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

RESEARCH

Reassessing the Interpretative Potential of Ethnographic Collections for Early Hunting Technologies

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Accepted: 30 November 2023

Abstract

Archaeological studies of early weaponry have relied for decades on ethnographic parallels—whether from ethnohistorical accounts, ethnographic literature, or from objects studied in museum collections. While such accounts and collected objects provided key data in the past, including of morphometrics and functionality, few studies have explored the quality of such data. In this paper, we critically assess a dominant theoretical paradigm, namely the utility of ethnographic collections to assess Pleistocene archaeological material. Our focus is how ethnographic spear morphometrics are used to propose delivery methods of archaeological weapons. We discuss the archaeological significance of early spears, and the role that ethnography has played in interpreting them. We provide new morphometric data of ethnographic wooden spears, which have been used analogically to assess the earliest archaeological hunting tools. We systematically collected data from ethnographic collections of wooden spears in five museums in the UK and Australia including mass, length, diameters and point of balance, alongside any recorded information on provenance and use. Older datasets, as well as the data in this paper, are limited due to collection bias and a lack of detailed museum records. By subjecting the new data to statistical analyses, we find that with a few exceptions morphometrics are not reliable predictors of delivery as thrusting or hand-thrown spears (javelins). Prevalent hypotheses linking variables such as mass, tip design, or maximum diameter with delivery are unsupported by our results. However, the descriptive statistics provided may remain useful as a means of comparative data for archaeological material. We conclude that using simple morphometrics to parse weapon delivery has had a drag effect on forming new and interesting hypotheses about early weapons.

Keywords Ethnographic analogy · Morphometrics · Spears · Pleistocene · Javelin

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Published online: 20 December 2023

Introduction

The origins and technological developments of weaponry have long featured in definitions of what it means to be human (e.g., Bunn, 2006; Darwin, 1871; Lee & Devore, 1968). Weaponry research continues to feature in academic publications and public-facing interpretations about the deep past including in discussions around the origins of human hunting, violence, running, throwing, division of labour, cultural evolution, and complex cognition (e.g. Bebber et al., 2023; Churchill et al., 2009; Eren et al., 2020; Haidle, 2010; Lieberman & Bramble, 2007; Lombard & Högberg, 2021; Roach et al., 2013; Shea & Sisk, 2010). The design and use of weapons in recent and contemporary small-scale societies serves as a key reference point, a practice that became particularly prevalent for evaluating function and performance. Yet, depending upon the quality of data, ethnographic analogy can be both incredibly useful and deeply problematic as a means of addressing questions obscured by the quality of the archaeological record.

Interpretations of design, function and performance of Pleistocene weapons routinely reference ethnographic data including those from ethno-historical and ethnographic literature, as well as from objects in museum collections (Churchill, 1993; Lombard, 2021, 2023; Lombard et al., 2022; Milks et al., 2019, 2023; Sahle et al., 2023; Shea, 2006; Waguespack et al., 2009). Conclusions specifically based on ethnographic data cascade into broader theories around hominin physiology, hunting capabilities and strategies, prey selection, hominin dispersals and cognition (e.g. Churchill, 2014; Lieberman et al., 2009; Shea & Sisk, 2010; White et al., 2016). As we will demonstrate in this paper, the quality and application of data from museum collections needs further consideration.

Undoubtedly the use of ethno-archaeology, ethnographic data and ethnohistorical records to interpret the past remains an area of debate, with cherry-picking single or a small selection of examples to support a theory of particular concern (French, 2019; G. Warren, 2021). There is also a controversial and unethical history of scientists making use of ethnography to support racist and colonialist interpretations of material culture, marginalisation of small-scale societies, and development of government policy to name but a few issues (see Porr & Matthews, 2019 and papers therein). It is also the case that all analogical tools that archaeologists employ are limited in their capability to fully address problems of equifinality and underdetermination in the archaeological record (Perreault, 2019). While we acknowledge these challenges, wide-ranging cross-cultural reviews and larger datasets with clear discussion of limitations hold potential to expand archaeological research questions and interpretations, and widen our awareness of the scope and variability of human behaviours and technologies.

The aim of this paper is to provide quality morphometric data of a sample of ethnographic plain wooden spears as a case study on the application of such data to Pleistocene material culture, and implications for behaviours. We highlight problems with previous datasets and explore how these data have been used to formulate hypotheses on early spear use. We apply descriptive and multivariate statistics to assess these hypotheses about links between morphometrics and function, and morphometrics and performance. Following this, we discuss the interpretative limitations and potential of these data in respect to early weapons and propose how to move forward on contextualising early weapons.

Background on Archaeological Wooden Spears

The earliest clear weapons in the archaeological record are complete and fragmented wooden pointed spears. 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; S. Warren, 1911). On the basis of the wood species, size, shape, and shaft break, the object is typically interpreted as a thrusting spear (Allington-Jones, 2015; Milks, 2018; 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 fragments of at least ten spears, some of which are complete examples (Schoch et al., 2015; Thieme, 1997). The 'Spear Horizon' is dated to MIS 9 and also contains the remains of a significant number of butchered animals (Conard et al., 2015). On the basis of morphometrics, the spears from Schöningen are interpreted as both throwing and thrusting spears (Milks, 2018; Schoch et al., 2015; Thieme, 1997). Also from the Eurasian Pleistocene record is the MIS 5e site of Lehringen (Germany), where in 1948 a complete yew spear was discovered in association with a butchered straight-tusked elephant (*Palaeoloxodon antiquus*) (Adam, 1951; Thieme & Veil, 1985). While the sites of Clacton, Schöningen and Lehringen are all attributed on the basis of dating to *H. heidelbergensis* and/or *H. neanderthalensis*, wooden spears are also known from archaeological sites attributed to *H. sapiens*, which accords with an ethnographic record showing continued use of these weapons through to the present day for hunting and violence (Milks, 2020).

Background on Ethnographic Spear Studies

Until now, the largest published morphometric dataset on ethnographic wooden spears is a sample of 36 spears from museum collections, undertaken as part of an analysis of the Clacton Spear point (Oakley et al., 1977). The morphometrics in that paper included length, mass, maximum diameter, point of balance, and three tip diameters at 100, 200 and 300 mm from the front point. Oakley et al. (1977) then proposed that it was possible to distinguish between use as a thrusting and throwing spear on the basis of this comparative sample of measurements. They constructed a series of hypotheses (*H*) including that H_1 thrusting spears are longer than throwing spears,[1] H_2 thrusting spears have larger diameters than throwing spears, H_3 thrusting

[1] Oakley et al.,'s 1977 publication gives two conflicting statements. The first states that "those used for stabbing are usually heavier, thicker and shorter." (p. 21) while subsequently they claim that "thrusting spears are heavier (283–1358 g: 113–453 g), thicker (24–30 mm; 12–23 mm) slightly longer (1845–2716 mm: 1587–2614 mm) than throwing spears" (p. 21). Although their thrusting sample has one slightly longer example, the mean lengths of both samples are comparable.

spears are heavier than throwing spears, H_4 throwing spears tend to be double-pointed while thrusting spears can be either double-pointed or proximally untapered, and H_5 throwing spears tend to be finer morphometrically at the distal (front) points.

The ethnographic data presented in that seminal paper have been very influential, and morphometrics continue to be referenced in relation to function and performance of Pleistocene spears (Carbonell & Castro-Curel, 1992; Churchill, 2002; Gaudzinski-Windheuser et al., 2018; Lombard, 2023; Lombard et al., 2022; Maki, 2013; Rios-Garaizar, 2016; Shea, 2006, 2009). Only a few researchers (e.g. Milks et al., 2016; Villa & Soriano, 2010) have critically engaged with the quality and utility of Oakley et al.'s (1977) data. Here, we reiterate that there are significant errors from their original dataset including conflicting statements (see above footnote), inadequate protocols for data collection, a lack of engagement regarding multifunctionality of spears, and a failure to clearly demonstrate a morphometrically based differentiation between thrusting and throwing spears. There is also a failure in the original paper, and in many subsequent papers citing their conclusions, to meaningfully connect these morphometric features with real-world data on spear delivery and hunting strategies.

To detail some of the problems, Oakley et al.'s data (1977) included eight 'thrusting spears' and 28 'throwing spears', but there are missing data for several variables (Table S1). Methodologically, it is unclear how Oakley et al. (1977) distinguished between 'thrusting' and 'throwing', exemplified by the fact that it was not possible in the present study to assess delivery of some of the same spears on the basis of either morphometrics or museum databases. The present study also identified measurement errors. One spear (MAEC 6377 1901) was originally recorded to have weighed 460 g (g) less than the weight measured in this study (see sample ID 25, Z 6377 in accompanying dataset on GitHub). Finally, Oakley et al.'s (1977) sample includes composite spears and a 'children's spear'. Both archaeologically and ethnographically, children's weaponry tends to be scaled for their smaller bodies (Crittenden, 2016; Hewlett et al., 2011; Losey & Hull, 2019), and its inclusion affects measurement ranges and means.

Publications continue to consider potential connections between mode of delivery and morphometrics including length, mass, and diameter (H_1, H_2, H_3), and presence/absence of an aerodynamic back (proximal) taper (H_4) (Berger & Trinkaus, 1995; Churchill, 2002, 2014; Gaudzinski-Windheuser, 2016; Lombard, 2023; Lombard et al., 2022; Milks, 2018; Milks et al., 2019; Schoch et al., 2015; Serangeli & Böhner, 2012; Thieme, 1997, 1999, 2007; Thieme & Veil, 1985; Villa & Lenoir, 2006). Morphometrics also appear in debates around the timing of the emergence of throwing in human evolution. Arguments that archaeological examples of Pleistocene spears were not functional as thrown weapons rest on ideas that they were too heavy, long, and/or thick to be aerodynamic (see H_1, H_2, and H_3 above) (Berger & Trinkaus, 1995; Boëda et al., 2008; Churchill, 2014; Churchill et al., 2009; Schmitt et al., 2003; Shea & Sisk, 2010), which has been rejected in experimental studies and reviews of ethnographic and historical data published in the 2000s (e.g. Milks, 2020; Milks et al., 2019; Rieder, 2001; Villa & Lenoir, 2006, 2009; Villa & Soriano, 2010). In contrast, proposals that the Schöningen spears were projectiles mention design features linked to physics of flight including (1) their aerodynamic double-pointed design and (2) the location of the maximum diameter (LMD) as an indication that the point of balance (PoB) was located in the front half of the spear (Schoch et al., 2015; Thieme, 1997), an essential flight feature (Johnson, 1987). By the same reasoning, the relatively thin spear from Lehringen (Germany) is interpreted as a thrusting spear due to its LMD near the back, which does not end in a finely worked point (Gaudzinski-Windheuser et al., 2018; Thieme & Veil, 1985). Oakley et al.'s (1977) idea that throwing spears possess finer distal points than thrusting spears (H_5) is rarely discussed in the literature on the earliest wooden spears (but see Lombard et al., 2022), but similar ideas appear in debates regarding determining weapon delivery method on the basis of stone point morphometrics (e.g. see Discussion in Sahle et al., 2023).

While new experimental work and ethnographic studies empirically demonstrated that some of Oakley et al.'s (1977) hypotheses around length and mass of throwing spears are not upheld (e.g. Milks, 2020; Milks et al., 2019; Sahle et al., 2023), other features have yet to be fully explored. Therefore a key objective of this paper is to evaluate whether better quality and finer-grained morphometric data, accompanied by a deeper exploration of provenance and functional information associated with spears from museum collections, uphold any of these original hypotheses, or indeed whether morphometrics are particularly indicative of function at all. The present study also provides a wider array of data, a larger sample, and greater transparency on data collection protocols, facilitating a detailed statistical analysis and an exploration of the validity of morphometrics for determining delivery of wooden spears.

Materials and Methods

Sample

We studied a sample of 58 ethnographic untipped wooden spears originating from Vanuatu, Papua New Guinea, Solomon Islands, New Caledonia, Malaysia, New Zealand, New Guinea, Southern Sudan, mainland Australia and Tasmania. Where listed by museums, the communities from which these spears originated include the Sepik (Papua New Guinea), Whanganui Māori (New Zealand), Dieri (Australia), Maraganji (Australia), Aboriginal Tasmanians (Tasmania, Australia), and likely the Pilatapa (Australia), and Bari (Gondokoro, Southern Sudan). Unfortunately, in many cases, detailed provenance information was not collected, and/or not listed in the databases at the time of data collection. Detailed information on each specimen can be found in Table S2 (Supplementary Information). The ethnographic collections were based at the Horniman Museum (London, UK), the Museum of Archaeology and Anthropology (MAA Cambridge; University of Cambridge, UK), Australian Museum (AM; Sydney, Australia), South Australian Museum (SAM; Adelaide, Australia) and the Tasmanian Museum and Art Gallery (TMAG; Hobart, Australia). Database searches were conducted in collaboration with curators, producing an initial list of suitable material. Permission to study the Aboriginal Tasmanian spears based at TMAG was sought and granted by the Aboriginal Council of Tasmania. Spear collections were then visually inspected with the assistance of curators to identify additional objects. Complete single-piece wooden spears were selected; if minor damage was present, this was noted. Spears with decoration including carving, painting/liming, or binding were included if the decoration was unlikely to affect functionality. A literature review (Milks, 2020) helped identify societies for which decorated spears were ceremonial, and these were excluded. Spears with evidence for use with a spearthrower in the form of an indentation or hole at the proximal end were excluded, as were barbed, composite, and one-piece wooden spears with distal morphologies that were wide and blade-like.

Terminology and Morphology

We use the term 'spear' in this paper because terms such as 'javelin' for a thrown spear or 'lance' for a thrusting spear presupposes function and overlooks multifunctionally. Distal (front) and proximal (back) morphologies (e.g. tapered point) were recorded. In terms of taper morphologies in the dataset, '1' represents double-pointed, '2' represents a proximal end that tapers but does not end in a point, and '3' represents any design that deviates from the first two. For most spears distal and proximal ends were evident but where it was not, a qualitative judgment was made based on end morphology (i.e. the sharper, pointier end was defined as 'distal'). Delivery method, upon which the spear categories are based, was only assigned if museum databases clearly indicated it, and/or on the basis of literature providing clarity (Table S3).

Measurements

Measurements were taken by one person (AM). Distance measurements were collected with calibrated measuring tapes, and mass with museum weighing scales. For diameters, circumference (c) was measured from which diameter (d) was calculated using the equation $d = c/\pi$. The diameter measurement method, validated prior to data collection with callipers, allows for more accurate measurements when cross-sectional morphology varies. In this paper, we use the term point of balance (PoB; also called 'centre of mass' and 'centre of gravity') to describe the location where a spear balances. This metric affects force and drag during flight, and thus influences throwing distance. PoB was established manually, by balancing each spear on the finger, and then recording that location. We additionally divided each spear's PoB and LMD values by their total length to calculate their location as a percentage of the overall length from the distal point (percent_po_b and percent_lmd in the dataset).

Analysis

To document the degree of variation in morphometric attributes between and among spear categories, descriptive statistics, including kurtosis, skewness and coefficient of variation/relative standard deviation (CV/RSD) measures are first described. The attributes were then examined through Shapiro–Wilk (W) testing, which considered the null hypothesis (H_0) that the samples derive from a normally distributed population. With assumptions met (refer to the R code for further information), an ANOVA (analysis of variance) of their respective morphometric variables with post hoc pairwise *t*-tests (with Bonferroni adjusted *p* values) was performed to test the null hypothesis (H_0) that spear categories (as characterised by associated contextual information) derive from the same population. An alpha level of 0.05 is used throughout this paper. Visual summaries of the maximum diameter of spears, and the relationship between LMD and PoB (vs. delivery type) were also examined through univariate and bivariate graphical methods, while facetted boxplots provide overviews of the differences and similarities between all three categories and each individual metric. A Pearson correlation matrix was then performed to investigate the relationship between all combinations of any two variables (morphometric attributes), and trends in the correlation of particular sets of variables.

All analytical procedures (including data transformation) were performed in R version 4.2.1 (R Core Team, 2022), using primarily the tidyverse (Wickham et al. 2019), ggcorrplot (Kassambara, 2019), tidymodels (Kuhn and Wickham, 2020) and skimr (Waring et al. 2022) packages. In promoting high standards of data transparency and reproducibility all data, code and commentary (including additional multivariate analyses) can be found on GitHub (https://github.com/CSHoggard/projectiles) and is deposited in an Open Science Framework (OSF) repository (https://osf.io/yudth/).

Limitations

Ethnographic museum spear collections typically lack details on provenance, function, and intention behind manufacture (e.g. ceremonial, trade, to give or sell to collectors, or personal use), with collector bias an additional problem (Allen, 2011). Plain wooden spears were likely under-collected in favour of elaborate designs (e.g. barbed, composite, painted). Delivery method (thrusting and/or throwing) was difficult to determine for the majority of the sample, reflecting multi-functionality alongside a poor understanding of the significance of design differences. The result are small samples of spears with a known delivery as throwing spears ($n = 14$; the majority of which were made by a single population of Aboriginal Tasmanians), and thrusting spears ($n = 3$). These limitations are taken into account in results and form a key part of the discussion.

Results

Descriptive Statistics

Mass

Masses range from 150 to 2246 g with a mean of 701 g (Table 1). Most spears ($n = 56$) weighed under 1500 g (Fig. 1). The masses of spears with a known delivery

Table 1 Descriptive statistics for measurements of ethnographic wooden spear sample. DIA, diameter; DIA_x, diameter at a specific location from the distal point; MID, midpoint; LMD, location of maximum diameter; PoB, point of balance (refer to GitHub/OSF for specific group-based measurements)

	$n=$	Min	Max	Median	Mean	SD	p25	p75	Kurtosis	Skewness	CV (%)
Mass (g)	58	150	2246	600	701	412	402	903	1.8	1.1	58.7
Length (mm)	58	1375	4385	2765	2804	569	2450	3198	0.3	0.4	20.3
Dia 10 (mm)	55	3	11	5	5.4	1.8	4	6	0.7	0.9	33.3
Dia 50 (mm)	55	5	17	10	9.9	2.7	8	11.5	−0.2	0.5	27.3
Dia 100 (mm)	57	6	22	11	12	3.1	10	14	0.7	0.8	25.8
Dia 150 (mm)	57	8	23	13	13.4	3.2	11	15	0.3	0.7	23.9
Dia 200 (mm)	58	8	23	14	14.6	3.2	13	16	0.1	0.4	21.9
Dia 250 (mm)	58	9	24	15	15.4	3.1	13	17	0.2	0.5	20.1
Dia 300 (mm)	58	10	24	16	16.1	3	14	18	−0.2	0.5	18.6
Dia 800 (mm)	58	11	28	19	19.6	4.4	17	23	−0.9	0.1	22.4
Dia mid (mm)	58	11	30	18.5	19.1	4.9	15.2	22.8	−0.8	0.3	25.7
Max dia (mm)	58	13	32	21	21.1	4.6	18	24.8	−0.8	0.1	21.8
LMD (mm)	58	110	2000	940	963	449	620	1349	−0.6	0.3	46.7
LMD %	58	4	66	33	35.3	16.5	25	50	−1	0	46.7
PoB (mm)	58	700	1770	1295	1305	242	1096	1484	0.7	0	18.5
PoB %	58	34	56	48.5	47	5.5	44.2	51	−0.4	−0.7	11.7

overlap. One of the lightest spears (sample ID 22, Museum ID Z 42280), weighing 150 g, is a thrusting spear. Thrown spears can also be very light, weighing as little as 242 g, with the heaviest (sample ID 29, Museum ID A39396) weighing 1004 g. Of all measurements taken, among all spears, mass is the most variable (CV = 58.7%, Table 1).

Length

Length of ethnographic wooden spears ranged from 1375 mm (1.4 m) to 4385 mm (4.4 m) (Table 1). Spears known to have been hand-thrown are longer than known thrusting spears (Fig. 1). The longest spears are those from Tasmania which were used exclusively as throwing weapons, with multiple sources reporting them as having been thrown in excess of 35 m for hunting and in human conflict (Lloyd, 1862; Robinson, 1966; Roth, 1890).

Diameter

Maximum diameters ranged from 13 to 32 mm (Table 1). Maximum diameters overlap, with thinner and thicker spears used for both thrusting and throwing (Fig. 2). Comparatively low levels of variability of distal point diameters from 10 to 300 mm suggests a standardisation of distal point design, a crucial feature for penetration. An exception to low variability is diameter at 10 mm (CV = 32.7%). Figure 3 illustrates

Fig. 1 Box-plot diagrams for each morphometric attribute and the three spear categories (hand-thrown, thrust and unknown)

examples comparing distal and proximal points of two spears (Fig. 3 b and c), as well as the distal point (Fig. 3d) of one of the Aboriginal Tasmanian spears.

Point of Balance and Location of Maximum Diameter

Measurement values for PoB and LMD (Table 1) are most useful when assessed as a percentage of the total length (PoB % and LMD %), which is more informative of function. The following results represent percentage calculations based on these measurements. The LMD % had a tendency to be farther forward (mean = 35.3%) than PoB % (mean = 47%), but in several cases ($n = 10$), this was reversed. PoB % tended to be in front of the midpoint, and in no cases was it > 56%. The Tasmanian throwing spears ($n = 8$) had LMDs between 4 and 19% of total length and PoBs

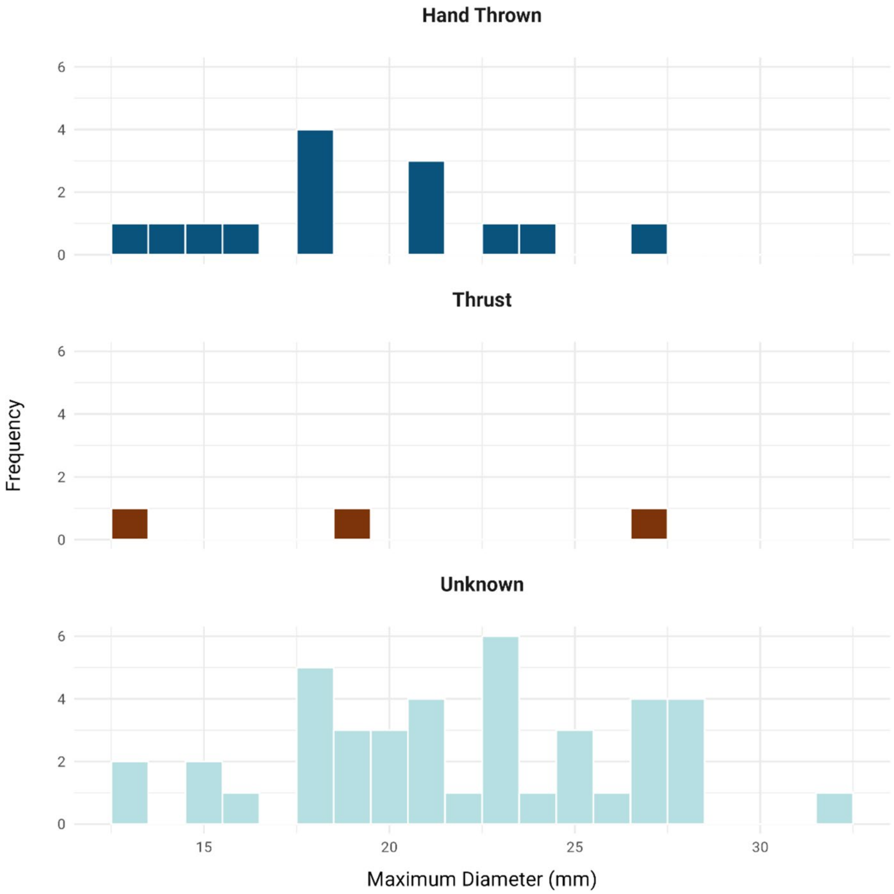

Fig. 2 Histogram of maximum diameter for hand-thrown, thrust and unknown spears

between 34 and 41% of total length. As a comparison, modern Olympic javelins, designed for distance, have a PoB from 35 to 39%, a location that, for safety reasons, has been set forwards of optimal aerodynamic performance (Terauds, 2015). PoB % has the lowest coefficient of variation (CV = 11.7%), suggesting that it is a relatively standardised design feature. In contrast, LMD % is more variable (CV = 46.7%).

ANOVA and Pairwise Testing

A Shapiro–Wilk test of normality confirmed that all morphometric variables were normally distributed (see R code for a full breakdown). An ANOVA of morphometric variables satisfies the null hypothesis that the spear categories (excluding unknown), as described in museum databases and other contextual information, derive from the same population ($F = 4.517$, $p = 0.0519$). Between hand-thrown and

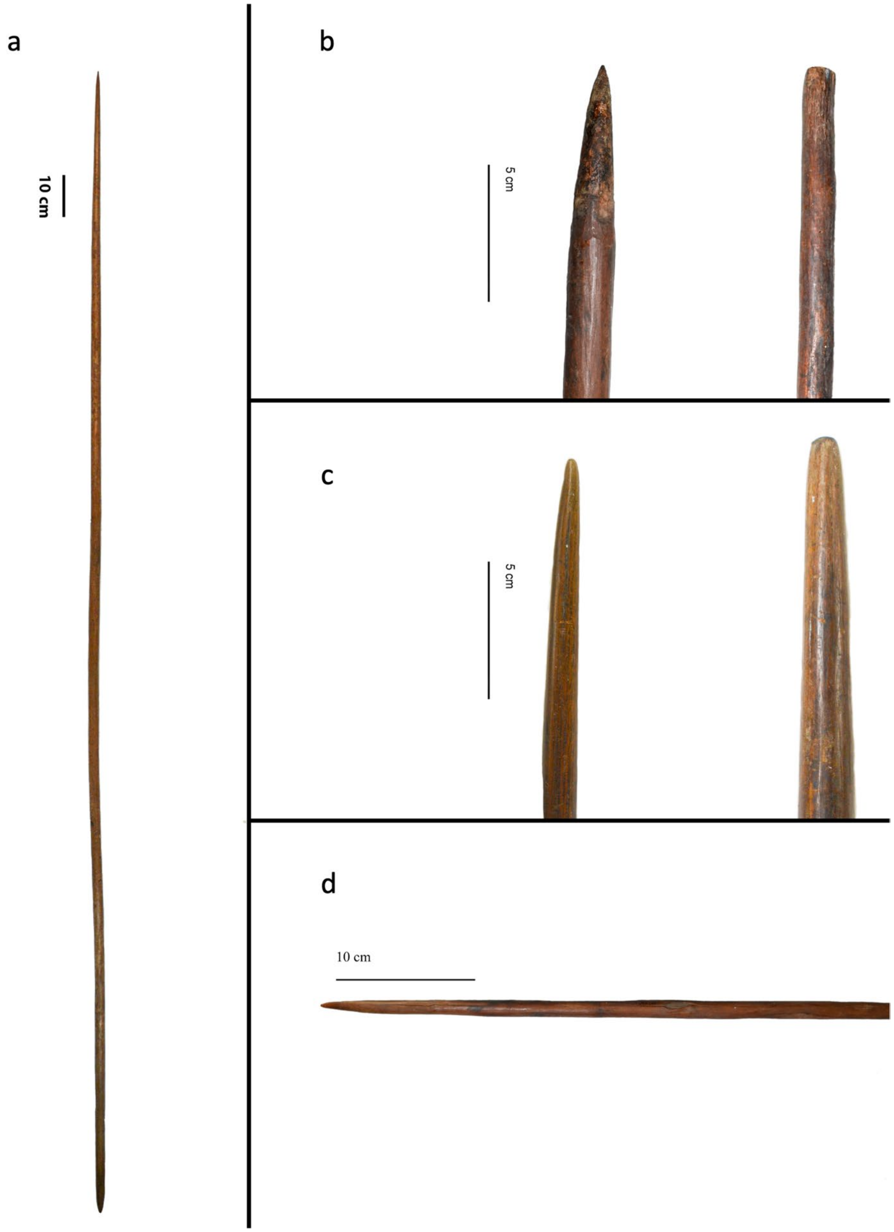

Fig. 3 Examples of ethnographic wooden spears. **a** Complete spear from Lake Eyre District, Australia, A.21570, South Australian Museum. **b** Left: distal point; right: proximal end of wooden spear from Gondokoro, South Sudan, E.20093, Australian Museum. **c** Left: distal point; right: proximal end of a Māori wooden spear from Wanganui, New Zealand, Z6377. **d** Distal point of an Aboriginal Tasmanian throwing spear, 2723, Tasmanian Museum and Art Gallery

Table 2 Bonferroni-adjusted pairwise *t* tests between the three different categories of spears and their respective morphological attributes (bold: statistical difference observed to the 0.05 alpha level)

	Hand-thrown vs. thrust	Hand-thrown vs. unknown	Thrust vs. unknown
length	**0.000**	**0.035**	**0.012**
max_dia	1.000	0.132	1.000
lmd	1.000	**0.001**	0.768
percent_lmd	**0.043**	**< 0.001**	1.000
po_b	0.072	0.644	**0.009**
percent_po_b	**0.002**	**< 0.001**	1.000
dia_10	1.000	0.25	1.000
dia_50	1.000	**0.001**	0.555
dia100	0.208	**0.001**	1.000
dia_150	0.242	**0.006**	1.000
dia_200	0.739	0.058	1.000
dia_250	0.469	0.191	1.000
dia_300	0.760	0.431	1.000
dia_800	1.000	0.2	1.000
dia_mid	0.948	**0.006**	1.000
mass	1.000	0.24	0.431

thrusting spears statistical difference is observed for their length, PoB % and LMD % (Table 2), with the other 13 measurements featuring no statistical significance. When both groups are compared against the unknown collection then a greater number of differences can be observed between the hand-thrown and unknown examples, with eight out of 16 metrics observing difference to the 0.05 alpha level. Between thrust and unknown examples only two attributes meet the above alpha level, PoB ($p = 0.009$) and length ($p = 0.012$) (Table 2). Further multivariate testing contained within the supplementary code and supplementary information, and explicitly the PCA and MANOVA of all PC scores, reaffirms the above degrees of difference between the three different spear categories.

Correlation

Distal point measurements from 10 to 300 mm are moderately to very strongly correlated (Fig. 4). Mass and maximum diameter are very strongly correlated (*r*: 0.81) as are mass and diameter at midpoint (*r*: 0.88), while length and mass have weak correlation (*r*: 0.36). Length and PoB (mm) are strongly correlated (*r:* 0.77), while LMD (mm) and PoB (mm) are moderately correlated (*r*: 0.58).

A key question for evaluating delivery of archaeological spears is whether we can estimate the PoB % on the basis of the LMD % of complete examples. These data help determine aerodynamic potential for a given archaeological spear. A scatterplot (Fig. 5) visualises how these correlate for the different groups and provides a guideline for estimating PoB % on the basis of LMD %. For the majority of the sample,

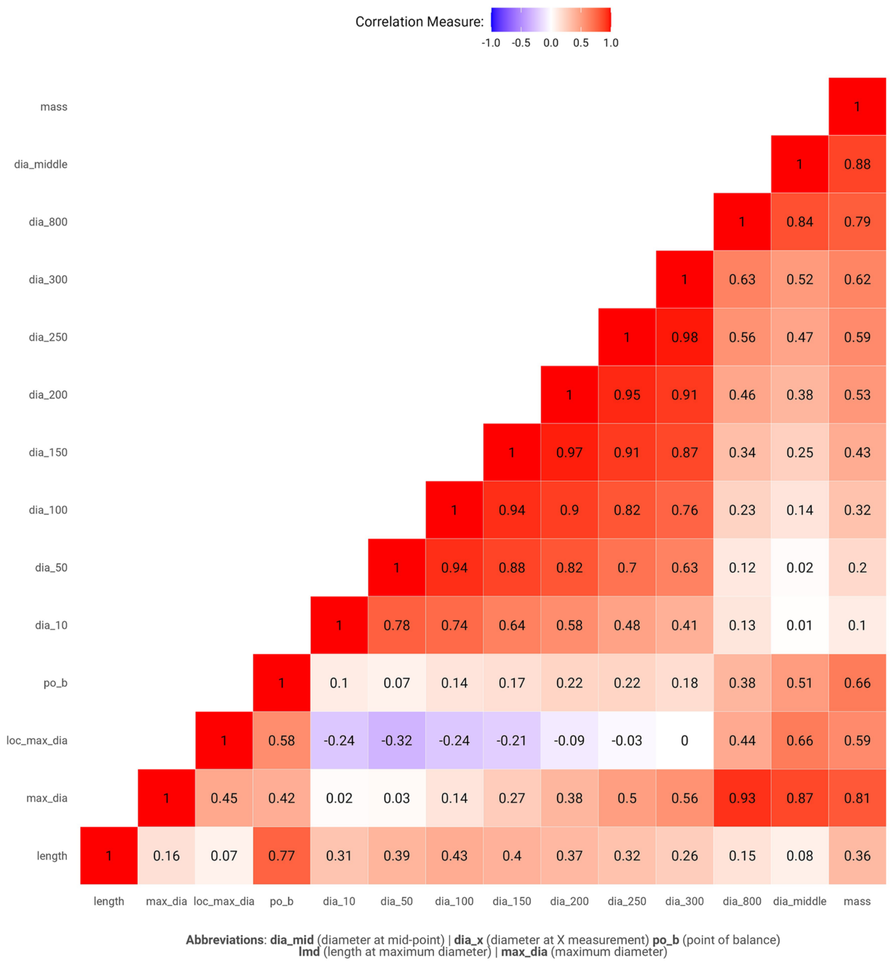

Fig. 4 Correlation coefficient (Pearson) matrix for all morphometric measurements. dia_x: diameter at a given location. loc_max_dia: location of maximum diameter (in mm). _ po_b: point of balance (in mm)

PoB % clusters in front of the midpoint, although two of the three thrusting spears have a PoB behind the midpoint.

Discussion

The descriptive statistics published in this paper will provide reference points for future work on understanding how complete and fragmented archaeological spears compare in terms of simple morphometrics. Across the whole sample, mass, length and diameters had wide ranges. Our descriptive statistics provide a wider set of ranges for spears than those reported in Oakley et al., (1977; see Table S1 in SI).

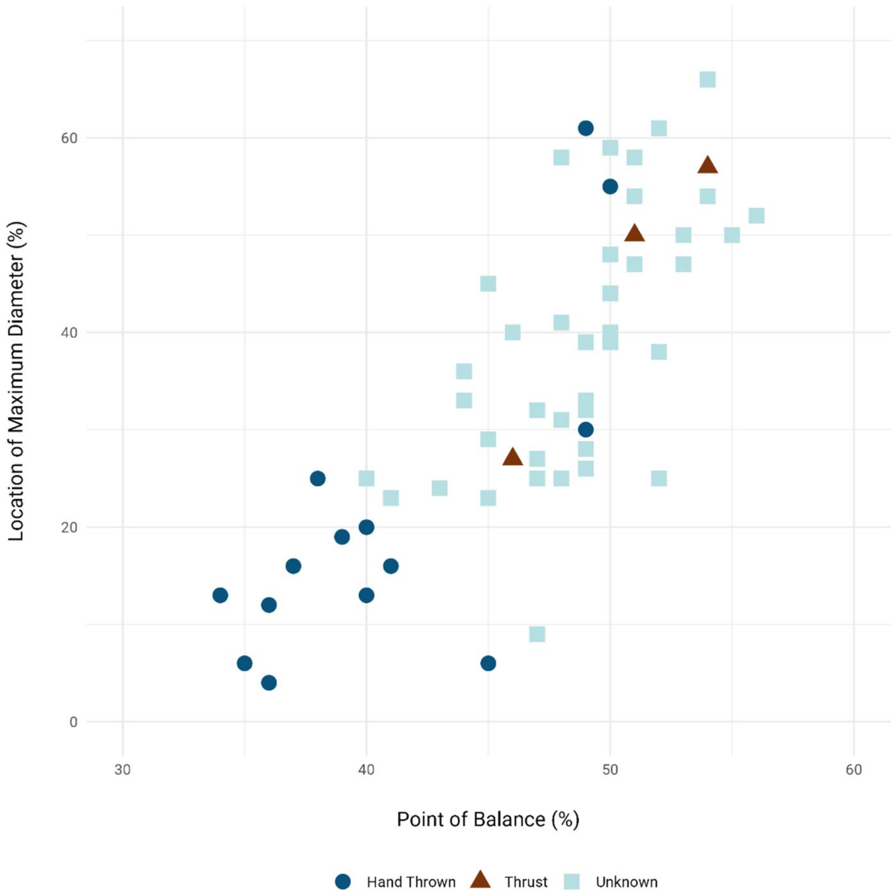

Fig. 5 A scatterplot of PoB (%) and LMD (%) by delivery mode

Notably, our results show the existence of significantly longer spears, with a maximum of 4.4 m (4385 mm) in comparison with Oakley et al.'s (1977) maximum of 2.7 m (2716 mm). We also demonstrate the presence heavier spears, with a maximum mass of 2246 g, compared with Oakley et al.'s (1977) maximum of 1358 g. The use of even heavier spears (~1000 to ~2000 g), including for throwing, is documented in the literature (Sahle et al., 2023; Spencer, 1914). Mass has the most variable measure (CV = 58.7%), followed by LMD (CV = 46.7%) and diameter at 10 mm (CV = 33.3%). The least variable measurement was PoB % (CV = 11.7%).

In future publications, our correlation statistics may help assess select features of archaeological specimens. The strongest correlations were between mass and maximum diameter, and between length and PoB (mm). The original mass of archaeological specimens cannot be reliably estimated on the basis of simple morphometrics, although this can be achieved through volumetric data and estimates of original wood density (Milks et al., 2023). Such estimates can be further supported though by the correlation between mass and maximum diameter, providing a likely range. While we find here that mass should not be used to determine delivery, it could be used to estimate potential kinetic energy. Weak to negligible correlations between diameter at 200 mm and length, maximum diameter, and PoB indicate that diameters of the points of fragmented spears should not be used to estimate original measurements nor to determine function. By extension, there is currently no justifiable reason to designate this spear fragment as being delivered as a thrusting spear (cf. Milks, 2018; Oakley et al., 1977).

The statistics had mixed results in relation to assessing mode of delivery. When comparing known spears of throwing and thrusting function, pairwise testing illustrated statistically significant differences between those spears known to be thrown vs. thrust only for length, PoB % and LMD %. Although other measures were not useful from a functional perspective, because of the influence thus far for these measures in discussions on early spear use, we explore each of the key measurements in more detail.

Of those spears with a PoB behind the middle (i.e., > 50%, $n = 16$; group 2 in Figs. S4 and S5), meaning they are not aerodynamic, mass ranged from 150 to 2246 g, identical to the range of the entire sample (Table 1). Although the mean of this subsample (995 g) is heavier than the entire sample (701 g), our results show that thrusting spears can be both light and heavy. Masses in the group 1 subsample ($n = 42$) range from 150 to 1300 g, but as mentioned, heavier throwing spears are also recorded in the literature. In sum, mass is not a measurement that can be linked to throwing or thrusting.

The longest spears in the sample were used exclusively for throwing and were made by Aboriginal Tasmanians. Further ethnographic data seem to support the use of longer spears for throwing, and shorter for thrusting, irrespective of mass. Although no plain Tiwi spears were identified in the museum stores for this study, Spencer (1914, p. 364) measured an average sized Tiwi wooden throwing spear as 3200 mm long. In contrast, measurements for wooden thrusting spears used by the Cocopa and Mohave (North America) for warfare measured between 914 and 1500 mm (Gifford, 1933; Stewart, 1947). The Kalahari San reported that longer spears are better for throwing (Hitchcock & Bleed, 1997), and longer shafts for Zulu throwing spears are also noted (see Lombard et al., 2022). Length measurements for both categories slightly overlap but in contrast to Oakley et al.'s (1977) data (Table S1, Supplementary Information), hand-thrown spears in our sample were longer. This is also reflected in the ANOVA results showing a significant difference between thrusting and throwing spear lengths. Although statistically there is a clear difference in length between the spears known to be thrown vs. those for thrusting, and this is backed up by the aforementioned literature references, we must be mindful of the very small sample size of spears understood to be thrusting weapons ($n = 3$), alongside potential for multifunctionality. To illustrate this point, BaYaka currently use spears measuring > 2000 mm for both throwing and thrusting (personal observation). Therefore, a longer spear can also be used for spear thrusting, although the efficacy of very short spears for throwing overhand seems doubtful.

The results do not at present support an ability to distinguish between thrusting and hand-thrown spears on the basis of maximum diameter (Fig. 2). The suggestion that throwing spears are thinner at the distal tip than thrusting spears is also not upheld in this study, and although these categories overlap for almost all diameter measurements from 10 to 300 mm, if anything the throwing spears have larger diameters (Fig. 1). It demonstrates that delivery of wooden spears is unlikely to be determined via distal point measurements, including for example tip cross-sectional area (TCSA) and perimeter (TCSP) measurements (*contra* Lombard, 2023).

Most spears ($n = 39$) double tapered, with both ends finished as a point. Some spears ($n = 12$) had proximal ends that taper but were not finely worked into a point, and this subsample includes both thrusting and throwing spears. One spear (sample ID 16, Museum ID NN18880) had a 'bulbous' proximal end. It has been proposed that spears with a thick and untapered proximal end would be ineffective as throwing spears (Cundy, 1989), but apart from the aforementioned example, these were not seen in the sample studied.

Considering the above caveat that longer spears could still be used for spear thrusting, LMD remains the only significant measurable feature of archaeological spears that could provide a reasonable link to delivery method, via a moderate correlation to PoB. This is on the basis of the physics, in that a spear with a PoB behind the midpoint is aerodynamically unstable, and therefore those with a PoB over 50% should be considered as thrusting spears. The ANOVA supports this, showing statistically significant differences for PoB and LMD between the two known groups.

Our study demonstrates that with statistical analysis of data collected with stringent criteria, none of the hypotheses summarised in the introduction are upheld by the data in this study. To review, these are as follows:

- H_1, that thrusting spears tend to be slightly longer than throwing spears is not supported by this study.
- H_2, that thrusting spears tend to have larger maximum diameters than throwing spears is not supported by this study.
- H_3, that thrusting spears tend to be heavier than throwing spears is not supported by this study.
- H_4, that throwing spears tend to be double-pointed while thrusting spears can be either double-pointed or untapered at the proximal end is neither supported nor rejected, as most spears in this study were double-pointed.
- H_5, that throwing spears are finer morphometrically at the tips than thrusting spears is not supported by this study.

In evaluating spear use in the deep past, others (Villa & Lenoir, 2006; Villa & Soriano, 2010) previously questioned H_1, H_2, and H_3. In addition to supporting their arguments that these hypotheses are not valid, we provide empirical support for their proposal that LMD and PoB are better candidates for establishing delivery method, we would add that multifunctionality confounds goals to distinguish between thrusting and throwing spears, so at best we can use these data to rule out throwing function.

Although it is not the purpose of this paper to provide a detailed analysis of the morphometrics of archaeological wooden spears in comparison with the ethnographic sample, we can make the following observations. The lengths of the complete and nearly complete spears from Schöningen (including Spear VI, also called a 'Lance') and Lehringen fall within the range of the ethnographic sample (Schoch et al., 2015; Thieme & Veil, 1985). The original length and maximum diameter of the broken artefact from Clacton is impossible to assess. Reported maximum diameters of Schöningen are overestimated due to measurement method (Milks et al., 2023), and will be revised in future publications. However, on the basis of current published data, some archaeological spears fall within the ethnographic sample of maximum diameters, while others exceed them (see also Milks, 2018). Balance points are difficult to assess without replicas, but experimental replicas of Schöningen Spear II have a balance point near the centre of the spear, making it suitable for flight (Milks et al., 2019). The Lehringen spear is suggested to have a balance point towards the back, on the basis of the LMD (Thieme & Veil, 1985), determined to be 88% from the distal point (Milks, 2018, p. 138). This LMD location does suggest a PoB well behind the centre (compare with Fig. 5), and thus, its use as a throwing spear is unlikely. The balance point of the Clacton Spear point cannot be assessed due to its fragmentary nature.

While the LMD of archaeological spears (none of which are in an unbroken state) may provide a pathway for ruling out a function as a throwing spear, ideally this would be supported by PoB measurements from replicas. At best we can, on the basis of morphology, replicated balance points, and experimentation, propose that at least some of the Schöningen spears were designed in such a way as to be capable of flight, while the Lehringen spear was likely not. The delivery mode of fragmented pieces is therefore not possible, although select measurements may still provide useful for determining whether wood fragments represent broken weapons.

Churchill (1993, p.17) proposed that for thrusting and throwing spears 'the distinction between these two weapon systems may not be entirely meaningful'. His assessment was based on the idea that for the spear-using societies included in his review, most (but not all) threw spears at such close distances as to necessitate similar hunting strategies as thrusting spears. However, ethnographic reviews are only as good as the data they include. The proposal that thrown spears are only short-distance weapons that are ineffective beyond 5–8 m, is not supported by subsequent publications detailing evidence of multiple cultures throwing both lightweight and heavy spears at distances of up to 50 m (e.g. Villa & Lenoir, 2006; Villa & Soriano, 2010; Milks et al., 2019, Supplementary Information; Milks, 2020; Sahle et al., 2023). The idea that thrown spears are short-distance weapons with low impact energy has also been rejected in several independent experiments (Bebber et al., 2023; Coppe et al., 2019; Milks et al., 2019; Rieder, 2001). Therefore, while the present paper demonstrates that there *is* a lack of a meaningful distinction in design between thrusting and throwing spears, this is not because spear throwing is (or was in the deep past) an ineffective hunting strategy. Rather, this is because weapon design reflects cross-cultural variability of hunting strategies, prey, environment, raw material use, socially mediated preferences, cultural transmission, and so on. In other words as Hitchcock and Bleed (1997) eloquently suggested, weapons are designed and selected 'according to need and fashion'.

In this paper, we presented a case study in which we demonstrated that ethnographic morphometric data underpinned by a statistical approach can provide comparative descriptive statistics for identifying potential weaponry in the archaeological record. However, using most of the morphometric variables to link form with delivery mode was more challenging. We concur with others (e.g. Clarkson, 2016; Hutchings, 2016; Sahle et al., 2023), who highlight myriad challenges in reliably distinguishing between different weapon types on the basis of ethnographic morphometric data. Even when we improve sample sizes and collect data systematically, as we did here, issues with quality and resolution remain. While ethnographic data on objects can be used well for archaeological purposes (e.g. Riede et al., 2022), we should be mindful of the limitations for object-based studies including collection bias, and lack of recorded data on provenance and function. This contributes to a wider crisis of confidence regarding the validity of ethnographic analogy. When done sensitively and systematically, reviews of ethno-historical accounts and ethnographic studies have the capacity to widen our understanding of potential functions and social and ecological contexts of hunting technologies, even though these alone cannot result in definitive functional assignments for archaeological specimens (e.g. see Hrnčíř, 2023; Milks, 2020). For evaluating weapon performance and use signatures, experimental archaeology, use-wear and residue analyses are more fruitful pathways.

An over-focus on associations between morphometrics and function of early weapons has had a drag effect on our ability to move forward and explore exciting research questions. Alternative questions include (but are not limited to) the multifunctionality and variability of weapon systems and weapon components (e.g. Eren et al., 2023; Sahle et al., 2023), the effects of socio-cultural norms and ecologies on weapon choice and hunting strategies (Ellis, 1997; Hitchcock & Bleed, 1997), how requisite skills for hunting are learnt in childhood and adolescence (Dira & Hewlett, 2018; Lew-Levy et al., 2022), and potential correlations between weapons with skill, age, gender and physiology (Bebber et al., 2023; Haas et al., 2020; Losey & Hull, 2019; Milks et al., 2021; Whittaker & Kamp, 2006). While morphometrics may sometimes intersect with these questions, such as smaller weaponry potentially signifying engagement with hunting technologies by diverse groups, we need to account for variability and multifunctionality. Experimental programmes and new ethnographic data collected in the 2000s have addressed questions relating spear characteristics to function and performance much more satisfactorily than simple measurements are ever likely to do. There is still utility for such measurements for simple comparisons with archaeological material, but we should exercise caution when attempting to connect form with function and performance on the basis of ethnographic comparisons. We are hopeful that this study may help avoid future overinterpreting of the archaeological record. Optimistically, understanding what is missing in current object collections highlights the potential for future multidisciplinary ethnographic research and cross-cultural studies to help fill in knowledge gaps, which could improve our ability to understand the archaeological record.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10816-023-09635-4.

Acknowledgements This research was made possible by AM's Arts and Humanities Research Council PhD studentship at UCL. We thank the curators at Horniman Museum, University of Cambridge Museum of Archaeology and Anthropology, Australian Museum (Sydney), South Australian Museum (Adelaide) and Tasmanian Museum and Art Gallery (Hobart), for access to their ethnographic spear collections. We thank the Aboriginal Council of Tasmania for permission to study the Tasmanian spears, and acknowledge the contributions and knowledge of Indigenous societies, past and present.

Author Contribution AM and MP conceived of the study. AM collected the data, which AM and CH analysed. CH wrote the code with help from AM. AM and CH wrote the manuscript with contributions from MP.

Funding Annemieke Milks is funded by a British Academy Postdoctoral Fellowship (PF21/210027).

Data Availability All data, code and commentary (including additional multivariate analyses) associated with this paper can be found on GitHub (https://github.com/CSHoggard/projectiles) and is deposited in an Open Science Framework (OSF) repository (https://osf.io/yudth/).

Declarations

Competing Interests The authors declare no competing interests.

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