Journal of Archaeological Science: Reports 14 (2017) 302–317

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

The performance of heat-treated silcrete backed pieces in actualistic and controlled complex projectile experiments

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ARTICLE INFO

Keywords:
Projectile weapons
Modern human behavior
Microlithic
Howiesons Poort
Complex technology
Technological evolution
Experimental archaeology
Ballistics

ABSTRACT

The origins of complex projectile weaponry provides insight into cultural and biological changes associated with the origins and spread of modern human populations. Middle Stone Age backed pieces are often thought to be components of such armaments, however our limited understanding of their functional characteristics as projectiles precludes understanding the adaptive problems they may have solved. Despite acknowledgment of raw material differences and intra-assemblage variability, whether variability in backed piece form reflects functional, economic, or stylistic variation has a paucity of empirical support. Here, the functional differences in backed piece form (size and shape) while hafted transversely and obliquely as high-velocity complex projectile armatures are examined. If there are performance tradeoffs simply in how backed pieces are arranged at the end of armaments that can influence effectiveness, then identifying the archaeological arrangement can provide insight into what variables were being prioritized in prehistoric technological systems. How variation in backed piece size, elongation, and hafting arrangement influences complex projectile performance is tested using experimental and actualistic projectile replications with a calibrated crossbow against animal and ballistics gelatin targets. The results of this study show that, within the size and shape variation of silcrete backed pieces examined, tool form plays a relatively limited role in their performance as projectile armatures. However, hafting orientation has very different performance characteristics for complex projectiles shot at ballistics gelatin compared to animal targets. We demonstrate that transversely hafted tools have more lethal internal wounds, but obliquely hafted backed pieces have greater puncture reliability. These functional differences represent different technological design emphasis: transversely hafted tools create large, deep wounds, while obliquely hafted arrows and darts create a puncture more reliably. Although obliquely hafted armaments cause less internal trauma, they are more likely to penetrate the hide of ungulate prey. Variability in MSA hunting tactics may have played a role in the design of weapon systems to optimize these performance tradeoffs. Despite similarities in shape with ethno-historic technologies, based on these results, MSA-sized backed pieces hafted as projectile armatures were unlikely to have been used with small, low-powered bows - but would have been lethal with a high-velocity delivery system.

1. Introduction

The development of complex, long-range, projectile weaponry has been linked to several behavioral and biological changes in human evolution (Bingham and Souza, 2009; Marean, 2015a; Marlowe, 2005; Rhodes and Churchill, 2009). The earliest forms of such armatures may consist of composite technological systems. A primary component of these systems are replaceable stone inserts that allow for quick, serial replacement of broken stone armament tips, without replacement of the entire shaft or delivery vehicle (e.g., foreshafts or other linkage). Small, stone flakes with steep retouch approaching 90-degree angle along one lateral edge and a sharp unretouched opposing edge termed, 'backed pieces' or 'backed tools' (Pargeter et al., 2016), are often argued to be components in such composite systems (Brown et al., 2012; Lombard and Phillipson, 2010).

Lithic backed pieces encompass a wide array of shapes, regions and extent of backing, sizes, and production processes (e.g., blade or flake blanks). The earliest securely dated forms of backed pieces are found in southern Africa during the MSA (Brown et al., 2012; Jacobs et al., 2008; Jacobs, 2010; Karkanas et al., 2015), and their earliest widespread

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http://dx.doi.org/10.1016/j.jasrep.2017.05.053
Received 4 November 2016; Received in revised form 23 May 2017; Accepted 26 May 2017

appearance as part of composite technologies is associated with the Howiesons Poort (HP) industry (Volman and Klein, 1984). Jacobs et al. (2008) dated layers from numerous HP assemblages to a restricted temporal period, most recently estimated to be between 66 and 58 ka (Jacobs and Roberts, 2017). At Pinnacle Point Cave 5–6 (PP5–6), Brown et al. (2012) argue for an early appearance of backed tools at 71 ka in the stratigraphic aggregate called the SADBS (shelly-ashy dark-brown sand), but use geometric morphometrics to suggest that the SADBS backed piece shape was substantially different compared to later HP backed tools from Montagu Cave and Klasies River. The published backed tool assemblage from Diepkloof rockshelter shows a similar pattern in backed tool morphological change through time, including an early appearance of backed tools that is termed "early-HP" as early as 105 ka (Porraz et al., 2013). Although there is debate over the chronological relationship between the assemblages, the commonalities in tool forms between the two assemblages suggest backed pieces were present in the MSA prior to their more widespread adoption and use ~66–58 ka in the "classic" HP defined at other sites (Jacobs et al., 2008; Jacobs and Roberts, 2017).

MSA backed pieces are often thought to be components of complex projectile armaments (Brown et al., 2012; Lombard and Phillipson, 2010; Lombard, 2011; Marean, 2015a), delivered with mechanical assistance using energy stored "exosomatically" to propel projectiles (Shea and Sisk, 2010). The fitness implications of effective and reliable long-range weaponry may include reduction of hunter mortality compared to short-range spears (Kaplan et al., 2000; Marlowe, 2005). Shea argues that projectiles may have reduced sexual dimorphism (Shea, 2011), while Kuhn suggests that increased diet breadth results from hunters having a range of specialized tools that include microlithic technology (Kuhn, 2002). This in turn can reduce nutritional shortfall frequency and pave the way for craft specialization including technological improvements, such as recurved and reinforced bows, and poison tipped arrows. Marean has argued that long-range weaponry coupled with increased population sizes ~70 ka may have served as an impetus for inter-group conflicts through warfare (Marean, 2015a), leading to the extreme levels of inter-group cooperation seen in modern humans (Boyd and Richerson, 2009). In this scenario, the combination of group cooperation and projectile weaponry allowed human populations to spread out of Africa across the globe within a relatively short period of time (Marean, 2015a).

Despite acknowledgment of raw material differences and inter- and intra-assemblage variability (Brown et al., 2012; Mackay, 2011; Wadley and Mohapi, 2008), whether backed piece size and shape variability reflects functional, economic, or stylistic variation has a paucity of empirical support. A functional explanation would imply that improvements in penetration depth, wound size, or reliability would determine the size and configuration of backed pieces in armature systems. An economic explanation would suggest that smaller backed pieces conserve raw material better, and that is their main advantage, or that different configurations resist breakage and are thus easier to maintain. Symbolic explanations would argue that the points themselves transmit social information, and the functional and economic considerations are less important. Additionally, the orientation and configuration of the lithic armament onto a projectile shaft may amplify or diminish the influence of the lithic morphology on functional performance. Various hafting configurations of backed tools have been suggested, but whether these would be functionally equivalent has implications for how variability in backed piece morphology writ large is contextualized. Wilkins et al. (2014) demonstrated that hafting a stone tool to the tip of a spear significantly improves the lethality of spears by creating a larger wound cavity. Whether backed piece form and hafting configurations have similar influence on weapon performance characteristics can provide insight into the meaning of backed piece variability in the archaeological record.

Here, the functional differences in backed piece size and shape, collectively referred to as 'form' (Zelditch et al., 2004), and hafting configuration when used as projectile armatures are examined. Two hypotheses that relate backed piece functional performance are posed. First, we hypothesize that backed piece form influences weapon performance. How backed piece size influences performance in different armature systems may provide insight into the empirical record for morphological change seen in HP and pre-HP assemblages. Second, we hypothesize that hafting configuration influences weapon performance. The functional differences in hafting arrangement have received relatively little attention and are often portrayed as interchangeable. However, if there are performance tradeoffs simply in how backed pieces are arranged at the end of armaments that can influence effectiveness, then identifying the archaeological arrangement can provide insight into what variables were being prioritized in prehistoric technological systems.

To test these hypotheses, we use a range of replicated HP-sized backed pieces produced on heat-treated silcrete and hafted transversely or obliquely to shafts that are then shot into ballistics gelatin and animal carcass targets as high-velocity projectiles. The combination of independent experimental methods that are both actualistic and controlled provide insight into the functional characteristics of backed piece projectiles which would be unavailable separately (Outram, 2008; Pettigrew et al., 2015). Ballistics gelatin targets provide highly controlled data on the internal wound characteristics that result from backed piece variability. Ballistic gelatin is a uniform medium which mimics the density of human and animal muscle tissue and insures that the target is standardized for each shot. With this experimental setup we are able to control for all variables and determine the influence of backed piece form and hafting orientation. The hypotheses are evaluated in the controlled gelatin experiment through paired *t*-tests since each piece is shot once in each hafting orientation with all other variables being equal. Using culled animal targets with a range of projectile weights provides a more actualistic test of the performance of these arrows because they have to penetrate actual bone and hide (Outram, 2008). The hypotheses are evaluated in the actualistic animal carcass experiment by constructing a generalized linear model and simultaneously evaluating the relative importance of tool size, tool shape, and hafting orientation to explain variation in the probability of the projectile successfully penetrating the carcass. Bivariate regressions are then used to identify more specific relationships between the model parameters and projectile performance metrics.

2. Background

2.1. Temporal variability

The appearance of backed pieces in many parts of the Old World occurs asynchronously, and is likely due to different factors relating to the interaction between local environmental and the technological needs of the local foraging groups (Hiscock et al., 2011). The earliest suggestion of backed pieces in the Middle Pleistocene are reported by Barham at Twin Rivers, Zambia (Barham, 2002). However, Herries (2011) casts significant doubt about the association of speleothem ages with the archaeological material, and suggests an age range of 141–48 ka. Diepkloof Rockshelter (DRS) on the West coast of South Africa contains evidence for systematic production of backed pieces. Tribolo et al. (2013) has dated these layers using thermoluminescence to 109 ± 10 ka and 105 ± 10 ka which are favored by Porraz et al. (2013) and supported by Feathers (2015). However, Jacobs et al. (2008) had previously dated these layers using optically stimulated luminescence (OSL) when the excavators associated these layers with the Still Bay industry (and not "pre-HP") to 70.9 ± 2.3 ka. More recently, Jacobs and Roberts (2015) reanalyzed OSL samples from DRS and obtained an age for the Early-HP of 62.6 ± 2.7 ka putting it in line with other HP assemblages dated by Jacobs et al. (2008) using OSL. At PP5–6, backed blades in the "SADBS" described by Brown et al. (2012) are notably narrower and thinner than classic HP backed segment