Journal of Archaeological Science: Reports 10 (2016) 191–203

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

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

Early spears as thrusting weapons: Isolating force and impact velocities in human performance trials

Annemieke Milks [a,*], Stephen Champion [b], Elizabeth Cowper [b,c], Matt Pope [a], Debra Carr [b]

[a] Institute of Archaeology, University College London, 31-34 Gordon Square, London WC1H OPY, UK
[b] Impact and Armour Group, Centre for Defence Engineering, Cranfield Defence and Security, Cranfield University, Defence Academy of the United Kingdom, Shrivenham, Oxon SN6 8LA, UK
[c] Centre for Advanced Materials and Performance Textiles, RMIT University, 25 Dawson Street, Brunswick, VIC 3056, Australia

ARTICLE INFO

Article history:
Received 29 March 2016
Received in revised form 16 September 2016
Accepted 19 September 2016
Available online xxxx

Keywords:
Weapon delivery systems
Middle Pleistocene
Projectiles
Experiment
Untipped wooden spears

ABSTRACT

Human hunting has been a cornerstone of research in human evolutionary studies, and decades worth of research programmes into early weapon systems have improved our understanding of the subsistence behaviours of our genus. Thrusting spears are potentially one of the earliest hunting weapons to be manufactured and used by humans. However, a dearth of data on the mechanics of thrusting spear use has hampered experimental research. This paper presents a human performance trial using military personnel trained in bayonet use. Participants thrusted replicas of Middle Pleistocene wooden spears into PermaGel™. For each spear thrust, impact velocity was recorded with high-speed video equipment, and force profiles were recorded using a force transducer. The results demonstrate that training improves performance when compared with previous experimental results using untrained participants, and that the mechanics and biomechanics of spear thrusting are complex. The trial confirms that previous spear thrusting experiments firing spears as projectiles are failing to replicate the entire spear thrusting event, and that crossbows are too powerful to replicate the low velocities involved in spear thrusting. In order to better understand evidence of spear thrusting in the archaeological record, experimental protocols accurately replicating and recording the mechanics of spear thrusting in the past are proposed.

1. Introduction: replicating and recognising thrusting spears in prehistory

The use of weaponry throughout human evolution has far-reaching implications for understanding human subsistence behaviours, interpersonal violence and self-defence against both animals and other humans (Churchill et al., 2009; Shea, 2006). These implications are most significant for understanding changes in cognitive or physiological capacities of earlier species of *Homo* as opposed to anatomically modern humans (e.g. Churchill, 1993; Churchill and Rhodes, 2009; McBrearty and Brooks, 2000; Rhodes and Churchill, 2009; Roach et al., 2013; Roach and Richmond, 2015; but see Lombard and Parsons, 2010), with the role of weapons contributing to recent discussions on hunting and scavenging strategies (e.g. Hardy et al., 2013; Villa and Soriano, 2010), human dispersal events (e.g. Shea and Sisk, 2010; Sisk and Shea, 2011) and tool use amongst extant primates (Huffman and Kalunde, 1993; Pruetz and Bertolani, 2007). While a significant trend in research has involved better understanding 'complex' projectile technologies, i.e. those mechanically aided such as spearthrowers and bow-and-arrows, much of the focus has recently shifted to an interest in hand-delivered thrusting and throwing spears, including those with hafted lithic points as well as untipped wooden spears (Hutchings, 2011; Iovita et al., 2016; Rieder, 2001; Schmitt et al., 2003; Shea et al., 2002, 2001; Wilkins et al., 2014a).

A better understanding of the timing of the development of weapon systems is not just a matter of interest in and of itself, as the development of weaponry has long been seen as key to understanding the abilities of our hominin ancestors to hunt ever more successfully with progressively complex technologies (e.g. Dart, 1949; Darwin, 1871; McBrearty and Brooks, 2000; Shea and Sisk, 2010; Washburn et al., 1968) . A simplified unilinear model of the evolution of weaponry suggests that thrusting spears were an early weapon, although the timing of their appearance remains poorly understood (Rieder, 2003; Shea, 2006; Shea and Sisk, 2010; Wilkins et al., 2014a, 2012; Iovita et al., 2016). The hand-delivered throwing spear, presumably coincident with or subsequent to the human capacity for throwing, is generally thought to have emerged after the first use of thrusting spears, though the timing of this is debated as well (Iovita et al., 2016; Rhodes and Churchill, 2009; Roach and Richmond, 2015).

The ability to distinguish between different weapon systems, for example by identifying delivery-dependent ballistic properties and

* Corresponding author.
E-mail addresses: a.milks@ucl.ac.uk (A. Milks), s.m.champion@cranfield.ac.uk (S. Champion), libby.cowper@rmit.edu.au (E. Cowper), m.pope@ucl.ac.uk (M. Pope), d.j.carr@cranfield.ac.uk (D. Carr).

http://dx.doi.org/10.1016/j.jasrep.2016.09.005
2352-409X/

usewear on lithic points would, according to the linear model, help to understand the timing of the appearance of weapon systems (Shea, 2006; Hutchings, 2011; Iovita et al., 2014). Leaving aside issues thrown up by the persistence of both untipped and composite hand-delivered spears amongst modern hunter-gatherer groups either alongside or in the absence of 'complex' projectile technologies (e.g. Driver, 1939; Goodale, 1994; Hiatt, 1968; Hitchcock and Bleed, 1997; Moseley, 1877; Spencer, 1914; Swanton, 1946), the search for these data is hampered by a poor understanding of the mechanics and biomechanics of hand-delivered weapons, with experimental work relying upon estimates of impact velocities and forces involved (e.g. Iovita et al., 2016; Shea et al., 2002, 2001; Wilkins et al., 2014a).

The earliest complete weapons in the archaeological record are a collection of 10 untipped wooden spears from Schöningen, Germany dating to MIS 9 (Richter and Krbetschek, 2015; Thieme, 1997; Schoch et al., 2015; Urban et al., 2011). A broken tip of a wooden implement, with a tip morphology similar to the collection of spears from Schöningen, comes from Clacton-on-Sea and probably dates to MIS 11 (Bridgland et al., 1999; Oakley et al., 1977). Interpretation of the function of these Middle Pleistocene wooden spears has varied and has included thrusting spears, hand-thrown spears and snow probes for locating carcasses (e.g. Gamble, 1987; Oakley et al., 1977; Schmitt et al., 2003; Thieme, 1997). Particularly in light of recent *Homotherium latidens* finds from the 'spear horizon' at Schöningen, and possible evidence of interpersonal violence at Sima de los Huesos dating to MIS 11, other possibilities include weapons for self-defence and violence amongst conspecifics (Sala et al., 2015; Serangeli et al., 2014). However, given the abundance of butchered zooarchaeological remains, in particular at least 46 *Equus mosbachensis* thus far described from Schöningen 13 II-4 (van Kolfschoten, 2014), an interpretation of these finds as hunting weapons remains a reasonable functional assignment.

With the 'spear horizon' at Schöningen probably corresponding to MIS 9, candidates for the species that made these weapons include *H. heidelbergensis* or possibly early *H. neanderthalensis* (Conard et al., 2015; Street et al., 2006; Stringer, 2012). Male *H. heidelbergensis* had an estimated mean body mass of 79.3 kg, compared with estimates of between 66.5 kg and 69.2 kg for Palaeolithic male *H. sapiens* (Froehle et al., 2013) and an estimate of 49 kg for *H. erectus* (Hatala et al., 2016). Stature estimates for *H. heidelbergensis* are around 175 cm (Stringer et al., 1998). The stature and body mass estimates for *H. heidelbergensis* imply a powerfully built, robust species of human.

In a landmark paper on prehistoric weapon technology, Susan Hughes (1998) identified a lack of reported data on thrusting spears, not only restricted to design of lithic tips of composite thrusting spears, but also on the forces and velocities that might occur during spear thrusting. Shea et al. (2001, p. 809) reiterated this absence of data, thus relying on data from one-handed stabbing experiments to design their controlled experiment investigating Levallois point-tipped thrusting spears. The one-handed stabbing experiments to which Shea et al. (2001) referred were conducted to understand the effects of knife stabbing (Table 1), in order to design appropriate clothing for law enforcement officers (Horsfall et al., 1999; Miller and Jones, 1996). However, the mechanics and biomechanics of one-handed stabbing are different from two-handed spear thrusting, and the weapon considered in this previous work (a knife) is different from a thrusting spear in mass, morphology and material, rendering use of these data not appropriate. Controlled experiments aiming to replicate two-handed spear thrusting continue to rely on estimates of velocity and force, with a wide range of velocities being tested, spanning from 1.0 m/s to 10.3 m/s (Table 2) (e.g. Iovita et al., 2016; Shea et al., 2001; Wilkins et al., 2014a, 2014b) and with force rarely being replicated (but see Iovita et al., 2016). The use of such a wide range of impact velocities calls into question results relating to the effectiveness of the weapons tested and damage caused to lithic points, and makes comparison of results between experiments problematic. In comparison, Schmitt et al. (2003) provided experimental data on thrusting spears, using aluminium poles on a 'padded' target, but the experiment was designed to understand the forces acting on the human body during two-handed spear thrusting in order to aid the identification of spear use on human fossil material. This difference in objective led to an under-reporting of data on impact velocities, an absence of data on forces imparted on the spear itself, and the use of untrained participants. A more useful study aimed at understanding differences in grips in one-handed spear thrusting in antiquity captured forces and velocities with a force transducer and accelerometer, albeit with one participant conducting a small number of thrusts ($n = 11$) with a 1350 g metal-tipped spear at a padded target (Connolly et al., 2001).

In response to these problems and the resulting need to develop a new experimental framework, the current paper describes the results from a human performance trial of 11 males trained in military bayoneting that was designed to record impact velocities and force profiles for two-handed spear thrusting. Trained males were chosen with the aim

Table 1
Impact velocities from previous studies.

Type experiment	Velocity (range)	Velocity (mean)	Velocity estimated or filmed	Firing mechanism	Source
Human performance One-handed stabbing: overarm and underarm	6–10 m/s	5.8 m/s (underhand) 8.9 m/s (overhand) ($n = 203$)	Calculated via acceleration data, verified with high speed video for some trials	Humans (n = not reported), mixed male/female	Horsfall et al. (1999)
Human performance One-handed stabbing: overhand, short forward thrust, side sweep	2.6–9.2 m/s	5.8 m/s ($n = 600$)	Six-camera VICON motion analysis system	Humans ($n = 20$), mixed male/female, mixed students and trained police	Chadwick et al. (1999)
Human performance One-handed stabbing: short underhand, short overhand, long underhand, long overhand	5.8–12.0 m/s	6.6 m/s short underhand; 7.0 long underhand; 9.1 short overhand; 12 m/s long overhand ($n = 10$ stabs each type)	Filmed, standard video recorder (Panasonic M10 video recorder)	Humans ($n = 10$), mixed male/female	Miller and Jones (1996)
Human performance One-handed slashing; various types and directions	Minimum not reported; maximum 14.88 (all directions)	5.94 m/s	Estimated via calculating length of slash on paper and time (s) to make slash	Humans ($n = 87$) mixed male/female	Bleetman et al. (2003)
Human performance Two-handed spear thrusting	1.7–4.5 m/s	Not reported	Filmed, standard video recorder, 60 frames per second	Humans ($n = 7$), mixed male/female (untrained)	Schmitt et al. (2003)
Human performance One-handed spear thrusting	3.3–6.7 m/s	4.7 m/s ($n = 11$ stabs all grips combined)	Calculated via acceleration data	Human ($n = 1$) male (trained)	Connolly et al. (2001)