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Flake morphology as a record of manual pressure during stone tool production

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ABSTRACT

Relative to the hominin fossil record there is an abundance of lithic artefacts within Pleistocene sequences. Therefore, stone tools offer an important source of information regarding hominin behaviour and evolution. Here we report on the potential of Oldowan and Acheulean flake artefacts to provide a record of the biomechanical demands placed on the hominin hand during Lower Palaeolithic stone tool production sequences. Specifically, we examine whether the morphometric attributes of stone flakes, removed via hard hammer percussion, preserve correlates of the pressures experienced across the dominant hand of knappers. Results show that although significant and positive relationships exist between flake metrics and manual pressure, these relationships vary significantly between subjects. Indeed, we identify two biomechanically distinct strategies employed by knappers; those that alter their hammerstone grip pressure in relation to flake size and mass and those who consistently exert relatively high manual pressures. All individuals experience relatively high gripping pressure when detaching particularly large flakes. Amongst other results, our data indicate that the distinctive large flake technology associated with the Acheulean techno-complex may be demonstrative of an ability to withstand, and by extension, to exert higher manual pressures. However inferences from smaller flake artefacts, especially, must be treated with caution due to the variable biomechanical strategies employed.

1. Introduction

The production of stone tools represents one of the few known behavioural constants amongst hominin populations during the last ~3 million years. Lithic artefacts also represent one of the most abundant sources of evidence available relating to the evolution of humans. Archaeologists and palaeoanthropologists have, therefore, long been concerned with how Palaeolithic artefacts may be used to shed light on our evolutionary history. Given the high cognitive demands associated with stone tool production techniques, a great deal of this attention has been focused on how the lithic archaeological record may inform our understanding of the evolution of human cognitive capabilities (Beaune et al., 2009; Gamble et al., 2014). These capabilities include the evolution of language, imitation, complex technological capabilities, increased brain size, complex social systems, cognitive and manual lateralisation, spatial cognition and shape recognition (Ambrose, 2010; de Beaune, 2004; Gowlett et al., 2012; Morgan et al., 2015; Schillinger et al., 2015; Stout, 2011; Stout et al., 2008; Uomini and Meyer, 2013; Wynn, 2002). Comparatively little work has investigated how lithic artefacts may be used to further our understanding of the evolution of human musculoskeletal anatomy and biomechanical capabilities.

Previous research examining relationships between lithic technology and the hominin upper limb has principally been concerned with identifying how stone tool use and production may plausibly have exerted selective pressures on anatomical features. This has included investigations into muscle recruitment levels, upper limb kinematics, manual pressure and force distributions, grip requirements and how tool-user biomechanical variation influences the efficiency of tool use or production (Hamrick et al., 1998; Key and Dunmore, 2015; Key and Lycett, 2011, in press; Maki, 2013; Marzke and Shackley, 1986; Marzke et al., 1998; Rolian et al., 2011; Shaw et al., 2012; Williams et al., 2010, 2012, 2014). Little of this work, however, addresses how Palaeolithic artefacts may be of use beyond their presence in the archaeological record confirming that stone tool related behaviours were being undertaken.

At a broad level, Marzke and Shackley (1986) demonstrated that flake, handaxe, and blade manufacturing techniques are all manually demanding, but require diverse and at times distinct manipulative actions. Faisal et al. (2010) compared the manual complexity of Oldowan and Acheulean stone tool production sequences in more detail and identified similar levels of grip complexity and diversity in each. In turn, it could be argued that the onset of the Acheulean ~900 Kya after

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the development of Oldowan technology may not have necessarily been consequent to changes in the manipulative anatomy of Lower Palaeolithic hominins. More recently, Key, Stemp and colleagues have investigated how lithic microwear traces may potentially be used to investigate the loading levels which hominins applied during stone tool use (Key et al., 2015; Stemp et al., 2015). Their research indicates that microwear traces may be used, potentially, to examine how stone tool use proficiency developed in relation to the evolution of the hominin upper limb. Others have since suggested that lithic microwear traces may be similarly used to reconstruct manual gestures and handling techniques associated with the use of Palaeolithic scraping technologies (Pfleging et al., 2015; Zupancich et al., 2015). Relatedly, Bello and colleagues demonstrated how the micromorphological analysis of cut-marked bones may be used to infer the working forces and manual application of stone tools (Bello, 2011; Bello et al., 2009). These important studies go beyond simply treating Palaeolithic artefacts as a binary indicator of their production or use, but instead emphasize the manual complexity required to produce such technology or how the traces of tool use could be used to infer biomechanical capabilities of Palaeolithic individuals.

The biomechanical capabilities of Palaeolithic hominins have on occasion been considered during investigations of lithic artefacts, however, these have largely been limited to comments made within research with an alternative focus. Gowlett (2015), for instance, has recently noted during a comparison of Acheulean and chimpanzee (*Pan troglodytes*) artefacts that a reoccurring average weight of ~0.5 kg within biface assemblages probably has a biomechanical origin. Delagnes and Roche (2005) were more specific during their analysis of the 2.34-million-year-old assemblage from Lokalalei 2C in West Turkana when noting that the precise and highly controlled flaking that they observed “implies not only a highly controlled movement [by the tool producers], but also a firm and constant grasp while handling both core and hammerstone”. In their description of the 3.3 Mya stone tools from Lomekwi, West Turkana, Harmand et al. (2015) similarly discussed their implications for the evolution of modern human-like manipulative capabilities. While providing a holistic review of all manipulative observations derived from Palaeolithic research is beyond the remit of this paper, to our knowledge, there are few studies that investigate how different technological or morphological aspects of the Palaeolithic record may preserve information relating to the upper limb biomechanics of Plio-Pleistocene hominins.

One potentially fruitful line of enquiry in this regard was raised by Dibble and Rezek (2009) during their investigation into how a number of variables relevant to knapping, including the striking force of the hammerstone, may influence the size and shape of removed flakes. Dibble and Rezek (2009: 1953) identified a “clear association between force and flake weight, suggest[ing] that it may ultimately be possible to determine the actual force used to detach flakes recovered archaeologically”. A similar relationship between the kinetic energy of hammerstones during flake removals and flake size has been noted by Nonaka et al. (2010). Certainly, within mechanical literature flake size is known to be in part a function of the forces applied during fracture propagation (Chai and Lawn, 2007; Cotterell and Kamminga, 1990). Hammerstone reaction forces and the need to maintain a secure grip on said stone during striking actions can, then, result in high pressures acting on the hand (Rolian et al., 2011; Williams et al., 2012). It is thus logical to predict that there may be direct relationships between the size or mass of flake stone tools and the manual pressures experienced by stone tool producers in their dominant (hammerstone holding) hand. Therefore, flake artefacts may potentially contain information relevant to our understanding of the loads that were routinely placed on the hands of Palaeolithic hominins and which may have influenced the evolution of the human hand.

Here, we experimentally test whether there is a relationship between the morphology or mass of flakes produced during stone tool production sequences and the pressures experienced by the hammerstone-holding (dominant) hand during their detachment. Specifically, we attach pressure sensors to the distal phalanges of the thumb, index and middle fingers of nine experienced knappers during Oldowan flake production and Acheulean handaxe shaping. Through the comparison of the manual pressures experienced during a flake's removal and its resultant morphometric attributes, we address whether flake stone artefacts may contain information relating to the manual pressures experienced by Palaeolithic hominins during stone tool production sequences. However, research has repeatedly highlighted that complex relationships exist amongst a range of independent factors that can influence the final form of stone flakes (Chai and Lawn, 2007; Cotterell and Kamminga, 1987; Dibble and Whittaker, 1981; Magnani et al., 2014) and as such, direct relationships between flake size or mass and hammerstone striking force should be “viewed with considerable caution” (Magnani et al., 2014: 47). Hence, we also analyse inter-individual variation to examine the relative relationships between flake morphometrics and manual pressure in an attempt to naturalistically control for such factors as varying levels of skill, differing core preparation strategies, and individual learned behaviours. Results are discussed in terms of whether Lower Palaeolithic flake forms are able to shed light on the evolution of the human hand and our ability to manipulate hammerstones forcefully and dexterously.

2. Materials and methods

2.1. Participants and experimental protocol

Nine individuals experienced in stone tool replication were recruited to take part in the experiment. Each had at least 3 years of experience producing stone tools and had the ability to consistently produce Acheulean handaxes when intended. Notably, some of the participants exceed this technological capability by a considerable margin and are known to demonstrate expertise within a variety of stone tool replication conditions (e.g. Eren et al., 2013; Winton, 2005). Descriptive data for individual participants are presented in Table 1. This includes basic biometric data from the dominant hand of each individual and potential indicators of knapping skill. Hand length was measured along the palmar surface from the distal tip of the 3rd digit to the distal crease line at the wrist. Grip and pad-to-side pinch strength were measured using a Jamar dynamometer and pinch-strength gauge, respectively. Flaking success was calculated by dividing the number of flakes removed by each participant by the total number of hammerstone strikes when attempting to produce these flakes, expressed as a percentage. Flaking success was calculated separately for the two flake removal sequences performed by each participant.

Each participant was asked to undertake both an Oldowan and Acheulean flake production sequence. In line with general consensus regarding the primary objectives of Oldowan stone tool production sequences (e.g. Stout et al., 2010; Toth, 1985), participants were asked to produce stone flakes that may conceivably be used as cutting tools. The Acheulean flake production sequence was similarly undertaken

Table 1
Descriptive data for each of the knappers included in these analyses.

Participant #	Hand length (mm)	Grip strength (kg)	Pad-to-side pinch strength (kg)	Years of knapping experience	Oldowan flaking success (%)	Acheulean flaking success (%)
1	198.5	63	12.9	5	73	59
2	189	42	10.2	32	83	83
3	183.5	57	9.7	12	80	77
4	196.5	46	10.4	41	74	62
5	193	63	10.1	25	80	90
6	181	50	10.2	14	53	59
7	174	59	11.3	39	60	77
8	174	51.5	10	6.5	81	70
9	195.5	58.5	10	34	70	89