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Early stage blunting causes rapid reductions in stone tool performance

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A B S T R A C T

Palaeolithic stone technologies have never been investigated in terms of how sharpness influences their ability to cut. In turn, there is little understanding of how quickly stone cutting edges blunt, how past populations responded to any consequent changes in performance, or how these factors influenced the Palaeolithic archaeological record. Presented here is experimental data quantitatively detailing how variation in edge sharpness influences stone tool cutting performance. Significant increases in force (N) and material displacement (mm) requirements occur rapidly within early stages of blunting, with a single abrasive cutting stroke causing, on average, a 38% increase in the force needed to initiate a cut. In energetic terms, this equates to a 70% increase in work (J). Subsequent to early stages of blunting we identify a substantial drop in the impact of additional edge abrasion. We also demonstrate how edge (included) angle significantly influences cutting force and energy requirements and how it co-varies with sharpness. Amongst other conclusions, we suggest that rapid reductions in performance due to blunting may account for the abundance of lithic artefacts at some archaeological sites, the speed that resharpening behaviours altered tool forms, and the lack of microscopic wear traces on many lithic implements.

1. Introduction

The geometry of a stone tool's edge affects its performance during cutting tasks. Numerous experiments attest to this by demonstrating that variable edge angles, edge lengths, the extent and presence of scalloping/serration, and edge curvature all influence the efficiency of cutting tasks (Walker, 1978; Jones, 1994; Collins, 2008; Clarkson et al., 2015; Key and Lycett, 2015; Key et al., 2016). While the relative influence of each trait is dependent upon the tool's context of use, within Palaeolithic contexts it is reasonable to conclude that each was at times likely to have had some influence on cutting performance and, consequently, may have been subject to functional selective pressures controlling for tool form variation (Torrence, 1989; Schiffer and Skibo, 1997; Key and Lycett, 2017). Quite logically, then, there has been a long history of interpreting the form of cutting edges on Palaeolithic artefacts in functional terms (Key and Lycett, 2017).

One attribute of Palaeolithic stone-tool cutting edges that has received more limited attention is sharpness. This is despite engineering and ergonomic research having repeatedly highlighted its impact on cutting processes. A particularly relevant example to studies of Palaeolithic stone tools is McGorry et al. (2003) who demonstrated that the sharpness of metal knives significantly influences the grip forces, cutting moments, and tool-use times required during the butchery of medium and large mammals. However, while lithic-related studies frequently and correctly acknowledge the importance of an edge's sharpness to its cutting performance, it is often the case that ‘sharpness’ is used interchangeably with the distinct morphological trait of edge angle, or no specific definition or measurement of sharpness is provided. In geometric terms, sharpness is often defined by the radius of the very tip (apex) of an edge (see: Reilly et al., 2004; Key, 2016). While tip radius and edge angle are highly correlated morphological traits, at least within modern metallic blades (Schuldt et al., 2013), the distinction between the two is important as each has distinct influences on the creation of cutting stress.

Sharpness is not, however, solely defined by an edge's tip radius but also relates to the force applied during cutting. As Schuldt et al. (2016: 13) state, “sharpness also depends on properties of the cutting substrate, and refers to the ability of a blade to initiate a cut

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at low force and deformation". A straightforward example to highlight this point is a paper cut. After all, the edge of a piece of paper is not sharp and able to initiate a cut across your skin until there is sufficient force in the 'slice' motion of its edge. Although widely established within engineering research (Atkins, 2009), this aspect of sharpness has rarely been discussed within Palaeolithic literature (although see: Ackerly, 1978; Key, 2016). Previous mechanical research has measured sharpness in different quantitative and qualitative terms for both geometric and force properties of edges (Maeda et al., 1989; Arcona and Dow, 1996; Komanduri et al., 1998; Szabo et al., 2001; McGorry et al., 2003; McCarthy et al., 2007; Wyen et al., 2012; Schuldt et al., 2013). Reilly et al. (2004) and Schuldt et al. (2013) discuss the co-dependence of a cutting edge's geometric and force properties in the determination of edge sharpness particularly well. The latter demonstrates that force measurements may be more sensitive than measurements of edge radius in the calculation of sharpness (Schuldt et al., 2013), although as highlighted by McCarthy et al. (2010), tip radius is significantly more effective in measuring sharpness than edge angle.

Edge angle (often referred to as the 'included angle' or 'wedge angle' in mechanical literature) impacts cutting performance, and has been demonstrated to do so to a significant extent within research using modern metal tools (Atkins, 2009; McCarthy et al., 2010). Although in certain contexts some studies with modern tools have returned more limited relationships. McGorry et al. (2005), for example, demonstrated that boning knives displaying edge angles of 20°, 30° and 45° did not display significant differences in terms of grip forces, cutting moments and cutting times during butchery processes (lamb). This is consistent with Key and Lycett (2015) who identified edge angle to be a variably influential factor on flake tool cutting efficiency (and was dependent, in part, on a stone tool's size). In sum, although each trait influences the local stress fields of a worked material in different ways, both tip radius and edge angle have the potential to significantly impact the forces required to initiate cuts in materials with metal tools (Hirst and Howse, 1969; Arcona and Dow, 1996; Komanduri et al., 1998; Kim et al., 1998; Szabo et al., 2001; Atkins, 2009; Schuldt et al., 2013), with greater measures in each increasing the forces required.

However, it is not known whether or not these basic mechanical principles that underlie the design of many modern cutting technologies are similarly demonstrated in Palaeolithic stone tool cutting technologies. Specifically, how are the forces required to use stone tools influenced by the sharpness (and therefore also bluntness) of their cutting edges? Further, although there has been a number of studies examining the influence of edge angle variation on stone tool cutting performance (Jobson, 1986; Key and Lycett, 2015; Key et al., 2016; Merritt, 2016), the relative influence that this morphological trait has on the forces required to cut materials with stone tools has never been examined in conditions absent of human actors (although also see Collins' (2008) investigation of scraping cutting actions that, although did not record force, used a mechanised rig). Furthermore, it is not known how any influence that edge angle variation may have varies alongside differences in edge sharpness.

In order to address these gaps in our understanding of the functional capabilities of Palaeolithic technologies, here we investigate the influence of edge sharpness (and, in turn, blunting) on a stone tool's ability to cut flexible, extensible material (i.e. 'soft-solids', such as those seen in many biological tissues). Further, we similarly examine the role of a stone tool's edge angle on the forces, work and displacement required to cut such material. This represents the first controlled study of how two of the most important aspects of a cutting tool's edge influence the functional performance of Palaeolithic stone technologies. We conclude by discussing the relative importance of sharpness and edge angle in relation to each other, the influence that each trait has on cutting processes, and the extent to which behaviours may have been influenced by these factors in prehistory.

2. Methods

2.1. Stone tool assemblage

Initially, hundreds of flakes were knapped from Texas Fredericksburg variety chert with the aim of producing flakes displaying edges suitable for cutting. From these, ~200 were selected on the basis of displaying straight edges greater than 20 mm long and no micro-flaking or fractures. The final assemblage of 50 flakes was chosen to display a range of edge angles (Fig. 1). Edge angle variation was recorded here using the Caliper Method first described by Dibble and Bernard (1980). It was only necessary to record edge angle across a 10 mm length of each flake's cutting edge. This edge portion was the only aspect of the tool applied during cutting and was principally chosen based on being located near the middle of the cutting edge. Six angle measurements were taken from this relatively short length of edge. Angles were recorded at three evenly spaced intervals (0 mm, 5 mm, and 10 mm) at depths away

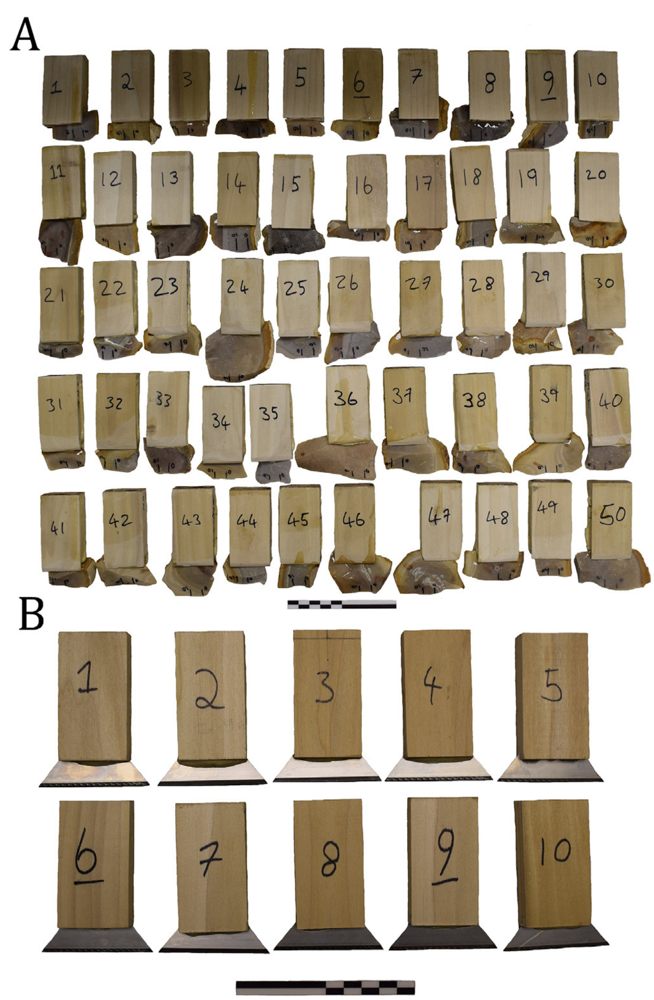

Fig. 1. The 50 stone flakes (A) and 10 metal blades (B) used during the cutting tests. Each has been secured into a wooden block so that it can be securely held by the upper grip of the Instron®.