experimental approaches to lithic industries in a range of capacities, which evince a renewed emphasis on providing quantifiable results that may be examined within a statistical framework (Clarkson, 2002; Collins, 2008; Dewbury and Russell, 2007; Eren et al., 2008, in press; Hiscock and Clarkson, 2005; Jennings et al., 2010; Machin et al., 2007; Prasciunas, 2007; Shea et al., 2001; Shott et al., 2000; Stout et al., 2000; Toth et al., 2006).

Some experimental studies have been directed specifically toward investigating factors that might influence efficiency. Some of these studies, such as Jones' (1980) butchery of medium sized animals, were largely qualitative in nature. Others, such as a pioneering study by Walker (1978) which looked at the influence of different forms of edge treatment on butchering efficiency, made a determined effort to quantify various aspects of the experimental design and its results. A recent study concerning stone tool efficiency was that of Machin et al. (2007). These authors investigated whether specific aspects of stone tool form (handaxe symmetry) correlated with efficiency in terms of butchery speed. Such studies reiterate the value of experimental approaches for addressing fundamental archaeological questions, especially when results are quantified and analysed statistically. However, to date, there has been no large-scale published experiment concerning the variability that *individual tool users* may impose on the efficiency of flakes or other stones tools, despite the fact that it appears reasonable to assume that a number of morphological adaptations may have evolved so as to maximise the return of using such tools. It is this deficit which we wish to begin to address in the present study, using a combination of experimental and statistical approaches. Here, therefore, we test experimentally the prediction that biometric variation in the hand influences the performance efficiency of simple cutting tools when applied to a replicable task. For comparison, we also assess whether the form of the particular tools used in the experiments is exerting an effect on efficiency.

2. Materials and methods

2.1. Experimental procedures

A total of 60 participants (mixed-sex) were used in the experiments (Table 1), drawn from the student population at the University of Kent, Canterbury, United Kingdom (mean age = 21, range = 18–31). A stipulation was made that no participant should have previous experience with stone tool use, or formal education relating to stone tools at university level. The handsize (dominant hand) of each participant was measured in centimetres from the tip of the index finger to the crease of the wrist using sliding calipers, with the forearm and hand supinated on a table; a common method of determining handsize in biometric studies (Clerke et al., 2005; Okunribido, 2000). Maximum isometric grip strength of the dominant hand was measured in kilograms using a dynometer (transverse hook grip), whereby the mean of three grip exertions was taken as the reading. Again, this is a commonly used procedure