In search of the origins of distance hunting – the use and misuse of tip cross-sectional geometry of wooden spears

Journal of Paleolithic Archaeology (2025) 8:9
https://doi.org/10.1007/s41982-024-00206-x

RESEARCH

In Search of the Origins of Distance Hunting—The Use and Misuse of Tip Cross-sectional Geometry of Wooden Spears

Dirk Leder[1] · **Annemieke Milks**[2]

Accepted: 20 December 2024

Abstract

The origins of weapons, and subsequent innovations, constitute a significant focus of archaeological research, particularly for the Pleistocene period. Due to preservation challenges, inorganic components of early weapons, such as lithic points, are often the only artefacts to survive. As a result, archaeologists rely on proxies for understanding performance and function of these lasting components including experimental research and ethnographic comparison. Within these analogical frameworks, and alongside use-wear and fracture analysis, morphometrics constitute a key method in assessing whether a point is a weapon component. Early attempts to use the cross-sectional geometries of weapon points (or tips), making use of complete archaeological specimens and ethnographic weapons as reference datasets, suggested clear demarcations between different delivery modes. Yet, subsequent studies have shown that there are considerable overlaps. Recently, it was proposed that on the basis of tip geometries, the earliest complete weapons, Pleistocene wooden spears, are best matched to thrusting spear use. Here we demonstrate that there are measurement errors involved in this classification, and that furthermore there are overlaps between thrusting spears and javelins (throwing spears) that undermine the use of tip geometries to define spear delivery mode. If the correct methods are applied, archaeological wooden spear tip geometries would fit within both thrusting and javelin categories, meaning this is not methodologically useful at this time. We overview the available archaeological, experimental, and ethnographic evidence and propose that these currently support a hypothesis that the technological capacity for use of distance hunting weapons was in place from at least 300,000 years ago.

Keywords Ethno-archaeology · Morphometrics · TCSA · TCSP · Spears · Javelins

Introduction

The question as to when and where certain technological innovations like control of fire, clothing, and weapons first manifested and how these intersect with adaptations to climatic and demographic shifts are focal points in our understanding of human behavioural and cognitive evolution (Ashton & Davis, 2021; Hosfield, 2020). The innovation of weaponry provided early hominins with a wider array of strategies beyond pursuit hunting (see Liebenberg, 2006) with which to hunt prey. One traditional unilineal model posits that the earliest hunting tools were essentially contact weapons, used either as stabbing spears or spears thrown at very short distances of ca. 5 m (Churchill, 1993; Shea, 2006). Medium (10–20 m) and long-distance (> 20 m) projectile weapons, including throwing spears (javelins), and eventually mechanically projected weapons, such as spearthrowers and bow and arrows, likely provided significant advantages. These include the ability to safely and effectively hunt, reducing risks of injury while increasing the distance between human hunters and prey, having a positive effect on individuals' and societies' health and life expectancy (Churchill, 1993; Shea & Sisk, 2010). Therefore, pinpointing the timing, regions, and species who first innovated distance weapons has been a focal point of archaeological research. The search for relevant data has relied heavily on ethnographic comparison. One means of evaluating isolated archaeological stone points that may have functioned as weapon tips is to evaluate their morphometrics and compare

✉ Annemieke Milks
a.g.milks@reading.ac.uk

[1] Department of Hunter-Gatherer Archaeology, Niedersächsisches Landesamt für Denkmalpflege (Lower Saxony State Office for Cultural Heritage), Hannover, Germany

[2] Department of Archaeology, University of Reading, Reading, United Kingdom

Published online: 13 February 2025

them to ethnographic and experimental points. Tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TCSP) measurements are particularly widely used as comparative methods for stone weapon points. This approach has recently been extended to attempt to determine the delivery method(s) of Pleistocene wooden spears. We suggest that such attempts are beleaguered with significant and probably unresolvable issues. We present new and recently published morphometric data on archaeologically preserved wooden spears from Clacton, Schöningen, and Lehringen in Europe dating from 400 to 120 ka BP and compare these with ethnographic data. We show, as others previously have (Clarkson, 2016; Newman & Moore, 2013; Sahle & Brooks, 2019; Sahle et al., 2023), that the TCSA/TCSP method involves too many morphometric overlaps to be especially useful as a means of determining mode of spear delivery. When evaluated with appropriate measurements for wooden spears, Pleistocene wooden spears would nevertheless fit comfortably within known parameters for both thrusting and throwing spears, likely reflecting both high levels of morphometric variability, as well as multifunctionality. Based on previous experiments and published ethnographic data, we conclude by outlining evidence that wooden spears could have served as effective hunting weapons both at short range as well as at a distance.

The Archaeological Record of Wooden Spears

Palaeolithic wooden tools rarely survive in the archaeological record, and most of our interpretations of early human evolution rest upon the data we can squeeze from stone, and in rare cases from bone and antler. Exceptional preservation conditions at a few sites across the globe enabled the survival of early wooden artefacts, providing evidence on classes of technologies and behaviours not often discussed for the Lower and Middle Palaeolithic (Aranguren et al., 2018; Barham et al., 2023; Leder et al., 2024; Rios-Garaizar et al., 2018). These include the earliest unequivocal weapons in the archaeological record, in the form of complete and fragmented wooden pointed spears (Fig. 1) (Adam, 1951; Thieme, 1997; Warren, 1911). These discoveries altered our perception of the hunting abilities of early hominins, leading to a paradigm shift with regard to hominin behaviours (Conard et al., 2015).

A broken point shaped from yew wood (*Taxus baccata*) discovered in freshwater deposits at Clacton-on-Sea (UK) dates to Marine Isotope Stage (MIS) 11 (Ashton et al., 2016; Bridgland et al., 1999; Warren, 1911, 1923). On the basis of the wood species, size, shape, and shaft break, the object has most often been interpreted as a thrusting spear, although other functional uses such as a snow probe and game stake have also been proposed (Allington-Jones, 2015; Gamble, 1987; Oakley et al., 1977). The archaeological site of Schöningen (Germany) is most famous for its collection of wooden weapons made from spruce (*Picea abies*) and pine (*Pinus* sp.), including multiple throwing sticks alongside fragments of at least 10 and as many as 18 spears, several of which are complete (Conard et al., 2020; Leder et al., 2024; Schoch et al., 2015; Thieme, 1997). The 'Spear Horizon' dates to MIS 9 and also contains the remains of a significant number of butchered animals (García-Moreno et al., 2021; Richter & Krbetschek, 2015; Starkovich & Conard, 2015; Van Kolfschoten et al., 2012, 2015; Voormolen, 2008). The Schöningen spears have been variously interpreted as throwing spears and/or thrusting spears, and as weapons for self-defence (Gaudzinski-Windheuser et al., 2018; Milks, 2018; Milks et al., 2023b; Schoch et al., 2015; Serangeli et al., 2015; Thieme, 1997). Also from the Eurasian Pleistocene

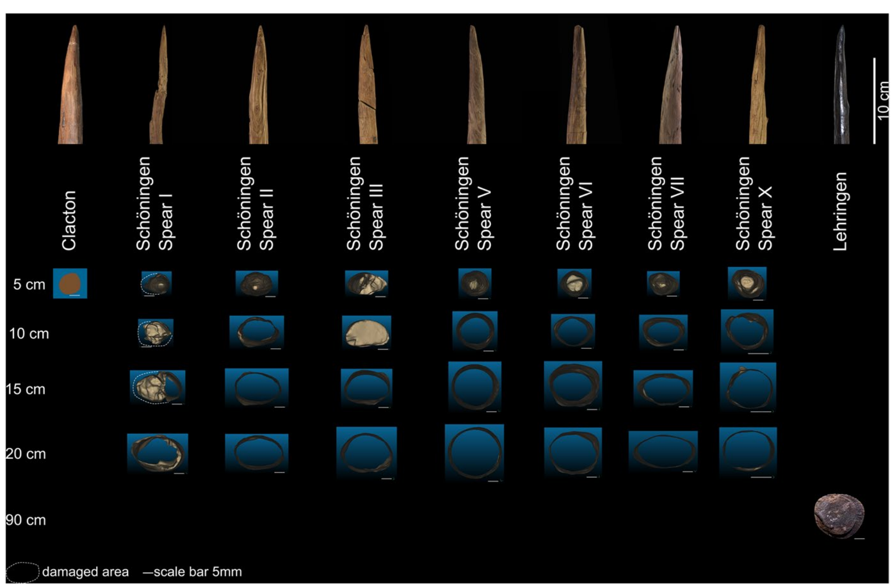

Fig. 1 Front points of wooden spears from Clacton-on-Sea, Schöningen, and Lehringen. The cross-section of Clacton is a mask from a microCT scan. Cross-sections of the Schöningen spears are taken from 3D models. The Lehringen cross-section is reproduced courtesy of Werner Schoch (2014). Elliptical outlines are a result of sediment pressure (see "Measurement Error 2: Original Published Diameter Data Were Overestimated" section)

record is the MIS 5e site of Lehringen (Germany), where in 1948 a complete yew spear was discovered in association with a straight-tusked elephant (*Palaeoloxodon antiquus*) (Adam, 1951; Movius, 1950; Thieme & Veil, 1985). The Lehringen spear—often called a 'lance'—is normally interpreted as a thrusting weapon, again on the basis of its morphometrics (e.g. Gaudzinski-Windheuser et al., 2018; Oakley et al., 1977; Tode, 1954; Villa & Lenoir, 2006).

In sum, authors typically accredit the wooden spears from Clacton and Lehringen to a function as thrusting weapons (Churchill, 2002; Gaudzinski-Windheuser et al., 2018; Lombard, 2022a, b; Oakley et al., 1977; Thieme & Veil, 1985). By contrast, in the case of the Schöningen spears, authors either consider them as having been used for distance throwing (Schoch et al., 2015; Thieme, 1997), as thrusting spears or for very short-distance (under ca. 5 m) throwing (Churchill, 2014, pp. 61–63; Gaudzinski-Windheuser et al., 2018), or multifunctionally as both thrusting and medium-distance throwing weapons (Leder et al., 2024; Milks, 2018; Milks et al., 2023b; Serangeli et al., 2023). The significance of morphometrics and reference to ethnographic examples to this debate cannot be overstated and thus requires a deeper investigation than has sometimes occurred.

Ethnographic Spear Point Morphometrics and Inference of Weapon Delivery

One way to approach the question of weapon delivery modes in the Palaeolithic is to integrate archaeological and ethnographic data. Until recently, the largest published morphometric dataset on complete ethnographic wooden spears was a sample of 36 spears from museum collections (Oakley et al., 1977), while Milks et al. (2023a) recently provided data on 58 complete ethnographic wooden spears. The morphometrics in both studies include length, mass, maximum diameter, point of balance, and tip diameters at various distances from the front point, which were compared to the data available at the time of known archaeological spears. Oakley et al. (1977) had proposed that it was possible to distinguish between thrusting and throwing spears on the basis of their comparative measurements. Through a critical engagement with Oakley et al.'s (1977) data and a statistical analysis of the new dataset, Milks et al. (2023a) demonstrated that none of the five criteria suggested for making a distinction between thrusting and throwing spears are upheld.

As complete hunting weapons rarely survive in the archaeological record, archaeologists focus on what typically preserves, namely stone points. Leaving aside the observation that not every early pointy artefact was likely to have been used as a spear point (Hutchings, 2016; Plisson & Beyries, 1998; Rots & Plisson, 2014; Shea, 1997), such studies rely on morphometric measurements, most often using calculations of tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TSCP). Analysing these archaeological stone points within a statistical framework, researchers compare these against tips of ethnographic weapons of known function to determine the likely weapon delivery mode(s) in the past (Lombard, 2021, 2022b; Lombard et al., 2022; Rios-Garaizar, 2016; Shea, 2006; Shea & Sisk, 2010; Sisk & Shea, 2011). Replicas of stone points tested as spear points have stood in as representative of stone points of known function, presenting a particular form of circular reasoning. To resolve the lack of data on spear tips, some have made use of ethnographic data of spears of known function tipped with different materials, and especially with metal (Lombard et al., 2022; Lombard, 2022a).

In this paper, we deliberately avoid conducting in-depth statistical analyses of the data for several reasons. First, the archaeological sample of wooden spears with relevant tip morphometrics ($n=9$) is too small for statistical analysis to prove useful; similarly, those ethnographic wooden spears for which function could be determined also represent small sample sizes, and often the provenance of these is from very specific groups and therefore unlikely to be representative of the weapon category as a whole. Second, a detailed statistical analysis of morphometrics of the ethnographic wooden spear reference dataset has recently been published (Milks et al., 2023a). Finally, we feel that with the issue of overlap of TCSA and TCSP for spear delivery mode being so significant, as we will demonstrate, even simple descriptive statistics can be misleading and misused. In fact, by stripping away statistics including means, medians, and probability, so often utilised for TCSA/TCSP, we illustrate that issues of overlap, sometimes but not always acknowledged in publications, make it challenging to assign delivery to a given archaeological weapon/weapon component.

Tip Cross-sectional Geometry

First introduced by Hughes (1998), TCSA has been widely explored by archaeologists as a proxy to infer differences between weapon delivery systems, as well as the penetrative effectiveness of weapon points (e.g. Eren et al., 2021; Grady & Churchill, 2023; Lazuén, 2012; Lombard, 2021, 2022b; Lombard et al., 2022; Sahle et al., 2013; Salem & Churchill, 2016; Sano, 2016; Shea, 2006; Shea & Sisk, 2010; Shea et al., 2001; Sisk & Shea, 2011; Sitton et al., 2020, 2022; Villa & Lenoir, 2009; Villa & Soriano, 2010). In the original publication, Hughes (1998, p. 350) emphasises that four variables influence projectile penetration including mass, velocity, tip cross-sectional area, and projectile shape. Therefore, area is only one component. We would add that material, an under-explored feature, may also influence penetration (Salem & Churchill, 2016; Waguespack et al., 2009; Wilkins et al., 2014). The integration of ethnographic and experimentally used weapons as reference datasets forms the key to this method. TCSP was introduced subsequently as an additional comparative morphometric to address the geometric differences between bifacial and unifacial stone tools (Sisk & Shea, 2009). The utility of both TCSA and TCSP has already been extensively debated, with key issues including:

1. Significant overlaps of the points' sizes *across* different weapon delivery systems, as well as wide variability *within* a given weapon delivery system in the ethnographic record (Clarkson, 2016; Newman & Moore, 2013; Sahle et al., 2023);
2. The TCSA/TCSP values of a given archaeological stone point in isolation of other functional evidence (e.g. use-wear, macroscopic impact fractures, distribution of edge damage) only indicates its *potential* for use as a weapon component (Hutchings, 2016; Lombard & Phillipson, 2010; Milks et al., 2016b; Rots & Plisson, 2014; Sisk & Shea, 2011);
3. Experimental results point to a negative correlation between TCSA/TCSP and penetration depth as one factor of weapon performance (with smaller areas and perimeters associated with greater depths of penetration), but other factors such as shape and energy also play a role and remain under-explored (Baldino et al., 2024; Clarkson, 2016; Grady & Churchill, 2023; Hughes, 1998; Salem & Churchill, 2016; Sitton et al., 2020, 2022).

The goal of this paper is not to discuss in depth the myriad issues of TCSA and TCSP in general, although these intersect with our concerns, but rather to address the specific application of these data to Pleistocene wooden spears and the conclusions that have been drawn concerning the weapon delivery mode of that particular type of weapon. In two recent publications (Lombard et al., 2022; Lombard, 2022a), TCSA values are calculated for fragmented and complete Pleistocene wooden spears. Lombard and colleagues compared TCSA values of wooden spears with ethnographic, experimental, and archaeological points made of stone and metal from various sites and of various ages. In these publications, a key aim appears to have been to strengthen and constrain the application of TCSA to archaeological weapons by expanding the ethnographic reference dataset (Lombard et al., 2022). The high values in comparison with ethnographic spears were used to propose that Pleistocene wooden spears did not function as javelins (thrown spears), but rather only as thrusting spears (Lombard, 2022a).

In this paper, we focus on the question of whether TCSA and TCSP are adequate proxies to determine the weapon delivery mode of the oldest known complete wooden hunting spears dating from ca. 400 to ca. 120 ka BP. We outline three prior measurement errors and discuss three broader conceptual issues regarding functional interpretations. We provide accurate morphometric measurements for the Pleistocene weapons and compare them to ethnographic data on wooden spears. The results provide further reasons to question the method of TCSA/TSCP in determining spear delivery mode. Moreover, and in spite of our concerns about the method, if others continue to use TCSA/TCSP to discuss early spears, we demonstrate that Pleistocene wooden spears would fit well with comparative data for both ethnographic throwing and thrusting spear morphometrics, including for both wooden and iron-tipped javelins.

Measurement Errors on Wooden Spears

Measurement Error 1: Formulas for TCSA and TCSP

The original formula for TCSA is identical to the calculation of a triangle's area, and was intended to produce estimated area data for unifacial and bifacial stone points (Hughes, 1998; Lombard, 2021; Shea, 2006). Sisk and Shea (2011) revised TCSA as a method, adding further reference datasets, and provided further equations to calculate tip cross-sectional perimeter (TCSP), enabling differentiation of perimeters of unifacial and bifacial points. The TCSA and TCSP calculations were arrived at using the following formulas:

Area of unifacial (triangular cross-sections) and bifacial (rhomboid cross-sections) points (TCSA)

$$\left(\frac{Width}{2}\right) * Thickness$$

Perimeter of unifacial points (TCSP)

$$Width + 2 * \sqrt{\left(\frac{Width}{2}\right)^2 + \left(\frac{\text{Thickness}}{2}\right)^2}$$

Perimeter of bifacial points (TCSP)

$$4 * \sqrt{\left(\frac{Width}{2}\right)^2 + \left(\frac{Thickness}{2}\right)^2}$$

These morphological criteria (triangular or rhomboid) are certainly not met by most archaeological and ethnographic wooden spear points, which tend to be round to elliptical in cross-section (Fig. 1) (Allington-Jones, 2015; Leder et al., 2024; Milks, 2018; Milks et al.,. 2023a; Oakley et al., 1977; Schoch et al., 2015; Thieme & Veil, 1985). Elliptical shapes in archaeological spears are due to sediment compression in deteriorated wood and originally had been approximately round (Fig. 1; "Measurement Error 2: Original Published Diameter Data Were Overestimated" section). Both Hughes (1998) and Salem and Churchill

(2016) calculate TCSA for prehistoric cylindrically shaped weapon points and weapon components (e.g. foreshafts) as:

π r2

where r = radius.

This equation provides a more accurate representation of TCSA for round cross-sections, although it still requires an accurate measurement method for the radius (see "Measurement Error 2: Original Published Diameter Data Were Overestimated" section). In an aforementioned publication (Lombard, 2022a) the original TCSA calculation intended for stone points was used to calculate the TCSA of wooden spears, which would in theory result in significantly *underestimating* the TCSA for wooden spears. For TCSP, the correct formula for this shape is

$\pi\ d$

where d = diameter (Hughes, 1998); Fig. 2; but see also "Measurement Error 3: Use of Maximum Diameter as a Proxy for Tip Measurements" section).

To further illustrate the appropriateness of calculations for wooden spears based on a circle rather than triangles and rhomboids, we use the example of a cross-section of the Clacton spear point. We measured the area and perimeter of this CT scan–generated cross-section directly in SketchAndCalc® and compared the results of calculations based on a circle (using the mean of width and thickness measurements, i.e. averaged diameter) to those based on a triangle/rhomboid. The difference between the area based on the equation for a circle from the direct measurement is 1.46 mm^2, whereas the difference when calculating it based on a triangle/rhomboid is 33.42 mm^2. Using the equation for a triangle/rhomboid results in underestimating its area by 37% (Fig. 3).

To confirm that the formula for the spears should be based on a circle, we show the underlying diameter measurements for the spears in Table 1 (also see Fig. 1 and "Measurement Error 2: Original Published Diameter Data Were Overestimated" section). For each of the spears, we demonstrate that the resulting TCSA values based on the triangle/rhomboidal equation consistently underestimates their area.

Measurement Error 2: Original Published Diameter Data Were Overestimated

The maximum diameter measurements for Pleistocene wooden spears used by Lombard (2022a; Lombard et al., 2022) were based on previously published measurement data (Oakley et al., 1977; Schoch et al., 2015; Thieme & Veil, 1985). For the Schöningen spears, diameter measurements were over-estimated as they were taken as single measurements of maximum width on objects that had suffered from sediment compression (Leder et al., 2024; Milks et al.,

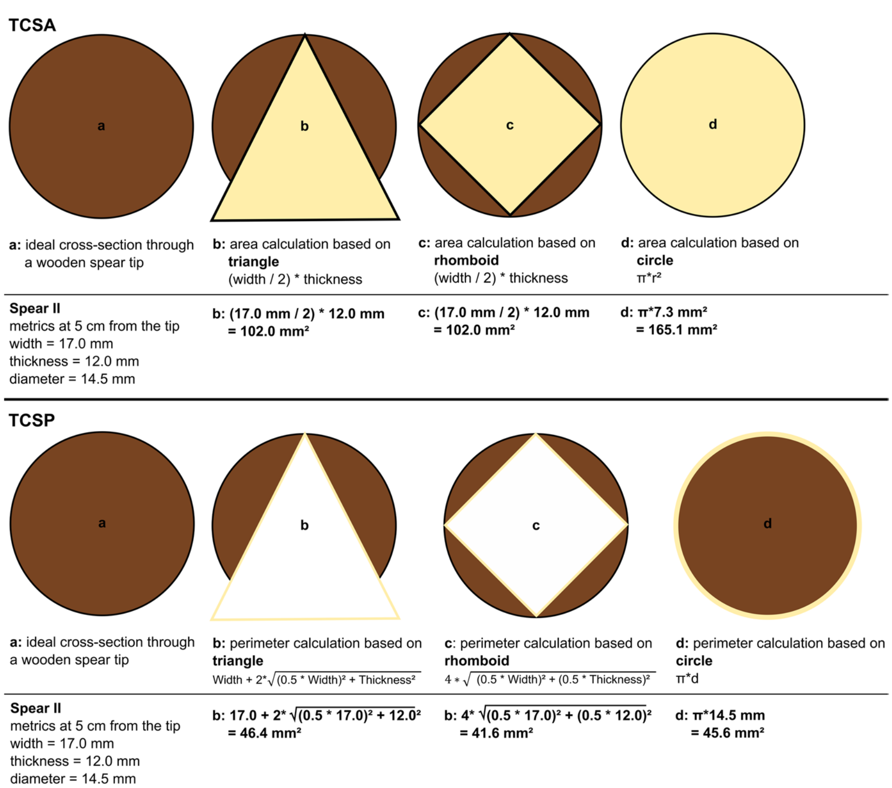

Fig. 2 Calculating the cross-sectional area (TCSA) and perimeter (TCSP) of Schöningen Spear II. **a** Represents an idealised cross-section through a wooden spear tip. Averaged diameter represents the mean between two measurements replacing 'width' and 'thickness' due to taphonomic compression (see "Measurement Error 2: Original Published Diameter Data Were Overestimated" section). **b** Area and perimeter calculated based on a triangular shape. **c** Area and perimeter calculated based on a rhomboid shape. **d** Area and perimeter calculated based on a circular shape. Depending on the shapes, area sizes differ as much as 38.2%. Differences in perimeter calculations are substantially smaller but still reach up to 10.4%

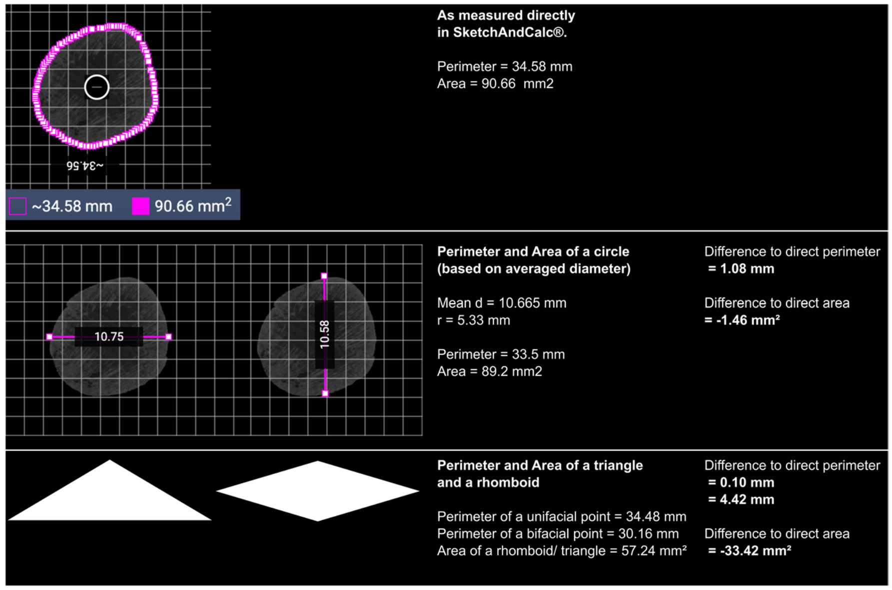

Fig. 3 Calculating the cross-section area of the Clacton spear point. Top: direct perimeter and area measurements from a CT scan slice taken ca. 4 cm from the point using the tool SketchAndCalc®. Middle: perimeter and area calculated using width and thickness measurements (averaged diameter) in SketchAndCalc, following the equation for the area of a circle, πr^2. Bottom: schematic triangular and rhomboidal shapes, with perimeter and area calculated based on the equation for these shapes [Width/2) *Thickness; note that the result is the same, regardless of which diameter measurement is used for width vs thickness]

Table 1 Comparison of the formulas for TCSA based on a circle vs based on a triangle/rhomboid for the archaeological wooden spears, using the two diameter measurements taken at 5 cm, using callipers

Spear	Measurement 1 at 5 cm (width)	Measurement 2 at 5 cm (thickness)	Mean value	TCSA based on circle	TCSA based on triangle/rhomboid*
Clacton	15	15	15	176.7	112.5
Schöningen Spear I (slightly damaged at 5 cm)	12.9	9.4	11.15	98.52	60.63
Schöningen Spear II	15.5	11.9	13.7	147.41	92.2
Schöningen Spear III	17	12	14.5	165.12	102
Schöningen Spear V	15	13	14	153.94	97.5
Schöningen Spear VI	15.3	12.5	13.9	151.75	95.6
Schöningen Spear VII	17	14	14.5	165.1	102
Schöningen Spear X	17	14	15.5	188.69	119
Lehringen	13	11	12	113.09	71.5

For the circle equation, this calculation uses the mean value of the two diameter measurements. For the triangle/rhomboid equation, the two diameter measurements are used for width and thickness

*These values remain constant, irrespective of which diameter measurement is selected for width and which for thickness

2023b). Analysis of these 'squashed' cross-sections, which had formerly been broadly round, confirms the taphonomic nature of the current morphology (Figs. 1 and 4). Woodworking alters the surface of wooden artefacts while truncating annual rings when carving into the wood (e.g. see Milks et al., 2023b). For the wooden weapons when both wood and annual ring cross-sections have elliptic shapes, such features suggest taphonomic alterations when cell wall degradation in wood has advanced (Schmitt et al., 2005) and superimposed sediments result in taphonomic compression. In the case of Schöningen, 15 m of sediment cover and a former ice-sheet induced immense pressure on these wooden artefacts over a period of 300 ka (Lang et al., 2015; Schoch et al., 2015). Computed tomography scans in combination with annual ring analysis together show that elliptical cross-sections of Schöningen spears are taphonomic in nature, while for at least one of the Schöningen double-pointed sticks, points were shaped to be elliptical as illustrated by the cutting away of annual rings (Leder et al., 2024; Milks et al., 2023b). We can thus understand that the Schöningen spears, generally with minimal deformation in cross-section, were designed to be round in cross-section, and should be analysed as such.

Consequently, the diameter measurements reported in those publications for archaeological weapons are larger than the true original diameter measurements would have been (Figs. 1 and 4), as previously published measurements reflected a single diameter measurement of the widest value (Schoch et al., 2015; Thieme, 1997). We revised

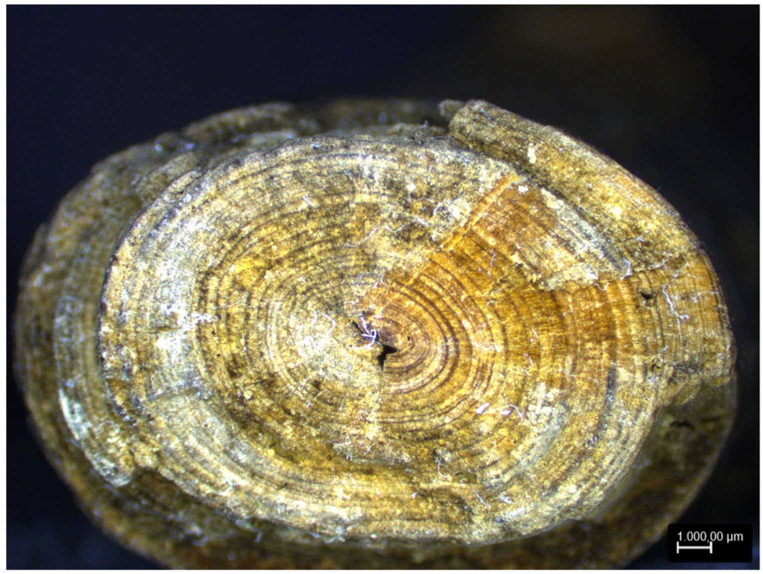

Fig. 4 Cross-section of Spear II from Schöningen at 148 cm from the front point. Note the elliptical shape of the cross-section and the shape of annual rings due to sediment compression. Photo M. Sietz, NLD

the measurement method to create more accurate diameter values by taking two perpendicular diameter measurements and using the average value; we recently published these corrected data (Fig. 3) (Leder et al., 2024; Milks et al., 2023b). We use this method here to present corrected tip data and resulting TCSA and TCSP calculations for the Clacton, Schöningen, and Lehringen spears (Table 2). We provide relevant ethnographic data for comparative purposes (Tables 3 and 4). We do so not because we feel these data are especially useful (see further discussion points below), but rather to provide accurate measurements and calculations for those who wish to make these comparisons, and as a reference dataset for future experimental replicas.

The TCSA and TCSP for ethnographic thrusting spears sit comfortably within the range of those for throwing spears (Tables 3 and 4), whether measured at 5 cm or at 20 cm. Therefore, on the basis of a direct comparison between the archaeological and ethnographic wooden spears, tip diameter does not appear to correlate with delivery mode of wooden spears (see also Milks et al., 2023a).

Table 2 Corrected TCSA and TCSP data for archaeological wooden spears with examples for 5 cm and 20 cm values (all raw data can be found in the accompanying datasets)

Artefact	Dia (mm) at 5 cm	TCSA (πr^2) at 5 cm	TCSP ($\pi Ø$) at 5 cm	Dia (mm) at 20 cm	TCSA (πr^2) at 20 cm	TCSP ($\pi Ø$) at 20 cm
Clacton	15.0	176.7	47.1	30.5	730.6	95.8
Sch. Spear I	11.2	97.6	35.0	21	346.4	66
Sch. Spear II	13.7	147.4	43.0	19	283.5	59.7
Sch. Spear III	14.5	165.1	45.6	22	380.1	69.1
Sch. Spear V	14.0	153.9	44.0	26	530.9	81.7
Sch. Spear VI	13.9	151.7	43.7	23	415.5	72.3
Sch. Spear VII	14.5	165.1	45.6	24	452.4	75.4
Sch. Spear X*	15.5	188.7	48.7	22	380.1	69.1
Lehringen	12.0	113.1	37.7	17	227	53.4
Minimum	**11.2**	**97.6**	**35.0**	**17**	**227**	**53.4**
Maximum	**16.0**	**188.7**	**48.7**	**30.5**	**730.6**	**95.8**
Mean	**13.9**	**151.1**	**43.4**	**22.7**	**416.3**	**71.4**
Standard deviation	**1.45**	**27.5**	**4.1**	**3.7**	**139.1**	**11.6**

*The point in Spear X was reworked and hence its original diameter probably changed considerably (Leder et al., 2024)

Table 3 TCSA and TCSP data at 5 cm and 20 cm for ethnographic wooden thrusting spears

Museum	ID	TCSA 5 cm	TCSP 5 cm	TCSA 20 cm	TCSP 20 cm
Horniman	NN18970	63.6	28.3	113.1	37.7
MAA Cambridge	Z 42280	95.0	34.6	154.0	44.0
MAA Cambridge	Z 6377	132.7	40.8	201.1	50.3
Minimum		**63.6**	**28.3**	**113.1**	**37.7**
Maximum		**132.7**	**40.8**	**201.1**	**50.3**
Mean		**97.1**	**34.6**	**156.0**	**44.0**
Standard deviation		**28.3**	**5.1**	**36.0**	**5.1**

Table 4 TCSA and TCSP data at 5 cm and 20 cm for ethnographic wooden throwing spears (javelins)

Museum	ID	TCSA 5 cm	TCSP 5 cm	TCSA 20 cm	TCSP 20 cm
Horniman	NN18960	63.6	28.3	153.9	44.0
Horniman	NN18952	50.3	25.1	132.7	40.2.18
Horniman	NN18950	95.0	34.6	201.1	50.3
Horniman	NN18958	78.5	31.4	176.7	47.1
SAM	A39396	NA	NA	415.5	72.3
Australian Museum	E.10755	132.7	40.8	227	53.4
Australian Museum	E.10756	132.7	40.8	176.7	47.1
Australian Museum	E.20093	153.9	44.0	176.7	47.1
TMAG	M.2721	227.0	53.4	314.2	62.8
TMAG	M.2724	78.5	31.4	132.7	40.8
TMAG	M.2723	63.6	28.3	132.7	40.8
TMAG	M.2722	176.7	47.1	254.5	56.5
TMAG	M.5902	153.9	44.0	254.5	56.5
TMAG	M.1207	153.9	44.0	254.5	56.5
Minimum		**50.3**	**25.1**	**132.7**	**40.8**
Maximum		**227.0**	**53.4**	**415.5**	**72.3**
Mean		**120.0**	**37.9**	**214.5**	**51.2**
Standard deviation		**50.9**	**8.3**	**77.2**	**8.8**

Measurement Error 3: Use of Maximum Diameter as a Proxy for Tip Measurements

A third error is that measurements of maximum diameter on archaeological wooden spears were used as though they were equivalent to a tip diameter (Lombard et al., 2022; Lombard, 2022a). The location of the maximum diameter (LMD) for complete and nearly complete Schöningen spears ($n = 6$) is between 19 and 41% of the total length from the tip (Leder et al., 2024, Tables S20, S24) meaning the widest diameter is placed along the shaft rather than the tip. For the Lehringen artefact, the LMD is located at the base of the spear, and is thus even more irrelevant as a tip value (Milks, 2018; Thieme & Veil, 1985). Maximum diameters of the Schöningen spears measure between 23 and 45 mm (Leder et al., 2024, Tables S6 S20, S24), while the maximum diameter for the Lehringen spear is 31 mm (Milks, 2018; Thieme & Veil, 1985). Maximum diameters are therefore significantly larger than the tip diameters of all known complete Pleistocene wooden spears, whether measured at 5 or 20 cm (Table 2).

To make a meaningful comparison with tip areas and perimeters of stone points possible, we use the appropriate formula of π r^2 ("Measurement Error 1: Formulas for TCSA and TCSP" section), coupled with corrected diameter measurements ("Measurement Error 2: Original Published Diameter Data Were Overestimated" section). Instead of having TCSA values between 481 mm^2 (Lehringen) and 722 mm^2 (Clacton) as previously calculated (Lombard, 2022a; see also different values of 408 mm^2 to 878 mm^2 published in Lombard et al., 2022), we present revised area and perimeter calculations for wooden spear tips (Table 2). These now range from 98.5 to 188.7 mm^2 at 5 cm, up to 227–730.6 mm^2 at 20 cm, with Clacton having by far the largest values. Interestingly, Lehringen, interpreted as a thrusting spear based on its location of maximum diameter, has the smallest area of the sample. Most of the Schöningen spears cluster within the throwing spear range, irrespective of whether areas and perimeters are measured at 5 or at 20 cm (Tables 2, 3, and 4). We examine the implications of these results in the following sections.

Conceptual Problems

Conceptual Problem 1: Correlating Morphometrics with Function

Besides the aforementioned technicalities, an essential question remains as to whether such tip area metrics are useful proxies to infer spear function/weapon delivery mode. In a recent review on the use of morphometrics of complete ethnographic wooden spears, the only measurements that were found to reliably correlate with mode of delivery were length, the location of the maximum diameter in relation to its overall length (LMD, expressed as a % of its total length), and point of balance (PoB, expressed as a % of its total length) (Milks et al., 2023a). Yet, it was noted in that analysis that the small samples of known delivery mode, strongly biased by a large percentage of extremely long javelins coming from a single group, present limitations to these correlations. And indeed, limitations of our data in that paper were highlighted by the contemporaneous publication ethnographic javelin lengths ranging from 108 to 314 cm (Sahle et al., 2023 Appendix A), meaning that the Schöningen spear lengths again fall comfortably within known ethnographic javelin lengths (Leder et al., 2024, Table S6). LMD can be viewed as a proxy for the point of balance (PoB), which is located in the front half of throwing spears, as this is a feature that is essential for flight (Johnson, 1987). LMD values for ethnographic wooden spears range from between 4 and 61% of the total length from the point, with the highest value corresponding to a PoB of 49% (see accompanying dataset). This feature does not prove the use of the spears for throwing as a projectile per se, nor does their use as projectile tools exclude use as a thrusting weapon. What is key is that the LMD of complete and nearly complete Schöningen spears is located in the front half making them likely to be *suited* for flight (Table 1, Fig. 5) (Leder et al., 2024; Milks et al., 2023a). This does differ with the Lehringen example, where an LMD of 88% means a PoB would almost certainly be toward the back of the weapon (Milks, 2018; Milks et al., 2023a; Thieme & Veil, 1985) making it unsuitable for throwing.

In terms of tip morphometrics, we avoid statistical modelling in this paper so as to avoid masking the spread of data. However, previous statistical modelling (Pearsons correlation coefficient and ANOVA) of the ethnographic sample found no support for Oakley et al.'s (1977) hypothesis that throwing spears are finer morphometrically at the tips than thrusting spears (Milks et al., 2023a). This illustrates that categorising early spears as being either thrown *or* thrust on the basis of morphometric comparison of their points with ethnographic examples is unlikely to be empirically viable. This is echoed in other studies showing likely overlaps in terms of tip geometry for different modes of weapon delivery (Clarkson, 2016; Sahle et al., 2023) and presents a major obstacle, if not a fatal flaw in attempts to use TCSA and TCSP as proxies for delivery systems. In a recent ethnographic field study, Sahle et al. (2023) demonstrate that Chabu and Manja peoples in southwest Ethiopia use ten different javelin types (categorised by size and mass). Weapon choice within this depended on multiple factors including the hunter's experience and age, prey size and prey speed, and hunting strategy among others, but not weapon delivery method (as these were all javelins). Measurements on 163 of the javelins in that study provided a wide range of TCSA and TCSP values which overlap with published values for ethnographic darts, throwing spears, and thrusting spears (Lombard et al., 2022; Newman & Moore, 2013; cf. Sahle et al., 2023, Tables 2–3, Fig. 4).

Key to our argument that TCSA and TCSP are not useful measures for spears is the issue of significant overlaps between spear tip measurements across thrusting and javelin use when the dataset is enlarged to include various weapon tip materials (Fig. 6). Comparing the archaeological data

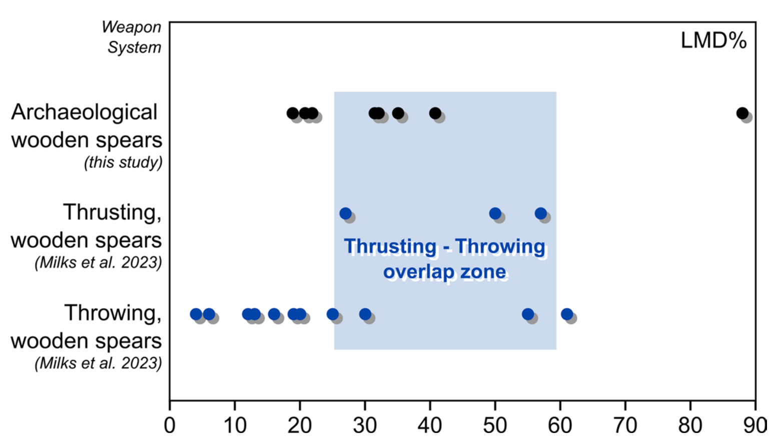

Fig. 5 Location of maximum diameters (LMD %) of archaeological (Schöningen and Lehringen) compared with ethnographic wooden spears of known function

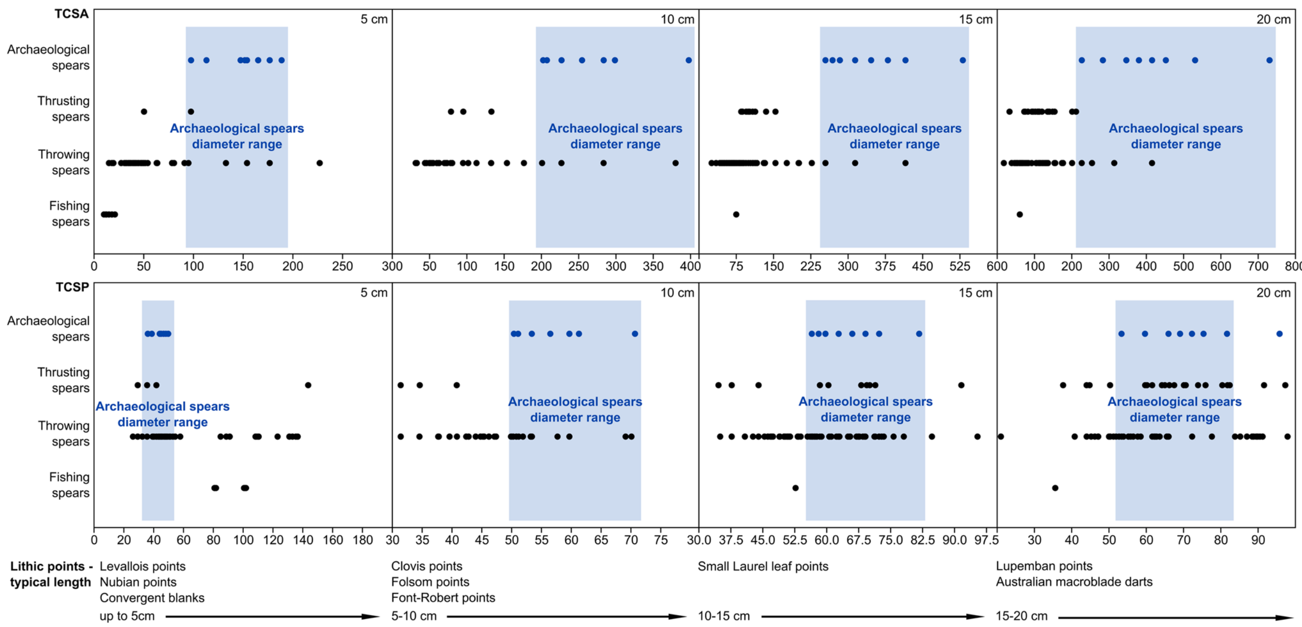

Fig. 6 TCSA and TCSP ranges for 490 known ethnographic fishing spears, ethnographic thrusting spears (combined with those categorised as 'stabbing spears' in Lombard et al., 2022), ethnographic throwing spears, and archaeological wooden spears. All ethnographic data underpinning this graph are culled from the associated publications (Lombard et al., 2022; Milks et al., 2023a; Sahle et al., 2023). Relevant metric data on archaeological wooden spears are provided here with previous publications providing some of these data already (Leder et al., 2024; Milks, 2018). Metric data on lithic points can be found in (Abadi et al., 2020; Aubry et al., 2008; Eren et al., 2020; Hallinan & Shaw, 2020; Leder, 2014; Milks et al., 2016b; Newman & Moore, 2013; Shott & Otárola-Castillo, 2022; Taylor, 2022)

(Table 2) with ethnographic data on wooden spear morphometrics (Tables 3 and 4; see also accompanying dataset) produces a wide range of TCSA values, while TCSP values are more constrained. The wide spread of TCSA data points holds true whether comparing point data at 5 cm or 20 cm from the tip. TCSA values for known Pleistocene wooden spears places most of them within the range of known ethnographic throwing spears of variable tip materials for each diameter measurement location (Fig. 6). TCSP values of the archaeological wooden spears also overlap with values for thrusting spears, particularly when comparing data as measured at 20 cm (Tables 2, 3, and 4, Fig. 6). Only at the 20 cm measurement location do we start to see archaeological spears pulling ahead of throwing spear TCSA, whereas thrusting spear TCSA values at this location are actually comparably smaller.

A further variable impacting on TCSA and TCSP values for wooden spears may be the repairing of tips; the Schöningen spear with the largest TCSA and TCSP values, Spear X, was reshaped after its tip was broken (Leder et al., 2024; Schoch et al., 2015), and therefore the original point was likely smaller in diameter because the location of the new point was moved farther back along the thicker shaft. In sum, any correlation between TCSA/TCSP—or indeed most morphometric measures with the exceptions of length, PoB and LMD—and throwability for wooden spears is not supported either ethnographically or archaeologically, and these should therefore be decoupled (Milks et al., 2023a). This becomes a greater issue when one engages in a transparent way about the quality of associated museum databases and provenance of ethnographic objects, the quality and opacity of some ethnographic reviews on weapon function, alongside the currently understudied effects of weapon tip material and shape. We would like to reiterate that we do not ourselves believe tip morphometric data support that archaeological spears served as throwing weapons, since these data do not appear to be clearly able to distinguish between throwing and thrusting, with overlaps in both TCSA and TCSP of comparative ethnographic reference samples across all measurement locations (Fig. 6).

The placement of 'tip diameter' measurements present an additional conundrum in comparing different weapon types that include single-component weapons such as wooden spears while previous datasets use maximum width of the hafted point instead, irrespective of its distance from the tip, shape, tip material, etc. (Fig. 6). Taper lengths on the Schöningen spears range from 25 to 50 cm, with a median of 37.6 cm (Leder et al., 2024). Archaeological lithic point lengths vary considerably (Fig. 6), and examples of early stone points, such as Levallois and convergent points thought to have been used in Eurasia to tip spears, are only ca. 5 to 7 cm long (e.g. Iovita et al., 2014; Rios-Garaizar, 2016; Rots, 2013). Ethnographic iron points of javelins also vary, with point lengths ranging between 3 and 37 cm (medians of 14 cm, Sahle et al., 2013, and 15 cm Lombard, 2022a; Sahle et al., 2023). For iron-tipped thrusting spears, existing data provide a range of 5 to 80 cm (median of 23 cm, Lombard, 2022a). Arguably, any measurements beyond the generally cited lethal penetration depth of 20 cm (Hughes, 1998; Salem & Churchill, 2016; Waguespack et al., 2009; Wilkins et al., 2014) might not be especially useful.

If tip area (as opposed to a simple width measurement) was a proxy for size of the point to open the wound for a narrower shaft to enter, we also encounter issues with the data because areas for cylinders tend to be larger than those of triangles and rhomboids of a similar width (see "Measurement Error 1: Formulas for TCSA and TCSP" section). Although shafts and their relationship to point sizes are not well-studied areas, we can visit area data presented by Hughes (1998, p. 354 Table II), with width, thickness, area, and perimeter data for a sample of ethnographic arrow and dart tips and foreshafts. Foreshafts are consistently larger in cross-sectional area than tips, although the opposite is true for thickness/diameter measurements. The same holds true for javelins (Sahle et al., 2023 Appendix) wherein the median of point widths is 1.2 times that of foreshaft diameters, whereas the median of cross-sectional areas in foreshafts is 6.1 times larger than for points. Therefore, a hypothesis that cross-sectional areas of hafted tips would be larger than shaft sectional areas is unsupported. Arguably on the basis of those data, only TCSP would be a valuable method to compare tips of different cross-sectional shapes (Hughes, 1998), yet median TCSP in foreshafts of recently published ethnographic spears (Sahle et al., 2023) is still 1.9 times larger than of their points.

Conceptual Problem 2: Experiments on Performance of Wooden Spears

Some researchers question whether early wooden spears could be effective as throwing weapons beyond 5 m distances (e.g. Churchill, 2014; Gaudzinski-Windheuser et al., 2018; White et al., 2016). In a recent paper, Lombard (2022a, p. 2) states that "experiments do not demonstrate that thrown from any distance wooden spears can penetrate the hides of the horses hunted at Schöningen". Yet, experiments have provided data affirming the capability of wooden spears to effectively wound horses, when used as both thrusting and throwing weapons; here we will briefly summarise the methods and results of those experiments (Milks, 2018; Milks et al., 2016a, 2019).

A series of four stepped experiments were designed in collaboration with Cranfield (UK) Defence and Security's ballistics engineers to understand the performance of Schöningen-type spears when used by skilled participants (Fig. 7). Two foundational experiments, both using replicas of Schöningen Spear II, were designed to provide reference data. Experiment A (Fig. 7) captured the forces involved during thrusting with wooden spears (Milks et al., 2016a). Experiment B captured accuracy, release velocity, and impact velocity data when wooden spears were thrown by javelin athletes at distances of 5, 10, 15, and 20 m at a target, and for maximum distance (Milks et al., 2019). The results of that experiment demonstrated that impact velocities and kinetic energy did not significantly vary by throwing distance (Milks et al., 2019 Fig. 1). Experiment C was built upon Experiment A (Fig. 7) and consisted of two male participants trained in martial arts using Spear II replicas to thrust the spears into a horse carcass (Milks, 2018). Meanwhile, Experiment D

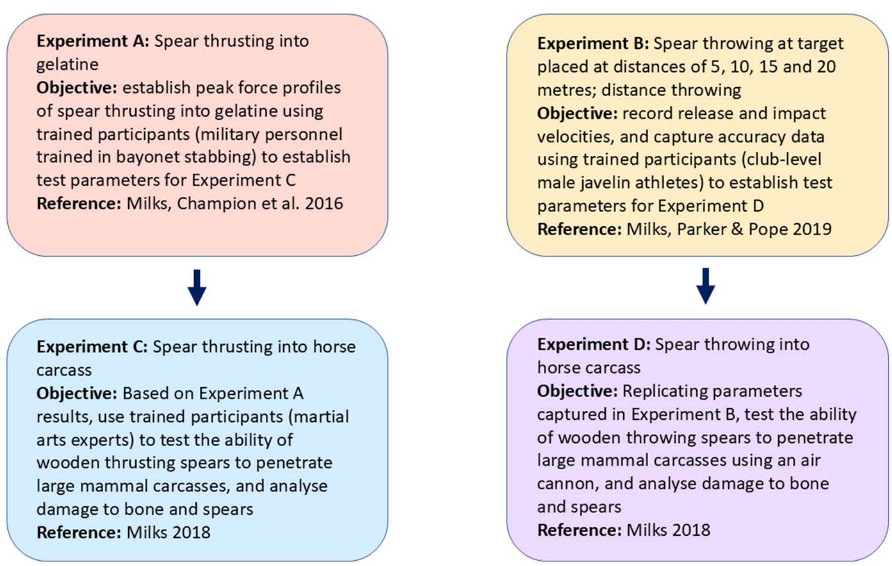

Fig. 7 Workflow of experiments described in "Conceptual Problem 2: Experiments on Performance of Wooden Spears" section

was designed to conduct tightly controlled testing by using an air cannon to fire the spears (Fig. 7), replicating the impact velocities and KE achieved when thrown by javelin athletes in Experiment B, into a second horse carcass (Milks, 2018). Experiments C and D captured data on depth of penetration, with spears and bones subsequently examined for damage. The impact velocities, and hence impact energies, were captured during all experiments through the use of high-speed video footage, using real-time calculations after each shot to ensure the impacts remained true to the delivery system. While a more detailed publication of Experiments C and D is forthcoming, the results are already available (Milks, 2018). Therefore, although Lombard (2022a) questioned whether the impact energies in these horse carcass experiments are equivalent to real-life use as distance weapons, we clarify that the *primary objective* of Experiment B was to provide accurate impact velocity and kinetic energy data for the subsequent controlled experiment, and that the controlled experimental impacts on the horse carcass therefore represent accurate impact velocities from human performance trials, including for distance throws. This is not of course the same as testing these weapons on a live animal, which naturally would have ethical implications.

To briefly summarise the results of Experiments C and D, these demonstrated the ability of wooden spears used in both thrusting and throwing modes to penetrate horse hide, and also their ability to damage bone and muscle tissue, and penetrate > 20 cm, the oft-cited value for lethal wounding (Hughes, 1998; Salem & Churchill, 2016; Waguespack et al., 2009; Wilkins et al., 2014). Notably in the experiments summarised here, while spear thrusts sometimes failed to penetrate the hide, the hide was *always* penetrated when replicating throwing. However, the mean penetration values for thrusting (15.5 cm) and throwing (15.7 cm) were very similar (Milks, 2018, p.330). Both thrust and thrown wooden spears are demonstrated therefore to be capable of lethally wounding a horse (as defined by > 20 cm depth of penetration). That experiment is the first to test wooden spears on large animal carcasses with hide intact and demonstrate the *capability* of these weapons to create lethal wounds on a large animal during both thrusting and throwing. However, the small sample sizes of these experiments present a limitation that would need further validation in a larger experimental study in order to assess *probability* of delivering a lethal wound with thrusting vs throwing, while the definition of 'lethal' depths of penetration is a further issue that is in dire need of experimental testing.

Conceptual Problem 3. Representations and Omissions Regarding Ethnohistoric Accounts on Use of Spears

Beyond experimental data, ethnographic evidence of the use of wooden javelins provides evidence of the capacity for hunting prey including kangaroo, emu, suids, and possibly jaguar (Milks, 2020). Spears were historically noted to have been thrown by a number of societies at distances of 30 to 50 m for hunting and violence (Tiwi, Melville Islands: Spencer, 1914; Morris, 1964; Aboriginal Tasmanians: Lloyd, 1862; Robinson, 1966; Roth, 1890; various mainland Aboriginal Australians: Christison & Edge-Partington, 1903; Giles, 1889; Bari, South Sudan: Baker, 1874; Mae Enga, Papua New Guinea: Meggitt, 1977; Chabu, Ethiopia: Sahle et al., 2023). Spencer (1914) staged a competition-style event with nine Tiwi men and recorded throwing distances of 31.8 to 43.7 m with a spear weighing 1.8 kg. As has been discussed elsewhere, an oft-cited estimate of 5–10 m for effective spear throwing is based on a mean value of 13 societies, within an overarching ethnographic review of weapon use (Churchill, 1993). While the underlying sources in that review are not clear, it could not have included all of the sources above. Churchill (1993, p. 19 emphasis added) explores distance throwing as a hunting technique as follows:

> The Tiwi and Tasmanian cases are curious exceptions to an otherwise robust pattern of hand spears used with disadvantage, ambush, and pursuit hunting. These cases show that hand-propelled spears *can be used as long-range projectiles with approach hunting* – although it was only the Tasmanians who threw the spear long distances (30–40 m) (Roth, 1890); the Tiwi approach prey closely before throwing (Goodale, 1971). If the Tasmanians are excluded, the average effective distance of the hand-thrown spear drops to 5.7 +/- 0.9 m (*N*=13).

With respect to the Tiwi, other sources indicate that they did in fact throw at significant distances (Morris, 1964; Spencer, 1914). We contend that on the basis of evidence, distance throwing is likely to be less related to the capacity of the technology and humans using them than to environment, prey, and socio-cultural factors including whether groups also use(d) mechanically projected weapons or not. As tempting as it is to rely on statistical means, confidence intervals, or significance values to establish categories, in itself an ongoing debate in the wider sciences (e.g. Amrhein et al., 2019), it masks the range of variability, which does not serve in helping us understand the potential range of human behaviours in the present and past.

Discussion and Conclusion

Ethnographic and experimental data help us build robust links with human behaviours in the deep past (Eren & Meltzer, 2024); yet following fundamental scientific principles (whether statistically led or otherwise) analogical tools and archaeological data can only be used to support or reject hypotheses but never to prove. Quantitative and qualitative data can serve to support or question existing narratives, or indeed build new ones. With that in mind, at this juncture, we find through multiple lines of enquiry no empirical basis to reject the hypothesis that Pleistocene spears were used as projectile weapons. Rather, thus far the ethnographic, archaeological, and experimental data on wooden spear use support the hypothesis that these were multifunctional tools, and several of the spears from Schöningen could have functioned as projectiles thrown at medium distances. We reiterate that this does not, and likely never could, *prove* that they functioned as such, but narratives to the contrary must be formulated by accounting for the data at hand.

In a recent paper, Lombard (2022a) proposed that the technological capacity to hunt with javelins was in place no earlier than MIS 6, i.e. 190 ka BP. This argument is stated to be based on ethno-historical and experimental data. Based on these same criteria, we show that there is no clear correlation between tip geometries and delivery method for spears, which instead are illustrated as having significant overlap. When applying the correct measurement data and equations, most of the Schöningen spears could, on the basis of tip geometries, fall within both thrusting and throwing categories, making a distinction on the basis of tip morphology problematic (as it is for spears as a whole). Furthermore, ethno-historic and experimental analogies support the functionality of at least some of the Schöningen spears as thrown weapons. Use-wear and fracture analysis have provided useful, if not entirely uncomplicated, methods for further evaluating the function of stone points (e.g. Iovita et al., 2014; Rots & Plisson, 2014; Wilkins et al., 2015). Future experimental approaches on use-wear and fracturing of wooden-tipped weapons, which do also fracture during use, could potentially provide similar insights into function. However, we would highlight that to our knowledge, there are as yet no reliable data on distinguishing between thrusting and throwing spears, even for stone points, though these data do appear to be emerging for spearthrower use (Coppe et al., 2023). While we demonstrate significant limitations for use of TCSA and TCSP to determine mode of delivery, these still play an important role as contributing factors to penetration. The variability of these measures observed within and across ethnographic weapon delivery systems may relate to myriad factors that may not always relate to function.

The Spear Horizon of Schöningen 13 II-4, dating c. 300,000 BP (MIS 9) is exceptional because unlike most archaeological sites and finds, it preserved complete weapons that allow us to analyse many different aspects of their manufacture and use; the complete examples show lengths and LMD consistent with throwing technologies (Leder et al., 2024; Milks et al., 2023a). Yet attempts to categorise the Schöningen spears as thrusting or throwing is, we argue, a false dichotomy. Both strategies can be used in tandem, for example to initially injure prey by throwing spears, and if necessary to deliver a fatal blow by then thrusting it into the animal, as well as to keep other predators and scavengers at bay. The site also bears evidence of another potential medium-distance throwing technology, namely double-pointed tools that have been interpreted by a number of scholars working independently from one another as throwing sticks (Bordes, 2014; Conard et al., 2020; Leder et al., 2024; Milks et al., 2023b; Thieme, 1997). The presence and interpreted function of these tools thus supports the hypothesis that distance weapons were used in Europe from at least 300 ka BP.

Based on physiological characteristics present in *Homo erectus*, it has been argued that hominins may have had the capacity for powerful and accurate throws as early as 2 million years ago (Roach & Lieberman, 2014; Roach & Richmond, 2015; Roach et al., 2013). In a finite element model, Berthaume (2014) found that humeri from Neanderthal and early Upper Palaeolithic populations were equally well-adapted to strains during throwing. Contributing to the complexity, there is human variation in humeral torsion (Cowgill, 2007; Larson, 2015), a key feature for interpreting fossil evidence of throwing. Hominin fossils also present a mixed picture with respect to bone remodelling in response to activities, with evidence both in favour of (Faivre et al., 2014) and against (Rhodes & Churchill, 2009) throwing in the pre-sapiens hominin record. Due to the paucity of postcranial remains, as well as issues of equifinality, this may not be resolvable via the fossil record. In absence of future ‘smoking gun’ type evidence, it could well remain one of the big ‘unknowns’.

In short, while archaeologists may never be able to definitively say how these early wooden spears were used, the evidence at Schöningen suggests that at least from a design perspective, the capacity for medium-distance projectiles was present. Furthermore, even though wooden spears are likely to be less effective than other weapon types in some respects (e.g. effective distance), experimental and ethnographic analogy demonstrates their capacity to injure and fatally wound animals and humans. We close by highlighting a series of points also made by Sahle et al. (2023), namely that when richly contextualised, ethnographic comparison illustrates that weapon variability can relate not only to delivery method, but also to hunting dynamics and strategies, prey type, and use by children, or in ceremonies. Similarly, Newman and Moore (2013) argue that it is essential to not make assumptions that tool design always closely tracks optimal performance, but rather may reflect technological approaches, and the dynamics of cultural transmission. Ethnographic analogy, whether through comparisons of material culture or behaviours, provide useful context and pathways for expanding our understanding of technological and behavioural variability. Yet statistical approaches that mask that variability in order to establish false categories should be reconsidered. In our opinion, the use and misuse of TCSA/TCSP to determine mode of weapon delivery has established a bias with respect to crucial human innovations in the form of prehistoric weapon systems.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41982-024-00206-x.

Acknowledgements We would like to acknowledge the contributions, skills, and knowledge of Indigenous communities from whom many of these data have come, both historically and more recently. We thank the Aboriginal Council of Tasmania for permission to study the Tasmanian spears. We would also like to thank the museums and curators who provided access to material including the Horniman Museum (UK), the University of Cambridge Museum of Archaeology and Anthropology (UK), the South Australian Museum (Adelaide, Australia), the Australian Museum (Sydney, Australia), and the Tasmanian Museum and Art Gallery (Hobart, Australia). We thank Thomas Terberger and the Forschungsmusuem for supporting the work on the Schöningen material, the Landesmuseum in Hannover for access to the Lehringen spear, and the Natural History Museum (London) for access to the Clacton spear. We appreciate Werner Schoch for permitting the re-use of one of his images from the Lehringen spear. We would also like to thank Metin Eren and 3 additional anonymous peer reviewers, as well as comments from Rob Hosfield, whose suggestions to improve our exploration of data and the manuscript greatly improved the paper. Any errors are of course our own.

Author Contribution Both authors, DL and AM, contributed equally to the conceptualisation, methodology, analysis, writing of the original draft, and review and editing of the manuscript. DL prepared Figs. 1, 2, 4, 5, and 6 and AM prepared Figs. 3 and 7. Both authors reviewed and approved the manuscript.

Funding D.L. and the data relating to the Schöningen material is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – project number 447423357, and by the Lower Saxony Ministry for Science and Culture, with funds from the Future Lower Saxony Programme of the Volkswagen Foundation – project number ZN3985. A.M. is funded by the British Academy Postdoctoral Fellowship PF21/210027. The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Data Availability Data is provided both within the manuscript (Tables 1 through 4), and as an accompanying datafile (xls).

Declarations

Competing Interests The authors declare no competing interests.

References

Abadi, I., Bar-Yosef, O., & Belfer-Cohen, A. (2020). Kebara V - A contribution for the study of the Middle-Upper Paleolithic transition in the Levant. *PaleoAnthropology, 2020*, 1–28.

Adam, K. D. (1951). Der Waldelefant von Lehringen, eine Jagdbeute des diluvialen Menschen. *Quätar, 5*, 79–92.

Allington-Jones, L. (2015). The Clacton spear: The last one hundred years. *Archaeological Journal, 172*(2), 273–296. https://doi.org/10.1080/00665983.2015.1008839

Amrhein, V., Greenland, S., & McShane, B. (2019). Retire statistical significance. *Nature, 567*, 305–307.

Aranguren, B., Revedin, A., Amico, N., Cavulli, F., Giachi, G., Grimaldi, S., Macchioni, N., & Santaniello, F. (2018). Wooden tools and fire technology in the early Neanderthal site of Poggetti Vecchi (Italy). *Proceedings of the National Academy of Sciences, 88*, 201716068. https://doi.org/10.1073/pnas.1716068115

Ashton, N., & Davis, R. (2021). Cultural mosaics, social structure, and identity: The Acheulean threshold in Europe. *Journal of Human Evolution, 156*, 103011. https://doi.org/10.1016/j.jhevol.2021.103011

Ashton, N., Lewis, S. G., Parfitt, S. A., Davis, R. J., & Stringer, C. B. (2016). Handaxe and non-handaxe assemblages during Marine Isotope Stage 11 in northern Europe: Recent investigations at Barnham, Suffolk, UK. *Journal of Quaternary Science, 31*(8), e2918–e2927. https://doi.org/10.1002/jqs.2918

Aubry, T., Bradley, B., Almeida, M., Walter, B., Neves, M. J., Pelegrin, J., Lenoir, M., & Tiffagom, M. (2008). Solutrean laurel leaf production at Maîtreaux: An experimental approach guided by techno-economic analysis. *World Archaeology, 40*(1), 48–66. https://doi.org/10.1080/00438240701843538

Baker, S. W. (1874). *Ismailia* (Vol. 1). Macmillan.

Baldino, J., McKinny, S., Taylor, J., Wilson, M., Buchanan, B., Walker, R. S., Story, B., Bebber, M. R., & Eren, M. I. (2024). North American Clovis Point Form and Performance V: An experimental assessment of spear thrusting penetration depth and entry wound size. *Lithic Technology, 49*(3), 295–310. https://doi.org/10.1080/01977261.2023.2270255

Barham, L., Duller, G. a. T., Candy, I., Scott, C., Cartwright, C. R., Peterson, J. R., Kabukcu, C., Chapot, M. S., Melia, F., Rots, V., George, N., Taipale, N., Gethin, P., & Nkombwe, P. (2023). Evidence for the earliest structural use of wood at least 476,000 years ago. *Nature*, 1–5. https://doi.org/10.1038/s41586-023-06557-9

Berthaume, M. A. (2014). *Were Neandertal humeri adapted for spear thrusting or throwing? A finite element study* [Master's Thesis]. http://scholarworks.umass.edu/masters_theses_2/72/

Bordes, L. (2014). *Les bâtons de jet préhistoriques et leurs représentations: Développement d'outils et de méthodes pour la mesure de leurs caractéristiques et l'évaluation de leurs fonctions* [Master's Thesis]. https://www.researchgate.net/publication/288554999_Les_Batons_de_jet_prehistoriques_et_leurs_representations_Developpement_d%27outils_et_de_methodes_pour_la_mesure_de_leurs_caracteristiques_et_l%27evaluation_de_leurs_fonctions_Memoire_de_Master_en_Prehist

Bridgland, D. R., Field, M. H., Holmes, J. A., McNabb, J., Preece, R., Selby, I., Wymer, J., Boreham, S., Irving, B., Parfitt, S. A., & Stuart, A. (1999). Middle Pleistocene interglacial Thames-Medway deposits at Clacton-on-Sea, England: Reconsideration of the biostratigraphical and environmental context of the type Clactonian industry. *Quaternary Science Reviews, 18*(1), 109–146. https://doi.org/10.1016/S0277-3791(97)00092-9

Christison, R., & Edge-Partington, J. (1903). 19. Notes on the weapons of the Dalleburra Tribe, Queensland, lately presented to the British Museum by Mr. Robert Christison. *Man, 3*, 37. https://doi.org/10.2307/2839962

Churchill, S. E. (1993). Weapon technology, prey size selection, and hunting methods in modern hunter-gatherers: Implications for hunting in the Palaeolithic and Mesolithic. *Archeological Papers of the American Anthropological Association, 4*(1), 11–24. https://doi.org/10.1525/ap3a.1993.4.1.11

Churchill, S. E. (2002). Of assegais and bayonets: Reconstructing prehistoric spear use. *Evolutionary Anthropology, 11*(5), 185–186. https://doi.org/10.1002/evan.10027

Churchill, S. E. (2014). *Thin on the ground: Neandertal biology, archeology, and ecology*. Wiley Blackwell. https://www.dropbox.com/home/Thin%20On%20the%20Ground

Clarkson, C. (2016). Testing archaeological approaches to determining past projectile delivery systems using ethnographic and experimental data. In R. Iovita & K. Sano (Eds.), *Multidisciplinary approaches to the study of stone age weaponry* (pp. 189–202). Springer.

Conard, N. J., Serangeli, J., Böhner, U., Starkovich, B. M., Miller, C. E., Urban, B., & Van Kolfschoten, T. (2015). Excavations at Schöningen and paradigm shifts in human evolution. *Journal of Human Evolution, 89*(C), 1–17. https://doi.org/10.1016/j.jhevol.2015.10.003

Conard, N. J., Serangeli, J., Bigga, G., & Rots, V. (2020). A 300,000-year-old throwing stick from Schöningen, northern Germany, documents the evolution of human hunting. *Nature Ecology & Evolution*, 1–6. https://doi.org/10.1038/s41559-020-1139-0

Coppe, J., Taipale, N., & Rots, V. (2023). Terminal ballistic analysis of impact fractures reveals the use of spearthrower 31 ky ago at Maisières-Canal, Belgium. *Scientific Reports, 13*(1), 18305. https://doi.org/10.1038/s41598-023-45554-w

Cowgill, L. W. (2007). Humeral torsion revisited: A functional and ontogenetic model for populational variation. *American Journal of Physical Anthropology, 134*(4), 472–480. https://doi.org/10.1002/ajpa.20689

Eren, M. I., & Meltzer, D. J. (2024). Controls, conceits, and aiming for robust inferences in experimental archaeology. *Journal of Archaeological Science: Reports, 53*, 104411. https://doi.org/10.1016/j.jasrep.2024.104411

Eren, M. I., Story, B., Perrone, A., Bebber, M., Hamilton, M., Walker, R., & Buchanan, B. (2020). North American Clovis point form and performance: An experimental assessment of penetration depth. *Lithic Technology, 45*(4), 263–282. https://doi.org/10.1080/01977261.2020.1794358

Eren, M. I., Meltzer, D. J., Story, B., Buchanan, B., Yeager, D., & Bebber, M. R. (2021). On the efficacy of Clovis fluted points for hunting proboscideans. *Journal of Archaeological Science: Reports, 39*, 103166. https://doi.org/10.1016/j.jasrep.2021.103166

Faivre, J.-P., Maureille, B., Bayle, P., Crevecoeur, I., Duval, M., Grün, R., Bemilli, C., Bonilauri, S., Coutard, S., Bessou, M., Limondin-Lozouet, N., Cottard, A., Deshayes, T., Douillard, A., Henaff, X., Pautret-Homerville, C., Kinsley, L., & Trinkaus, E. (2014). Middle Pleistocene human remains from Tourville-la-Rivière (Normandy, France) and their archaeological context. *PLoS ONE, 9*(10), e104111–e104113. https://doi.org/10.1371/journal.pone.0104111

Gamble, C. (1987). Man the Shoveler: Alternative models for middle Pleistocene colonization and occupation in northern latitudes. In O. Soffer (Ed.), *The Pleistocene Old World: Regional perspectives* (pp. 81–98). Plenum.

García-Moreno, A., Hutson, J. M., Villaluenga, A., Turner, E., & Gaudzinski-Windheuser, S. (2021). A detailed analysis of the spatial distribution of Schöningen 13II-4 'Spear Horizon' faunal remains. *Journal of Human Evolution, 152*, 102947. https://doi.org/10.1016/j.jhevol.2020.102947

Gaudzinski-Windheuser, S., Noack, E. S., Pop, E., Herbst, C., Pfleging, J., Buchli, J., Jacob, A., Enzmann, F., Kindler, L., Iovita, R., Street, M., & Roebroeks, W. (2018). Evidence for close-range hunting by last interglacial Neanderthals. *Nature Ecology & Evolution, 2*, 1087–1092. https://doi.org/10.1038/s41559-018-0596-1

Giles, E. (1889). *Australia Twice Traversed*. Libraries Board of South Australia.

Goodale, J. (1971). Tiwi wives: A study of the women of Melville Island, North Australia. Seattle: University of Washington Press.

Grady, J. H., & Churchill, S. E. (2023). Projectile point morphology and penetration performance. *Journal of Archaeological Science: Reports, 48*, 103893. https://doi.org/10.1016/j.jasrep.2023.103893

Hallinan, E., & Shaw, M. (2020). Nubian Levallois reduction strategies in the Tankwa Karoo, South Africa. *PLOS ONE, 15*(10), e0241068. https://doi.org/10.1371/journal.pone.0241068

Hosfield, R. (2020). *The earliest Europeans*. Oxbow Books. https://books.casematepublishers.com/The_Earliest_Europeans.pdf

Hughes, S. S. (1998). Getting to the point: Evolutionary change in prehistoric weaponry. *Journal of Archaeological Method and Theory, 5*(4), 345–408.

Hutchings, W. K. (2016). When is a point a projectile? Morphology, impact fractures, scientific rigor, and the limits of inference. In R. Iovita & K. Sano (Eds.), *Multidisciplinary approaches to the study of stone age weaponry* (pp. 3–12). Springer.

Iovita, R., Schönekeß, H., Gaudzinski-Windheuser, S., & Jäger, F. (2014). Projectile impact fractures and launching mechanisms: Results of a controlled ballistic experiment using replica Levallois points. *Journal of Archaeological Science, 48*(C), 73–83. https://doi.org/10.1016/j.jas.2013.01.031

Johnson, C. (1987). *Javelin throwing* (6th ed.). British Amateur Athletic Board.

Lang, J., Böhner, U., Polom, U., Serangeli, J., & Winsemann, J. (2015). The Middle Pleistocene tunnel valley at Schöningen as a Paleolithic archive. *Journal of Human Evolution, 89*, 18–26. https://doi.org/10.1016/j.jhevol.2015.02.004

Larson, S. G. (2015). Humeral torsion and throwing proficiency in early human evolution. *85*(C), 198–205. https://doi.org/10.1016/j.jhevol.2015.03.003

Lazuén, T. (2012). European Neanderthal stone hunting weapons reveal complex behaviour long before the appearance of modern humans. *Journal of Archaeological Science, 39*(7), 2304–2311. https://doi.org/10.1016/j.jas.2012.02.032

Leder, D., Lehmann, J., Milks, A., Koddenberg, T., Sietz, M., Vogel, M., Böhner, U., & Terberger, T. (2024). The wooden artifacts from Schöningen's spear horizon and their place in human evolution. *Proceedings of the National Academy of Sciences, 121*(15), e2320484121. https://doi.org/10.1073/pnas.2320484121

Leder, D. (2014). *Technological and typological change at the Middle to Upper Palaeolithic Boundary in Lebanon* (Vol. 255). Habelt.

Liebenberg, L. (2006). Persistence hunting by modern hunter-gatherers. *Current Anthropology, 47*(6), 1017–1026. https://doi.org/10.1086/508695

Lloyd, G. T. (1862). *Thirty-three years in Tasmania and Victoria: Being the actual experience of the author, interspersed with historic jottings, Narratives, and Counsel to Emigrants*. Houlsten and Wright.

Lombard, M. (2021). Variation in hunting weaponry for more than 300,000 years: A tip cross-sectional area study of Middle Stone Age points from southern Africa. *Quaternary Science Reviews, 264*, 107021. https://doi.org/10.1016/j.quascirev.2021.107021

Lombard, M., & Phillipson, L. (2010). Indications of bow and stone-tipped arrow use 64 000 years ago in KwaZulu-Natal. *South Africa. Antiquity, 84*(325), 635–648.

Lombard, M., Lotter, M. G., & Caruana, M. V. (2022). The tip cross-sectional area (TCSA) method strengthened and constrained with ethno-historical material from Sub-Saharan Africa. *Journal of Archaeological Method and Theory*. https://doi.org/10.1007/s10816-022-09595-1

Lombard, M. (2022a). A standardized approach to the origins of light-weight-Javelin hunting. *Lithic Technology*, 1–11. https://doi.org/10.1080/01977261.2022.2091264

Lombard, M. (2022b). Re-considering the origins of Old World spearthrower-and-dart hunting. *Quaternary Science Reviews*, 8. https://doi.org/10.1016/j.quascirev.2022.107677

Meggitt, M. J. (1977). *Blood is their argument: Warfare among the Mae Enga Tribesmen of the New Guinea*. McGraw-Hill Humanities Social. http://books.google.co.uk/books?id=hDSOtQEACAAJ&dq=Blood+is+their+argument&hl=&cd=3&source=gbs_api

Milks, A. (2020). A review of ethnographic use of wooden spears and implications for Pleistocene hominin hunting. *Open Quaternary, 6*(1), 79–20. https://doi.org/10.5334/oq.85

Milks, A., Champion, S., Cowper, E., Pope, M., & Carr, D. (2016a). Early spears as thrusting weapons: Isolating force and impact velocities in human performance trials. *Journal of Archaeological Science: Reports, 10*, 191–203. https://doi.org/10.1016/j.jasrep.2016.09.005

Milks, A., Dinnis, R., & Pope, M. (2016b). Morpho-metric variability of early Gravettian tanged 'Font-Robert' points, and functional implications. In R. Iovita & K. Sano (Eds.), *Multidisciplinary approaches to the study of stone age weaponry* (pp. 135–146). Springer. https://doi.org/10.1007/978-94-017-7602-8_9

Milks, A., Parker, D., & Pope, M. (2019). External ballistics of Pleistocene hand-thrown spears: Experimental performance data and implications for human evolution. *Scientific Reports, 9*(1), 820. https://doi.org/10.1038/s41598-018-37904-w

Milks, A., Hoggard, C., & Pope, M. (2023a). Reassessing the interpretative potential of ethnographic collections for early hunting technologies. *Journal of Archaeological Method and Theory*. https://doi.org/10.1007/s10816-023-09635-4

Milks, A., Lehmann, J., Leder, D., Sietz, M., Koddenberg, T., Böhner, U., Wachtendorf, V., & Terberger, T. (2023b). A double-pointed wooden throwing stick from Schöningen, Germany: Results and new insights from a multianalytical study. *PLoS ONE, 18*(7), e0287719. https://doi.org/10.1371/journal.pone.0287719

Milks, A. (2018). *Lethal threshold: The evolutionary implications of Middle Pleistocene wooden spears* [PhD Thesis]. https://discovery.ucl.ac.uk/id/eprint/10045809/1/MILKS%20PhD%20Final.compressed%20no%203%20party.pdf

Morris, J. (1964). *Relationship between the British and the Tiwi in the vicinity of Port Dundas*. Historical Society of the Northern Territory.

Movius, H. L. (1950). A wooden spear of third interglacial age from Lower Saxony. *Southwestern Journal of Anthropology, 6*(2), 139–142.

Newman, K., & Moore, M. W. (2013). Ballistically anomalous stone projectile points in Australia. *Journal of Archaeological Science, 40*(6), 2614–2620. https://doi.org/10.1016/j.jas.2013.01.023

Oakley, K. P., Andrews, P., Keeley, L. H., & Clark, J. D. (1977). A reappraisal of the Clacton spearpoint. *Proceedings of the Prehistoric Society, 43*, 13–30. https://doi.org/10.1017/S0079497X00010343

Plisson, H., & Beyries, S. (1998). Pointes ou outils triangulaires? Données fonctionnelles dans le Moustérien levantin [with commentry]. *Paléorient, 24*(1), 5–24.

Rhodes, J. A., & Churchill, S. E. (2009). Throwing in the Middle and Upper Paleolithic: Inferences from an analysis of humeral retroversion. *Journal of Human Evolution, 56*(1), 1–10.

Richter, D., & Krbetschek, M. (2015). The age of the Lower Paleolithic occupation at Schöningen. *Journal of Human Evolution, 89*(C), 46–56. https://doi.org/10.1016/j.jhevol.2015.06.003

Rios-Garaizar, J. (2016). Experimental and archeological observations of Northern Iberian Peninsula Middle Paleolithic Mousterian point assemblages. Testing the potential use of throwing spears among Neanderthals. In R. Iovita & K. Sano (Eds.), *Multidisciplinary approaches to the study of Stone Age Weaponry* (pp. 213–225). Springer.

Rios-Garaizar, J., López-Bultó, O., Iriarte, E., Pérez-Garrido, C., Piqué, R., Aranburu, A., Iriarte-Chiapusso, M. J., Ortega-Cordellat, I., Bourguignon, L., Garate, D., & Libano, I. (2018). A Middle Palaeolithic wooden digging stick from Aranbaltza III, Spain. *Plos ONE, 13*(3), e0195044-e195115. https://doi.org/10.1371/journal.pone.0195044

Roach, N. T., & Lieberman, D. (2014). Upper body contributions to power generation during rapid, overhand throwing in humans. *The Journal of Experimental Biology, 217*(Pt 12), 2139–2149. https://doi.org/10.1242/jeb.103275

Roach, N. T., & Richmond, B. G. (2015). Clavicle length, throwing performance and the reconstruction of the Homo erectus shoulder. *Journal of Human Evolution, 80*, 107–113. https://doi.org/10.1016/j.jhevol.2014.09.004

Roach, N. T., Venkadesan, M., Rainbow, M., & Lieberman, D. (2013). Elastic energy storage in the shoulder and the evolution of high-speed throwing in Homo. *Nature, 498*, 483–487. https://doi.org/10.1038/nature12267

Robinson, G. A. (1966). *Friendly mission: The Tasmanian journals and papers of George Augustus Robinson 1829–1834* (N. J. B. Plomley, Ed.). Tasmanian Historical Society Research Association.

Roth, H. L. (1890). *The aborigines of Tasmania*. Kegan Paul, Trench, Trübner & Co.

Rots, V. (2013). Insights into early Middle Palaeolithic tool use and hafting in Western Europe. The functional analysis of level IIa of the early Middle Palaeolithic site of Biache-Saint-Vaast (France). *Journal of Archaeological Science, 40*(1), 497–506. https://doi.org/10.1016/j.jas.2012.06.042

Rots, V., & Plisson, H. (2014). Projectiles and the abuse of the use-wear method in a search for impact. *Journal of Archaeological Science, 48*, 154–165. https://doi.org/10.1016/j.jas.2013.10.027

Sahle, Y., & Brooks, A. S. (2019). Assessment of complex projectiles in the early Late Pleistocene at Aduma, Ethiopia. *Plos ONE, 14*(5), e0216716-e216719. https://doi.org/10.1371/journal.pone.0216716

Sahle, Y., Hutchings, W. K., Braun, D. R., Sealy, J. C., Morgan, L. E., Negash, A., & Atnafu, B. (2013). Earliest stone-tipped projectiles from the Ethiopian rift date to >279,000 years ago. *PLoS ONE, 8*(11), e78092. https://doi.org/10.1371/journal.pone.0078092.s004

Sahle, Y., Ahmed, S., & Dira, S. (2023). Javelin use among Ethiopia's last indigenous hunters: Variability and further constraintson tip cross-sectional geometry. *Journal of Anthropological Archaeology, 70*, 101505. https://doi.org/10.1016/j.jaa.2023.101505

Salem, P. E., & Churchill, S. E. (2016). Penetration, tissue damage, and lethality of wood- versus lithic-tipped projectiles. In R. Iovita & K. Sano (Eds.), *Multidisciplinary approaches to the study of Stone Age weaponry* (pp. 203–212). Springer.

Sano, K. (2016). Evidence for the use of the bow-and-arrow technology by the first modern humans in the Japanese islands. *JASREP, 10*, 130–141. https://doi.org/10.1016/j.jasrep.2016.09.007

Schmitt, U., Singh, A. P., Thieme, H., Friedrich, P., & Hoffmann, P. (2005). Electron microscopic characterization of cell wall degradation of the 400,000-year-old wooden Schöningen spears. *Holz Als Roh- und Werkstoff, 63*(2), 118–122. https://doi.org/10.1007/s00107-004-0542-6

Schoch, W. (2014). Holzanatomische Nachuntersuchungen an der eemzeitlichen Holzlanze von Lehringen, Ldkr. Verden. *Nachrichten Aus Niedersachsens Urgeschichte, 83*, 19–29.

Schoch, W., Bigga, G., Böhner, U., Richter, P., & Terberger, T. (2015). New insights on the wooden weapons from the Paleolithic site of Schöningen. *Journal of Human Evolution, 89*(C), 214–225. https://doi.org/10.1016/j.jhevol.2015.08.004

Serangeli, J., Van Kolfschoten, T., Starkovich, B. M., & Verheijen, I. (2015). The European saber-toothed cat (Homotherium latidens) found in the 'Spear Horizon' at Schöningen (Germany). *Journal of Human Evolution, 89*, 172–180. https://doi.org/10.1016/j.jhevol.2015.08.005

Serangeli, J., Verheijen, I., Rodríguez-Álvarez, B., Altamura, F., Bigga, G., Schoch, W. H., Urban, B., van Kolfschoten, T., Venditti, F., & Conard, N. J. (2023). Schöningen: A reference site for the Middle Pleistocene. *Journal of Human Evolution*. https://doi.org/10.13133/2280-6148/18154

Shea, J. (1997). Middle Paleolithic spear point technology. In H. Knecht (Ed.), *Projectile technology* (pp. 79–106). Plenum Press.

Shea, J. (2006). The origins of lithic projectile point technology: Evidence from Africa, the Levant, and Europe. *Journal of Archaeological Science, 33*(6), 823–846.

Shea, J., & Sisk, M. (2010). Complex projectile technology and Homo sapiens dispersal into western Eurasia. *PaleoAnthropology, 2010*, 100–122.

Shea, J., Davis, Z., & Brown, K. (2001). Experimental tests of Middle Palaeolithic spear points using a calibrated crossbow. *Journal of Archaeological Science, 28*(8), 807–816. https://doi.org/10.1006/jasc.2000.0590

Shott, M. J., & Otárola-Castillo, E. (2022). Parts and wholes: Reduction allometry and modularity in experimental Folsom points. *American Antiquity, 87*(1), 80–99. https://doi.org/10.1017/aaq.2021.62

Sisk, M., & Shea, J. (2009). Experimental use and quantitative performance analysis of triangular flakes (Levallois points) used as arrowheads. *Journal of Archaeological Science, 36*(9), 2039–2047.

Sisk, M. L., & Shea, J. J. (2011). The african origin of complex projectile technology: An analysis using tip cross-sectional area and perimeter. *International Journal of Evolutionary Biology, 2011*(1, article 13), 968012–968018. https://doi.org/10.4061/2011/968012

Sitton, J., Story, B., Buchanan, B., & Eren, M. I. (2020). Tip cross-sectional geometry predicts the penetration depth of stone-tipped projectiles. *Scientific Reports, 10*(1), 13289. https://doi.org/10.1038/s41598-020-70264-y

Sitton, J., Stenzel, C., Buchanan, B., Eren, M. I., & Story, B. (2022). Static penetration assessment of stone weapon tip geometry metrics and comparison of static and dynamic penetration depths. *Archaeometry*, *n/a*(n/a). https://doi.org/10.1111/arcm.12841

Spencer, W. B. (1914). *Native tribes of the Northern territory of Australia*. Macmillan and Co.

Starkovich, B. M., & Conard, N. J. (2015). Bone taphonomy of the Schöningen 'Spear Horizon South' and its implications for site formation and hominin meat provisioning. *Journal of Human Evolution, 89*(C), 154–171. https://doi.org/10.1016/j.jhevol.2015.09.015

Taylor, N. (2022). Riddles wrapped inside an enigma. Lupemban MSA technology as a rainforest adaptation: Revisiting the lanceolate point. *Philosophical Transactions of the Royal Society B: Biological Sciences, 377*(1849), 20200484. https://doi.org/10.1098/rstb.2020.0484

Thieme, H. (1997). Lower Palaeolithic hunting spears from Germany. *Nature, 385*, 807–810.

Thieme, H., & Veil, S. (1985). Neue Untersuchungen zum eemzeitlichen Elefanten-Jagdplatz Lehringen, Ldkr. Verden. *Die Kunde, 36*, 11–58.

Tode, A. (1954). *Mammoth hunters 100,000 years ago. Nature and man in northwest Germany during the last ice age based on excavations near Salzgitter-Lebenstedt*. Appelhans.

Van Kolfschoten, T., Knul, M., Buhrs, E., & Gielen, M. (2012). Butchered large Bovids (Bos primigenius and Bison priscus) from the Palaeolithic throwing spear site Schöningen 13 II-4 (Germany). *Groningen Archaeological Studies, 12*, 32–45.

Van Kolfschoten, T., Buhrs, E., & Verheijen, I. (2015). The larger mammal fauna from the Lower Paleolithic Schöningen Spear site and its contribution to hominin subsistence. *Journal of Human Evolution, 89*(C), 138–153. https://doi.org/10.1016/j.jhevol.2015.09.014

Villa, P., & Lenoir, M. (2009). Hunting and hunting weapons of the Lower and Middle Paleolithic of Europe. In J.-J. Hublin & M. P. Richards (Eds.), *The evolution of hominin diets* (pp. 59–85). Springer. http://halshs.archives-ouvertes.fr/halshs-00437411

Villa, P., & Lenoir, M. (2006). Hunting weapons of the Middle Stone Age and the Middle Palaeolithic: Spear points from Sibudu, Rose Cottage and Bouheben. *Southern African Humanities, 18*(1), 89–122.

Villa, P., & Soriano, S. (2010). Hunting weapons of Neanderthals and early modern humans in South Africa: Similarities and differences. *Journal of Anthropological Research, 66*, 5–38.

Voormolen, B. (2008). Ancient hunters, modern butchers: Schöningen 13 II-4, a kill-butchery site dating from the northwest European Lower Palaeolithic. *Journal of Taphonomy, 6*(2), 71–141. https://doi.org/10.1002/9781118659991

Waguespack, N. M., Surovell, T. A., Denoyer, A., Dallow, A., Savage, A., Hyneman, J., & Tapster, D. (2009). Making a point: Wood-versus stone-tipped projectiles. *Antiquity, 83*(321), 786–800.

Warren, S. (1911). Proceedings: 'First Published Report and exhibition of the specimen, May 10th, 1911.' *Quarterly Journal of the Geological Society, 67*(1–4), XCIX. https://doi.org/10.1144/GSL.JGS.1911.067.01-04.02

Warren, S. (1923). The Elephas-Antiquus bed of Clacton-on-Sea (Essex) and its flora and fauna. *Quarterly Journal of the Geological Society, 79*(1–4), 606–636. https://doi.org/10.1144/GSL.JGS.1923.079.01-04.28

White, M., Pettitt, P., & Schreve, D. (2016). Shoot first, ask questions later: Interpretative narratives of Neanderthal hunting. *Quaternary Science Reviews, 140*(C), 1–20. https://doi.org/10.1016/j.quascirev.2016.03.004

Wilkins, J., Schoville, B. J., & Brown, K. S. (2014). An experimental investigation of the functional hypothesis and evolutionary advantage of stone-tipped spears. *PLoS ONE, 9*(8), e104514. https://doi.org/10.1371/journal.pone.0104514

Wilkins, J., Schoville, B. J., Brown, K. S., & Chazan, M. (2015). Kathu Pan 1 points and the assemblage-scale, probabilistic approach: A response to Rots and Plisson, "Projectiles and the abuse of the use-wear method in a search for impact." *Journal of Archaeological Science, 54*, 294–299. https://doi.org/10.1016/j.jas.2014.12.003