Lethal Threshold:
The Evolutionary Implications of Middle Pleistocene Wooden Spears

ANNEMIEKE GISELLE MILKS

UCL

INSTITUTE OF ARCHAEOLOGY

PHD

Author's Declaration

I, Annemieke Giselle Milks, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This thesis provides empirical data pertaining to the use of the earliest weapons in the archaeological record, which are a collection of plain wooden spears dating to the Middle Pleistocene. These weapons have been variously interpreted as objects for scavenging, hunting and self-defence. It is important to test these functional interpretations with a multi-disciplinary data-led approach, as these interpretations have implications for theories on the origins of human hunting, shifts in cognition, social structures and language. This is the first time a systematic, holistic approach to these artefacts has been taken, and is timely as several of the key sites of the period are currently undergoing further detailed analysis, resulting in reinterpretations of human behaviours during Middle Pleistocene.

In this document the performance of these artefacts is addressed through three research strands. The archaeological strand looks at both wooden spears as well as potential hunting lesions from their use. The approach to these include qualitative and quantitative analyses. The ethnographic strand comprises a review of the literature pertaining to the use of wooden spears in pre-industrialised societies. Alongside this, a morphometric analysis of a large sample of wooden spears from museum collections in the UK and Australia is presented for comparative purposes. The third strand consists of a multi-phase experimental programme, examining human performance when using replicas as thrusting and throwing spears; effectiveness of the spears on large mammals; hunting lesions resulting from use of the spears on large mammals; hammerstone impact damage to scapulae addressing questions of equifinality; and guided free-fall impact drop tests to better understand spear tip design. Results from the different approaches are brought together and compared, to better address the archaeological record from the Middle Pleistocene, including both the weapons themselves and potential zooarchaeological signatures resulting from their use.

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List of Abbreviations used in the text

BMD bone mineral density
C Celsius
cm centimetre
CV coefficient of variation
CT computed tomography
DIA diameter
DoP depth of penetration
fps frames per second
g gram
HSV high speed video
Hz Hertz
IE throwing impact event
IMP hammerstone impact episode
J Joules
KE kinetic energy
kg kilogram
m metre
Max maximum
Min minimum
mm millimetre
ms milliseconds
m/s metres per second
MIS Marine Isotope Stage
MP Middle Pleistocene
N Newton
n sample size
P participant
PB personal best
PoB point of balance
RE recorded event
Sch Schöningen
SD standard devlation
SEM scanning electron microscope
TE thrusting impact event
μm micrometre

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For Clara

Chapter 1. Introduction

1.1 Overview of thesis

In the year 1911 Samuel Hazzledine Warren, a British amateur geologist, made a special discovery - a wooden artefact from Pleistocene sediments in Clacton-on-Sea (UK), which he reported to the Royal Geological Society as possibly representing 'the point of a palaeolithic spear' (Warren 1911). The discovery was made during a period when very little was understood of European Pleistocene humans: the following year witnessed the discovery of 'Piltdown Man', a fraud that was not revealed as such for decades, demonstrating how opaque the knowledge of even the most fundamental aspects of human evolution was at the time (Thackeray 2012). Just over a century later, there have been a small number of further discoveries of European Pleistocene archaeological wooden spears as well as two proposed hunting lesions representing their use (Jacob-Friesen 1959; Thieme 1997; Roberts & Parfitt 1999; Smith 2010; Schoch et al. 2015). While the physiology of hominin species, their technologies, and behaviours throughout the Pleistocene are considerably clearer now than when the Clacton spear point was discovered, our understanding of these early weapons has remained relatively stagnant, with basic questions about design, function and performance still debated. Therefore this thesis sets out to provide the first holistic assessment of the use of wooden spears as hunting weapons during the Middle Pleistocene, which helps to shed light on technology-assisted hunting behaviours of hominins during the period. As a result of preservation bias, wooden spears form a miniscule percentage of total artefacts from the period. With a total of 12 examples of complete or fragmentary wooden spears from the entire European Middle Pleistocene (MP) and early Late Pleistocene (Oakley et al. 1977; Thieme & Veil 1985; Schoch et al. 2015), large-scale analyses are impossible and intersite comparisons are challenging. At the same time, these rare wooden spears are significant objects in helping understand human evolution, particularly for research of a period that faces major challenges in reconstructing behaviours on the basis of the archaeological evidence alone. They provide direct evidence of the early use of weaponry, have laid to rest major debates about hunting vs. scavenging by MP hominins, and are frequently linked with hypotheses regarding increased encephalisation, advances in cognition, adaptations for throwing, and social organisation (e.g. Gaudzinski & Turner 1999; Conard et al. 2015; Roach & Richmond 2015b).

Prehistoric weapon technologies have received increasing attention over the last few decades, in part due to hypotheses that innovations are indicative of concurrent shifts in human behaviours, dispersals and/or cognition (e.g. Rots & Plisson 2014; Iovita & Sano 2016a). Many of the hypotheses regarding behavioural similarities and differences of species within our genus rest on the theory that simple forms of weaponry were in place for earlier *Homo* - although the timing for this is poorly understood - while mechanically-aided projectiles were exclusive to *H.*

sapiens (e.g. Shea 2006; Churchill & Rhodes 2009; Shea & Sisk 2010a). These models also often propose that untipped weapons delivered by hand are inferior in myriad ways to tipped and complex projectiles, typically on the basis of estimates of performance and use (Churchill 1993; Lieberman et al. 2007; Shea & Sisk 2010a; Shea 2006; Churchill 2014). Although many argue that untipped wooden spears were used during the MP or earlier to hunt medium to large game (e.g. Thieme 1997; Voormolen 2008b; Smith 2013; Schoch et al. 2015), as will be demonstrated throughout this thesis the capacity of these weapons to lethally wound such an animal has not yet been conclusively demonstrated and there are multiple aspects of their use and performance that remain poorly understood. A critical and empirical evaluation of wooden spear performance is imperative because weapons are so frequently used as behavioural vectors in human evolutionary studies, and because they directly inform us about Pleistocene hominins' ability to compete with carnivores to hunt for meat.

1.2 Aims and objectives

This thesis has as its core aim an improved understanding of some of the most basic assumptions made about the performance of hand-delivered wooden spears. It will replace a number of estimates in the literature with empirical data on key features of spear performance including:

- Their design, energy at impact, and ability to penetrate large mammals for the purpose of hunting.
- Their effective distance as hand-thrown spears.
- How their use corresponds to prey and environments.
- Any archaeologically visible signatures their use may leave to faunal remains.

An aspiration of the research is to evaluate linear models of weaponry over time to determine whether such models are masking variability, and if so what this might mean for narratives about life in the European Lower and Middle Palaeolithic. Ideas about limitations or benefits of use in comparison to later weaponry innovations will be evaluated on the basis of multidisciplinary approaches.

The objectives that are set to meet the above aims are as follows

1. To establish the mechanics of hand-delivered untipped wooden spears, used as thrusting and hand-thrown spears with a particular focus on mechanics, encompassing impact velocities (thrusting and hand-thrown spears), force (thrusting spears), kinetic energy (thrusting and hand-thrown spears), and effective distances (hand-thrown spears).
2. To analyse the morphometrics of archaeological and ethnographic hand-delivered wooden spears, with a particular focus on the penetrating tips of the spears, examining how the archaeological examples compare with one another, as well as with ethnographic examples, and whether any of the features are indicative of function.

3. To further illuminate the performance parameters as well as the environments, prey, hunting strategies, and the global spread of wooden spears in recent contexts through a review of the ethnographic literature.
4. To determine whether hand-delivered untipped wooden spears are capable of lethally wounding a large adult mammal.
5. To establish through an analysis of potential Middle Pleistocene hunting lesions and experimentally-produced bone damage the characteristics of any resulting lesions from wooden spears, and to initiate an investigation of whether these characteristics are diagnostic of wooden spear use or whether they may overlap with other human or taphonomic processes.
6. To compare all of the resulting data for implications about the hunting behaviours, social organisation, and cognitive capacities of Middle Pleistocene *Homo*.

1.3 Research framework: scope and limitations

The thesis is specifically concerned with the use of weapons during European Middle Pleistocene spanning ca. 781-130,000 BP. However, because the sample size of wooden spears from this period is so small, all known archaeological examples will be discussed in the thesis, which not only provides means of further morphometric comparisons but also improves our understanding of the geographical spread and chronological persistence of these weapons. The thesis is concerned with the morphometrics of wooden spears; with access to analyse the distal points of the Schöningen sample, and the Clacton spear point representing a broken tip, it was logical to particularly focus the morphometric study on the distal parts of the spears but where possible, a broader analysis including published data is included. The hunting lesions covered in the thesis are those from the MP British sites of Boxgrove and Swanscombe as they are the only two suggested thus far to be the result of impact from a wooden spear (Roberts & Parfitt 1999; Smith 2010; Gaudzinski-Windheuser 2016). The focus was on providing a clear quantitative and qualitative analysis of these archaeological examples, and further exploring these by experimental analogy.

Because the thesis is primarily concerned with the performance characteristics of wooden spears, the research does not cover traces of manufacture or use. Although both intersect with effectiveness, it was outside the scope of this thesis to systematically and comprehensively analyse such marks, though where possible and particularly appropriate, these are photographed and described either in the body of the thesis or in the Appendices. The thesis is not concerned with the physics or biomechanics of hand-delivered wooden spears, though such studies are discussed when relevant and any relevant observations are made when appropriate, which should aid researchers concerned with these aspects of spear use in designing further studies. This research also does not investigate the cognitive capacities, skills, or *chaînes opératoires* behind the manufacture of simple wooden spears, as these questions have been addressed, and/or are currently the subject of other research (Oakley et al. 1977; Hayden 1979; McNabb 1989; Haidle 2009; Haidle 2010).

1.4 Theoretical and methodological approaches

The objectives set out in 1.2 will be met in a series of studies throughout the thesis. Because the nature of the objectives is that they are wide-ranging and cover broad periods of time, they need to be met with a variety of theoretical and methodological approaches. A multi-proxy approach must be interdisciplinary and rests upon both previously published and original research using findings and adopting methodologies from wound and terminal ballistics, forensic science, and sports science along with more traditional archaeological, palaeoanthropological, and ethnographic approaches.

In order to evaluate wooden spears, this thesis has three strands, each with different datasets and methods for analysis. The first strand addresses the archaeological evidence for wooden spears, including the weapons themselves and potential hunting lesions, using quantitative and qualitative approaches to both, and additionally making use of previously published research on wooden spears and hunting lesions from later periods. The second strand is ethnographic research, and acknowledging the limitations of such an approach, reviews the most relevant published literature on the use of wooden spears in pre-industrial societies, as well as conducting an original research study of a large sample of ethnographic wooden spears creating a reference sample for archaeological examples.

Finally, the thesis heavily relies on experimental approaches, not only due to the dearth of experimental research concerning wooden spears, but also because experimental approaches provide quantifiable proxies of past behaviours. The experimental studies in this thesis first establish performance parameters that are then used for a second phase of experimental work. The experimental work was largely collaborative, including most significantly with researchers from the Impact and Armour group, Centre for Defence Engineering at Cranfield Defence and Security, using their facilities and equipment located within the Defence Academy of the United Kingdom (Shrivenham Station, Wilts, UK). Such access to expertise and equipment helps raise the standards of experimental prehistoric weapon research and increases confidence in the results. Experts in spear use were sought, and one such collaboration involved working with throwing athletes from Loughborough University. A sharp force weapons expert, and an expert in wound ballistics, both of whom regularly consult with impact and armour engineers at Cranfield Defence and Security were also involved. The experiments in this thesis were designed to balance the need for excellent quality data with sample sizes, taking into consideration the high costs associated with the use of the aforementioned equipment and facilities (see Appendix 2 for further discussion on theoretical approaches in experimental archaeology and setting of protocols). For each experiment presented in this thesis there is an individual set of specific research questions, allowing for more open-ended inquiries, a wide range of outcomes to be reported, and proposals for future research. Finally, because the lines of evidence are often initially disparate, quantitative comparative analyses are made, linking experimental and ethnographic findings directly back into the archaeological record. Original conclusions are made regarding both published datasets and the original research conducted in this thesis.

1.5 Thesis structure

Because the methodological approaches and ensuing results are frequently diverse and interactive, the thesis does not follow a traditional structure with methods/materials, results and discussion. Instead the thesis is thematic, and thus the methods/materials, results and discussion relating to each topic are contained within the relevant chapters. Although the opening review chapters (2 and 3) contain some broadly useful information and definitions, details of background research are contained within the later relevant chapters. This approach was taken to facilitate coherence for the reader.

The first two chapters consist of a broad and wide-ranging review. Chapter 2 opens with a historical perspective on the views of early hominins and weaponry, followed by a brief review of the European Middle Pleistocene hominin record and evidence for early hunting behaviours, concluding by reviewing a selection of relevant studies from palaeoanthropology, primatology, and behavioural sciences. Chapter 3 covers previous approaches to the use of wooden spears, including definitions of weaponry and models, the archaeological evidence for the use of early weaponry, previous assessments of use based on ethnography, and an overview of experimental analogies and methods. Chapter 4 covers the archaeological research on wooden spears, including backgrounds of the main sites as well as the original research and preliminary conclusions. Chapter 5 is structured similarly, addressing the evidence for hunting lesions. Chapter 6 begins with a review of the ethnographic literature on the use of hand-delivered wooden spears, taking a critical approach to previous datasets about their use in terms of distances, prey, and hunting strategies, making some fresh conclusions. The second half of Chapter 6 presents a museum-based study of ethnographic examples of hand-delivered wooden spears, providing a reference dataset for those studied in Chapter 4, concluding with a comparative analysis of archaeological vs. ethnographic examples. Chapters 7 and 8 present the experimental work undertaken for the thesis. Because an analysis of the performance of wooden spears cannot be separated from their means of projection - as both thrust and thrown weapons - Chapter 7 tackles some of the most fundamental aspects of performance. Any experiments, whether controlled or not, struggle to be compelling if basic parameters of their use are not first reliably established. Therefore, Chapter 7 consists of two human performance trials, using experts to thrust and throw wooden spears in order to capture data on velocities, force and distances. Chapter 8 presents a second phase of experiments. The first is an actualistic study using hammerstones to open marrow and grease reserves in horse scapula and is designed to help evaluate questions around potential alternative causes for the possible hunting lesions from the British sites of Boxgrove and Swanscombe. The second experiment, a free-fall impact drop test, looks to evaluate small variations in distal tip diameter of wooden spears, linking in with morphometric data in Chapters 4 and 6. The third experiment uses the data from Chapter 7, using wooden spear replicas on horse carcasses in order to evaluate their effectiveness on a large mammal. The chapter concludes by making a comparative analysis between the potential MP hunting lesions analysed in Chapter 5 with the bone damage from both the hammerstone and spear experiments, making a conclusion about the most likely cause of damage based on a combined quantitative and descriptive analysis. Chapter 9 closes the thesis with a broad review of how the aims and objectives were met, and suggestions for future research that will help expand our understanding of the earliest weapons, followed by an exploration of the implications of the wide-ranging conclusions for evaluating hominin lifeways during the Pleistocene.

Chapter 2. Weapons and human evolution: historical background and patterns of human predation in the European Middle Pleistocene

Technology reveals the active relationship between man and nature…
- Karl Marx (Theses on Feuerback, Marx & Engels 1998)

This research sits at the centre of questions about the interface between technology and subsistence behaviours, physiology, cognitive abilities, and social structures of the hominins inhabiting northwest Europe during the Middle Pleistocene (MP). Although on the surface the subject matter may appear constrained to a single technology with few archaeological examples, the results of the study have relevance for the interpretation of the entire Pleistocene hominin record. As a result of the wide range of subjects that the thesis touches upon, an interdisciplinary approach provides the best way of making connections. Such an approach is necessary in order to contextualise wooden spears in the wider interpretations of hominin lifeways during this key period of shifts in behaviours, as well as providing context for the wide range of artefacts studied and methods used later in the thesis. This chapter and the next make a broad review of literature from multiple disciplines. Beginning with a historical background of links between weapon use and human evolution (2.1), it then continues by reviewing the evidence for hominins and behaviour in the MP, giving an overview of prey behaviours and predator-prey relationships including hunting strategies as well as the use of palaeolandscapes (2.2), and finishes by touching upon relevant research from biomechanics and primate studies (2.3).

2.1 A short 'prehistory' of weaponry: historical background

2.1.1 Introduction to historical background

As Palaeolithic archaeologists and anthropologists, we regard human hunting, and by extension evidence of weaponry, as key to the evolution of our genus, with an extraordinary amount of research focused in some way around meat eating. As an example, one of the dominant paradigms in human evolutionary studies that had roots in the late 19th century were a related group of theories including the 'hunting hypothesis', 'Man the Hunter', 'Killer Ape' and to some extent home-base/food-sharing models (e.g. Dart & Craig 1959; Lee & Devore 1968a; Ardrey 1976; Isaac 1978). The validity of the hunting hypothesis - the idea that hunting drove human evolution and defined our genus - was questioned by proponents of the New Archaeology who argued that early *Homo* was a scavenger (e.g. Binford 1981; Blumenschine 1986), and while most generally now accept the importance of meat-eating and hunting for human evolution, there are still uncertainties about the timing of the origins of hunting for our genus *Homo*. Interwoven with these debates have been questions about the role of tool use, including weapons, in defining our genus. ‘Man the Toolmaker’ was an influential work that can be connected with the later ‘Man the Hunter’ model, particularly through Oakley’s discussion of the role of weapons in early hunting behaviours and the function of stone tools as shaping these weapons (Oakley 1949, p.13). These culture-dependent hypotheses regarding hunting shared origins in 19th century scholarship, particularly with the idea that bipedalism was directly connected to the freeing of the hands for tools (Darwin 1871; Morris 1886). Even after the ‘Single Species Hypothesis’ - which had emerged out of a single-phase artefact-determinant explanation for human evolution - was overturned by multiple lines of evidence in the 1970s, the idea that tool-use is part of what makes us human persists (Jolly 2009). The interplay of morphological adaptations and material culture in the Pliocene and Early Pleistocene is currently being debated in a series of hypotheses modeled primarily on evidence from palaeoanthropological, palaeoclimate, zooarchaeological and primate research, some of which explicitly debate the role of weaponry (Bramble & Lieberman 2004; Pickering & Bunn 2007; Lieberman et al. 2007; Bunn & Pickering 2010). Connections between tool use and the origins of hominin hunting behaviours remains a key research area, even though many now view differences in tool behaviours between humans and primates as quantitative (C. Boesch et al. 2009). This review (section 2.1) briefly covers key developments in theories mentioned above about subsistence in human evolution, with a particular focus on the role that weapons have played in models, and how historical and contemporary views of human violence have influenced interpretations of human hunting and developments in weaponry.

2.1.2 Historical references to the use of weaponry in human evolution

2.1.2.1 The Antiquarians

As early as the 16th century the Italian naturalist Michele Mercati made a connection between ‘ceraunia’ - or stones with unusual shapes - and ethnographic tools and weapons that explorers had begun collecting and bringing to Europe from the New World (Goodrum 2002). However, it took over a century for these ideas to get published, and it was not until the 18th century that naturalists and antiquarians began to widely recognize that many ‘ceraunia’ were not natural but rather man-made objects (Goodrum 2002), providing a foundation for recognizing that worked stone had anthropogenic origins. In 1690 an Acheulean handaxe was discovered in London in association with ‘elephant’ remains (probably a mammoth or extinct elephant), and John Bagford described the handaxe as a humanly-crafted tool (Goodrum 2002). However, he contextualized this find within the current understanding of human antiquity, assigning the artefacts to the Roman period (Trigger 2006, p.139). Significantly, Bagford described the stone artefact as representing the tip of a spear wielded by a Briton to kill a Roman elephant, thus imagining the stone tool to have functioned as a weapon of war (Goodrum 2002, p.267). In 1800, John Frere published the discovery of flint handaxes from Hoxne, England. Frere was interested in the context of the artefacts – found at a depth of 4 m and together with faunal remains of unknown animals (Frere 1800; Trigger 2006). Like Bagford’s description of a handaxe a century before, he interpreted the shape of the flint artefacts as being indicative of their use as 'weapons of war' (Fig. 2.1) (Frere 1800, p.204) in spite of the stone tools being found in association with fauna. It is intriguing that antiquarians would conclude not only that the stone tools represented spear heads, which is understandable given their morphology, but also that they had been used in warfare rather than hunting.

Figure 2.1. Handaxe from Hoxne, discovered by Frere, with the caption showing his interpretation of the tools as weapons (Frere 1800, Plate XIV)

Sixty years after Frere's paper, Joseph Prestwich (1860) connected the Hoxne finds with bifaces discovered in France, similarly referring to the flint tools as weapons, albeit more cautiously, describing a handaxe discovered by Boucher de Perthes as '…a flint, rudely fashioned into a cutting instrument, somewhat resembling the old flint weapons known by the name of celts, yet having a peculiar type of its own.' (Prestwich 1860). In this same paper a letter from John Evans put the Hoxne finds into three categories: the flint flakes were apparently intended as either knives or arrowheads, the 'pointed weapons' were spear heads, and oval-shaped implements provided cutting edges. Acheulean handaxes long continued to be interpreted as weapons, and still occasionally are (O'Brien 1981; Crosby 2002, p.28), though most anthropologists and archaeologists today would reject such a functional assignment (Costa 2012). In 1872, the year after Darwin's publication *The Descent of Man; and Selection in relation to sex*, Evans published a book titled *The Ancient Stone implements, Weapons and*

Ornaments of Great Britain (Evans 1872). Antiquarianism was slowly evolving into the field of archaeology and researchers such as Evans - who began experimentally replicating lithic weapon tips and analysing stone tools - were becoming more discerning in assigning function. In his book, he suggests, for example, that while bifacial tools from Kents Cavern and Le Moustier may have been hafted, it seemed more probable to him that they had been some sort of hand-held implement (Evans 1872). With the changes that were occurring in the understanding of geological and archaeological evidence, more thoughtful approaches emerged that took into account the very different life ways of human ancestors living in what had become evident was 'a very remote period indeed' (Frere 1800).

2.1.2.2 Darwin: two legs good

When Darwin applied his views of natural selection to humans in *The Descent of Man* (1871), he made connections between humans evolution and hunting that were to prove highly influential. In particular, Darwin suggested that adopting a bipedal gait would have been directly advantageous to our primate ancestors as it would have freed their hands, enabling them to '…better defend themselves with stones or clubs, to attack their prey, or otherwise to obtain food' (Darwin 1871, p.53). He goes further in connecting bipedal behaviours with weaponry, by suggesting that '…the hands and arms could hardly have become perfect enough to have manufactured weapons, or to have hurled stones and spears with a true aim, as long as they were habitually used for locomotion…' (Darwin 1871, p.52). However, as Jolly (Jolly 2009) points out, this and other similar passages do not necessarily indicate that Darwin believed that it was the use of tools that *drove* bipedal behaviours.

In the 1880's, Charles Morris (Morris 1886) made Darwin's suggestion of a connection between weaponry and bipedalism more explicit, proposing that limb proportions had evolved in order to enable our ape ancestors to wield hunting weapons. Harry Campbell (1913; cited in Cartmill 1993, p.193), proposed a theory that bears similarities to the 'Killer Ape' theory that gathered attention later in the 20th century, particularly from the public sphere, when he discussed hominins' lack of natural weaponry such as large teeth or claws. Another proponent of an early version of this theory was Carveth Read (1914; cited in Cartmill 1993, p.194-195). Read, a psychology professor at UCL, wove into his model of early hominin hunting with weaponry the need for co-operative social structures in group hunting, as a result of their inability to hunt using 'natural' weapons. These examples show the development of frameworks connecting weaponry with predatory behaviours early in approaches to human evolution (Cartmill 1993, p.192-195).

2.1.2.3 Killer Apes!

In the 1920's, Raymond Dart famously discovered *Australopithecus africanus* in South Africa (Dart 1925). His discoveries and assignment of the fossil specimens as ancestral to *Homo* were widely dismissed by the scientific community. In order to demonstrate a link with our later hominin ancestors, Dart later suggested that australopithecines were carnivorous (Dart 1949). Dart referred to Darwin's (Darwin 1871) proposal that early hominin weapon use would have resulted in smaller dentition, and reasoned that australopithecines, upon adopting a bipedal stance, would have been forced to use their hands rather than their teeth as weaponry. Dart proposed that the australopithecines, without sharp canines, claws, or evidence of stone tools, would have used the faunal remains discovered alongside the hominin fossils as weapons (Fig. 2.2) (Dart 1949; also see Binford 1981, p.13).

Figure 2.2. Raymond Dart, demonstrating the damage done with a scapula on a pig skull. (From Dart & Craig 1959 between pages 160-161)

Dart pointed to the use of humeri as clubs and horns as daggers (Dart & Craig 1959), rather than suggest as Oakley (1949) had that hominins may have manufactured tools from organic materials such as wood, which would not have survived in the archaeological record. Dart wanted direct material evidence to support his claim that *A. afarensis* was a hominin, and he provided this by claiming that shared with *H. sapiens* a predilection for flesh eating, hunting, and violence (Fig. 2.3) (Domínguez-Rodrigo 2002). Ironically, it was an inability to verify that these faunal bones were used as tools that brought so much criticism from colleagues. Although infamous for his proposals of an early ‘Osteodontokeratic culture’, this idea had at least one precedent, put forward by Abbé Breuil at a conference in 1936. Describing a purported bone tool industry from the much later site of Zhoukoudien, Breuil had suggested that humans were

> …surrounded by animals better armed by Nature than himself…What more natural than to rob them of these weapons to use against them? Ever a hunter, Man had around him the skeletal remains of his victims…Some of the completed longer bones made excellent clubs with handles not easily broken. (cited in Binford 1981, p.11)

Dart was aware of Breuil’s claims of a material culture involving bone weapons at Zhoukoudien, as well as Breuil’s claims of bone tool cultures at Cave of Hearths in South Africa (Dart & Craig 1959). Dart’s ideas were once again questioned by established academics, including Sherwood

Washburn in *Australopithecus: The Hunters or the Hunted?* (Washburn 1957) on the basis of similar patterns at carnivore sites, with Dart's theory ultimately disproven by C.K. Brain in his study of cave taphonomy (Brain 1980).

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Figure 2.3. Left: two Australopithecines engaged in interpersonal violence. Right – an australopithecine with weapon in hand, having hunted a baboon for meat (Dart & Craig 1959; p. 112, p. 115)

A colourful character in this history was Robert Ardrey, an American playwright with a background in anthropology, whose life and writings were influenced by Dart's research following a trip he took to Africa where the two met (Weidman 2011). Ardrey became entranced with Dart's theory, and the implications it had for modern humanity. He proceeded to publish a series of highly successful popularized versions of Dart's ideas (e.g. Ardrey 1961; Ardrey 1976), and occasionally involved himself in the academic debates (Weidman 2011). For Ardrey, the claim that a supposed human desire to kill had roots deep in hominin evolution was connected to his ideological fight against the social control pursued by totalitarian, and in particular Marxist, states (Weidman 2011). For Ardrey weapons themselves had practically driven human evolution, and the human instinct not only to hunt but to commit acts of violence was rooted deep in time, rendering it an unchangeable trait, which in turn indicated that humans were not able to be re-programmed to be cooperative or peaceful by governments.

Although attacked by the academic community for being 'unscientific' (e.g. Brace 1978), Ardrey's books were arguably just popularised manifestations of academic theories that human evolution was intertwined with hunting, violence, and weaponry. Contemporary zoologists, physical anthropologists, and primatologists such as C. Loring Brace, Sherwood Washburn, Louis Leakey and Konrad Lorenz were expressing varying academic versions of the idea that the human capacity and even pleasure in hunting, and interpersonal and collective violence were embedded in a long evolutionary history (Cartmill 1993; Weidman 2011). In a post-war era, many were attracted to these theories as an explanation of the horrific world events of two world wars (Cartmill 1993).

2.1.2.4 'Man' the toolmaker, 'man' the hunter

In his book *Man the Toolmaker,* Kenneth Oakley (1949) theorised that australopithecines probably used improvised weapons for defence, and that this eventually led to use of tools in hunting activities. For Oakley the key behavioural difference between australopithecines and later *Homo* was that of tool-using vs. tool-making. This idea was also promoted heavily by the American physical anthropologist Sherwood Washburn (C. Boesch & H. Boesch 1989). In reaction to Washburn, Donna Haraway (1988) argued that a western male scientific community had crafted a definition of hominisation that reflected those who were re-defining our species in a post-war era. She argues that in Washburn's early writings, characteristic hominin adaptations were broadly linked with bipedalism and tool-use, but by the late 1950's his work more specifically included the idea that hunting with weapons was a driving force of hominisation (Haraway 1988, p.227).

Washburn's theories eventually led to a symposium in Chicago in 1966, with a resulting publication in 1968 (Lee & Devore 1968a). The editors, Richard Lee and Irven Devore were former students of Washburn (Haraway 1988), and the edited volume titled '*Man the Hunter*' primarily consisted of ethnographic accounts, with a very small contribution of archaeological evidence supporting the hunting hypothesis (Lee & Devore 1968a; Domínguez-Rodrigo 2002). The narrative of hominin hunting at this stage was saturated with sexism: a key part of the 'Man the hunter' hypothesis stipulated that the disappearance of natural weaponry including canine teeth - considered a 'feminization' of males - in australopithecines necessitated culturally-crafted weapons (Haraway 1988). Conversely, the weaponry itself symbolized masculinity, and as hunting with weapons was a cooperative male activity, the process of hominisation became inextricably linked with being male as exemplified in the following three quotes from the volume:

> ...hunting is so universal and is so consistently a male activity that it must have been a basic part of the early cultural adaptation (Lee & Devore 1968b, p.7)

> Among modern hunter-gatherers, exclusion of females from the individualistic hunting of larger mammals seems to be closely related to the making and using of hunting weapons…Women have no weapons of their own….Ethnographic data suggest that perhaps the development of hunting weapons and ideas associated with them is one of the factors relevant to the tendency towards the exclusion of females from hunting. (Watanabe 1968, p.74)

> Human hunting is made possible by tools, but it is far more than a technique or even a variety of techniques. It is a way of life, and the success of this adaptation (in its total social, technical, and psychological dimensions) has dominated the course of human evolution…In a very real sense our intellect, interests, emotions, and basic social life - all are evolutionary products of the success of the hunting adaptation. (Washburn & Lancaster 1968, p.293)

The message that humanity was defined by behaviours practiced exclusively by males was eventually to become one of the drivers for dismantling ‘Man the Hunter’. If the key to hominisation was cooperation amongst armed males, thus giving males all the credit for the process of becoming human, then it was inevitable that a feminist critique would eventually play a role in dismantling large parts of ‘Man the Hunter’. This included a critique of the contribution that female gathering makes in hunter-gatherer food economies, countering the idea that meat eating was fully responsible for the evolutionary success of our genus (Dahlberg 1981). Ethnographic studies documenting female hunting in hunter-gatherer societies (e.g. Goodman et al. 1985) also showed that male-centred models of the emergence of human hunting were too simplistic.

The established theory of hunting by early hominins was understandably thought to necessitate weaponry but in the absence of any direct evidence, 17th through 19th century interpretations of Acheulean stone tool technologies as weaponry were perpetuated by speculating that early bifaces may have been hafted as weapons, and that a function as projectiles might have been the cause for their symmetry (Washburn & Lancaster 1968). Glynn Isaac (1968) on the other hand, argued that there was no evidence for hunting weapons at the Acheulean site Olorgesailie, a site well-known for its large quantity of bifaces. To what degree australopithecines were hunters was undoubtedly a matter of debate, but most at the time agreed that by the time our genus emerged, hunting with tools was a part of the package.

2.1.3. The hunting and scavenging debate: 1970s-present

2.1.3.1 Binford, Bunn, and Beyond: new models

Models centering around ideas of food sharing and home bases emerged in the 1970s; highly influenced by ‘Man the Hunter’, they were initially developed most intensively by Isaac using case studies of African Early Stone Age sites (Domínguez-Rodrigo & Pickering 2003). Although Isaac did not necessarily advocate for early hunting of large animals, meat eating was a significant aspect of the model, involving the sharing of meat, sexual division of labour, and a home base that provided a safe location for the group (Isaac 1978). An important feature of Isaac’s model was the social group behaviours that were attributed to Plio-Pleistocene hominins, and which did not inherently rely upon hunting as a signifier of such behaviour, but rather upon food-sharing as the central feature around which other behaviours including the use of equipment including weapons emerged. In contrast to meat-centric models are Jolly’s ‘Seed-Eaters’ hypothesis which proposed that the earliest hominins had established a seed eating econiche, based primarily upon dentition but also taking into account palaeoecology, shifts in bipedality, and use of the forelimb (Jolly 2009). A period followed that Domínguez-Rodrigo (2002) calls ‘revisionist’, in which primarily Lewis Binford (e.g. Binford 1981), C.K. Brain (e.g Brain 1980) and Robert Blumenschine (e.g. Blumenschine 1986) questioned models that placed hunting at the centre of the emergence of early *Homo* on the grounds of zooarchaeological evidence, whilst the 'Woman the Gatherer' model was proposed from the perspective of feminist academics (Dahlberg 1981). Isaac and others (e.g. Isaac 1983; Bunn & Kroll 1986) in return developed the 'Central Place Foraging' model which sought to explore the interplay between social interactions and subsistence activities, while Richard Potts proposed a 'Stone Cache' model (Potts 1988; Domínguez-Rodrigo & Pickering 2003). Binford (1985) claimed in one of his many papers aimed at dismantling the hunting paradigm that recent researchers including Isaac and Richard Leakey were responsible for developing the 'consensus view' that early hominins were hunters. This review has clarified that this model had a rich and long history, weaving its way between antiquarians, palaeoanthropologists and popular science writers long before the 1970s.

Because of calls for more empirical evidence in assessing early hominin behaviours, research in this arena shifted from being primarily informed by ethnography and primatology, to using archaeological and experimental evidence. With scores of papers that provided evidence on cutmarks, taphonomic processes, and faunal body-part representation (e.g. Bunn et al. 1980; Binford 1981; Bunn 1981; Potts & Shipman 1981; Shipman 1981; Binford 1985), the 'hunting and scavenging debate' was born. Due to the dearth of artefactual evidence from the Early Stone Age/Lower Palaeolithic directly representing weaponry, questions about *how* hominins might have hunted were mostly sidelined in favor of determining whether they hunted at all. The only solid evidence for Early and Middle Pleistocene weaponry that did exist was the Clacton spear point, and during the heat of this debate it and the later-dated Lehringen spear was suggested by Clive Gamble to have possibly functioned as snow probes for scavenging frozen carcasses, arguing that hominins at the time were not able to colonise Europe during fully interglacial periods because of the dense forest environments (Gamble 1986; Gamble 1987; Gamble 1992). In light of the fact that both artefacts came from interglacial contexts, Gamble was conscious that his proposed model was speculative (Gamble 1987, p.95) and the search for alternative explanations for what have typically been viewed before and since as hunting weapons shows the strength of the scavenging paradigm at the time. For the most part, critical studies of potential archaeological weaponry from the Middle Pleistocene did not really come into play until researchers (e.g. Villa & d'Errico 2001; Shea et al. 2001) began examining and searching for evidence in the early 2000s, looking for possible examples in the stone and bone tool record. This emergence of interest in the earliest weaponry was at least partly in reaction to new archaeological discoveries providing further direct evidence of weapon use in hunting in the Eurasian Lower and Middle Palaeolithic (Boëda et al. 1999; Thieme 1997).

A significant development in the hunting and scavenging debate came about with a paper by Leslie Aiello and Peter Wheeler proposing 'The Expensive-Tissue Hypothesis' (Aiello & Wheeler 1995). The authors argue that because brains are such metabolically expensive organs to run, and yet basal metabolic rates are not especially different in mammals, encephalisation in hominins was enabled by a reduction in the gut, another metabolically expensive organ. In order for this reduction in the gut to be possible, the hominin diet would have had to improve significantly, and included along with increased consumption of underground tubers and possibly the cooking of foods, a big increase in nutritionally rich animal products. The hypothesis has become extremely influential, finding much support not only among palaeoanthropologists but also among biologists and medical researchers (Fish & Lockwood 2003; Kaufman et al. 2003; Mau et al. 2009; Pfefferle et al. 2011; Santoro et al. 2006). Clearly the assertion that animal foods drove encephalisation has lasting implications for the hunting and scavenging debate, though not all researchers have agreed that there is enough empirical evidence to support it (Hladik et al. 1999; Navarrete et al. 2012; Allen & Kay 2012). Hunting is once again considered by many to be a part of the human behavioural package, though vast disagreements remain about the timing and importance of scavenging and/or hunting strategies, and associated advances in hunting technologies (Villa & Lenoir 2009; Villa & Soriano 2010; Wilkins et al. 2012; Sahle et al. 2013; Brown et al. 2013; Roach et al. 2013).

Large parts of the hypothesis that hunting was an important behavioural adaptation of our genus have needed rethinking. For one thing, the data do not support the idea that males drove expedient tool using, more complex tool making, or hunting adaptations. It is female chimpanzees who display more success with tool use in nut-cracking activities (Zihlman 2012), and the documented cases of chimpanzees making and using spears to hunt show more weapon-assisted hunting executed by the females (Pruetz et al. 2015). Ethnographic data on hunter-gatherers *do* largely document more male than female hunting (Villotte et al. 2010), but even this is not black and white, with some studies evidencing female hunting amongst recent hunter-gatherers (Bird 1999; Zihlman 2012; Goodman et al. 1985). Furthermore, recent analyses of archaeological and palaeoanthropological evidence point to females partaking in hunting activities in the Palaeolithic (Kuhn & Stiner 2006; Villotte et al. 2010). Therefore primatological, palaeoanthropological, and archaeological evidence together currently suggest that the pattern of a male/female division of labour may have been an adaptation of *H. sapiens* (Kuhn & Stiner 2006), or an even later socio-economic shift that took place between the Upper Palaeolithic and Mesolithic (Villotte et al. 2010). Thus the *Man* portion of the hypothesis can now be considered highly questionable, if not dismissed, not only on the grounds of evidence proposed by initial feminist critiques such as ‘Woman the Gatherer’, but indeed even on the initial claims that *male* cooperative hunting was an early adaptation.

2.1.3.2 Weaponry, human evolution, and ‘behavioural modernity’

Despite intensive research in prehistoric weaponry (see Iovita & Sano 2016a for a review), and although strides have been made in understanding early hominin subsistence behaviours, the specifics of the timing of the behavioural adaptation of hunting with weapons, what role it plays in hominisation, and in the evolution of our genus and/or species remains unresolved. As we progress in our research aims of further understanding these developments, it is hoped that this review of the historical background provides a lens through which to view current debates around the timing of innovations in weaponry in human evolution. In a time when identity politics are again coming to the fore, we are reminded that we interpret the archaeological record with our own biases. Those who research the Palaeolithic currently tend to approach the period from an ‘archaeological science’ perspective, which can sometimes result in a failure to engage in the theoretical constructs underpinning the interpretations of scientific research (Martinón-Torres & Killick 2015). Looking back several decades it is not difficult to view the killer ape/hunting hypothesis/man the hunter paradigms as identity construction. These theories have mostly fallen out of favour, in part due to a lack of evidence and issues with oversimplification and equifinality, but there are also concerns over the construction of human identity being predicated on concepts such as fixed gender roles and innate aggression. Assuming this assessment is at least partly valid, we must turn this same lens upon current research trends (see Shea 2011). Although some would argue that in evolution ‘only differences matter’ (Sisk & Shea 2011, p.100), homologous behaviours are also important in terms of insights. The case of the Aboriginal Tasmanians, explored further in Chapter 6, stands as a cautionary tale: linking low technological variability and/or simple weaponry with cognitive capacities was underpinned with racist and colonialist objectives aiming to disenfranchise the indigenous population and justify genocide (Bryden 1960, p.2; Ryan 2012 p.xix). It will be demonstrated in this thesis that current models of the development of weaponry are oversimplified partly on the basis of such views of recent foragers (see 2.2.2) and therefore claims regarding the behavioural vectors that weaponry represents may be overstated. This historical perspective will aid in the contextualisation and assessment throughout this thesis of current theories linking the use of weaponry to the evolution of our genus and the implications for human behaviours.

2.2 The European Middle Pleistocene: humans and animals

The Middle Pleistocene (MP) spanning ca. 781-130,000 BP is a key period in human evolution, and particularly so for northern Europe, with evidence for behavioural shifts and an increase in sites and assemblages thought to take place around 600-500,000 BP (Fig. 2.4) (e.g. Hosfield 2011; Ashton 2015). It is outside the scope of this thesis to present an in-depth review of the evidence for MP hominin fossils, or the debates around species and behavioural implications, but the significance of understanding the hominins manufacturing and using untipped wooden spears during this period in the European record warrants a brief discussion of the current evidence and state of the debate.

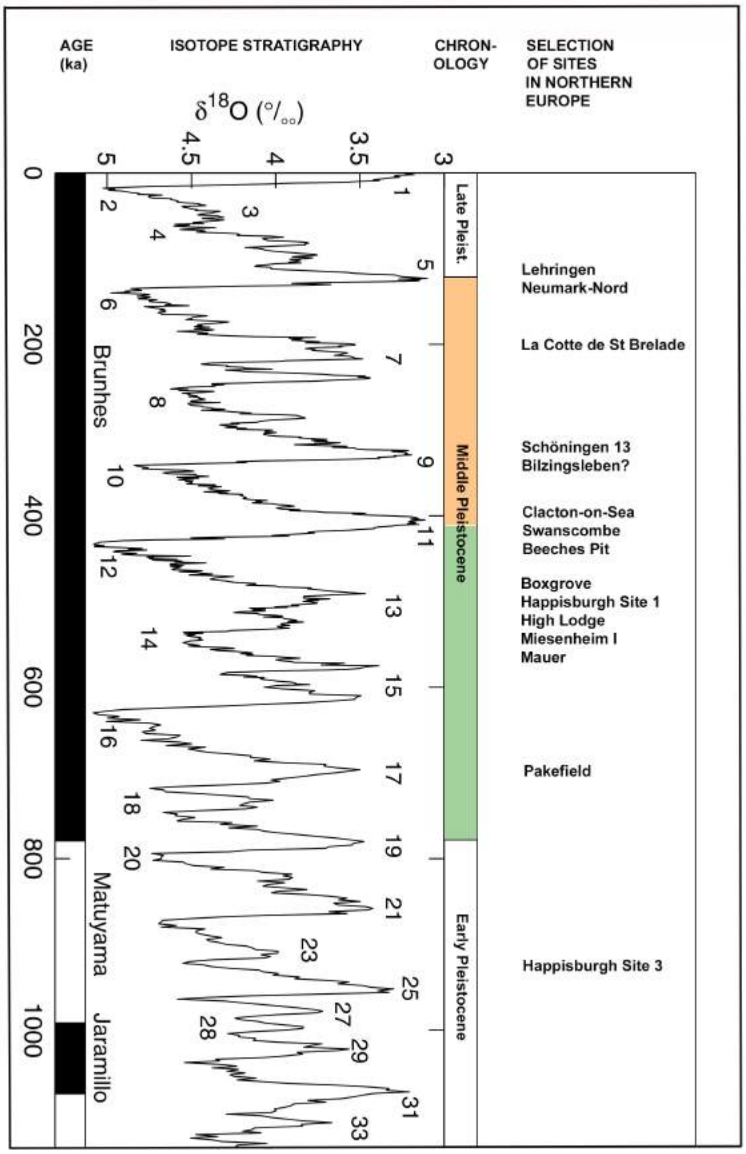


Figure 2.4. Marine Isotope Stages and Ages with a selection of northern European sites relevant to the thesis. The green filled section represents the early Middle Pleistocene, and the orange filled section represents the late Middle Pleistocene (isotope stratigraphy modified after Lisiecki & Raymo 2005)

2.2.1 Still a 'muddle in the middle'? European Middle Pleistocene hominins and their toolkits

Chronological control of the European MP is often controversial and problematic, and overall the fossil evidence is relatively poor, with much morphological diversity, leading to the nickname 'the muddle in the middle' (Isaac 1975; Buck & Stringer 2014; Daura et al. 2017). Fig. 2.5 is a map of a selection of sites mentioned in the text, focusing on those discussed specifically in relation to MP human or archaeological remains relating to hunting and/or weapon use. Hominin fossils attributed to the European MP (listed alphabetically by country) include those from Biache-Saint-Vaast (France), Arago Cave (France), Le Lazaret (France), La Chaise Bourgeois-Delaunay (France), Montmaurin (France), Bilzingsleben (Germany), Bad Cannstatt (Germany), Ehringsdorf (Germany), Mauer (Germany), Steinheim (Germany), Ochtendung (Germany), Petralona (Greece), Vértesszöllös (Hungary), Altamura (Italy), Ceprano (Italy), Saccopastore (Italy), Gruta da Aroeira (Portugal), Atapuerca Sima de los Huesos (Spain), Boxgrove (UK), Pontnewydd (UK), and Swanscombe (UK) (Cook et al. 1982; Street et al. 2006; Klein 2009; Dennell et al. 2011; Stringer & Andrews 2011; Churchill 2014; Lari et al. 2015; Marra et al. 2015).

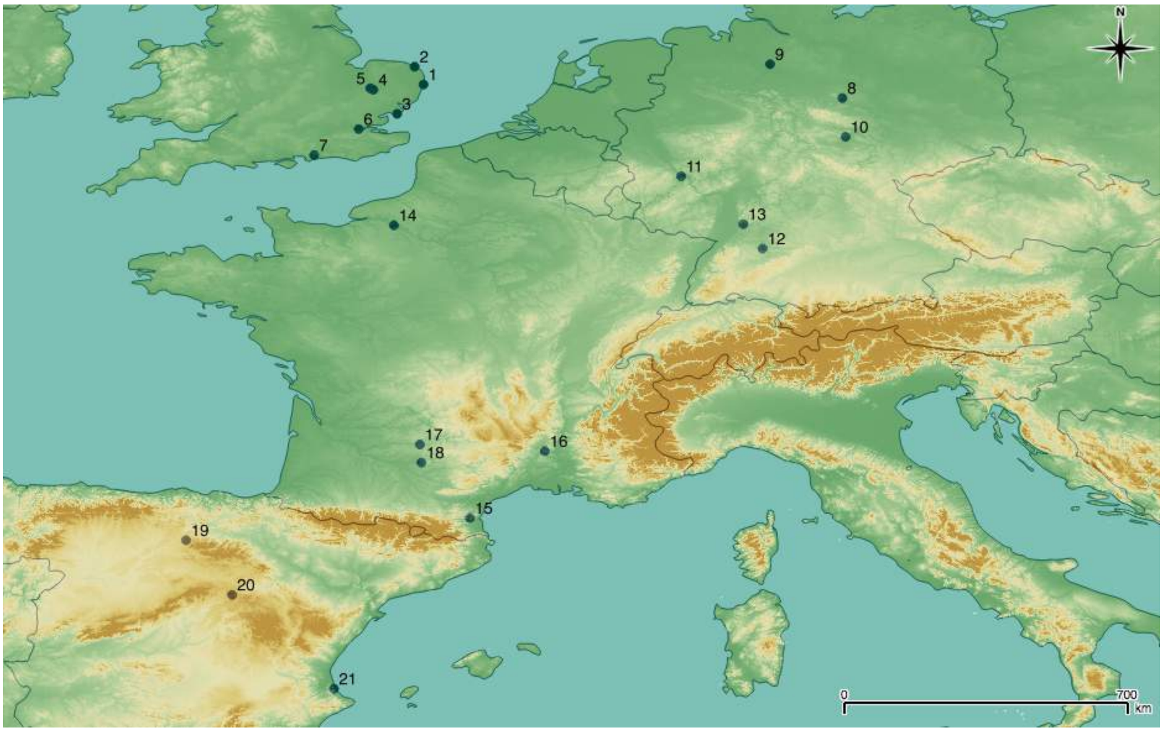


Figure 2.5. Map of a selection of the key Middle Pliestocene sites discussed in the text. Sites are 1. Pakefield 2. Happisburgh 3. Clacton-on-Sea 4. Beeches Pit 5. High Lodge 6. Swanscombe 7. Boxgrove 8. Schöningen 9. Lehringen 10. Bilzingsleben 11. Miesenheim 1 12. Bad Cannstatt 13. Mauer 14. Tourville-la-Rivière 15. Arago Cave 16. Orgnac 17. Coudoulous 1 18. Bruniquel Cave 19. Atapuerca, Sima de los Huesos 20. Torralba 21. Bolomor Cave

European MP hominin fossil material represents both *H. heidelbergensis* (Fig. 2.6) (or possibly *H. rhodesiensis*) as well as early *H. neanderthalensis* and potentially *H. sp. Altai.* The acceptance of the species *H. heidelbergensis* rests upon whether or not the Mauer mandible, the type specimen, is included in the sample. If excluded, then the species name would be assigned to *H. rhodesiensis* (Buck & Stringer 2014), and is considered by some to be ancestral to both *H. sapiens* in Africa and *H. neanderthalensis* in Europe, while others recognise it only as the latter (see Stringer 2012). Whether the Sima de los Huesos sample, dated to ca. 430,000 BP is interpreted as *H. heidelbergensis*, early Neanderthals or even Denisovans is under debate (e.g. Arsuaga et al. 1993; Stringer 2012; Buck & Stringer 2014; Arsuaga et al. 2014). Postcranial fossils from the MP, which are particularly significant for evaluating spear use, are relatively rare, with the largest sample coming from Sima de los Huesos, but further postcranial remains include three upper limb long bones from Tourville-la-Riviére (France); a tibia from Boxgrove; fragmented limb bones from L'Abri Bourgeous-Delaunay, Pofi (Cava Pompi), Venosa (Notarchirico), Ponte mammolo and Sedia del Diavolo; a vertebra from Montmaurin; and a number of postcranial bones from Ehringsdorf, Castel di Guido, Arago Cave, and Altamura (Cook et al. 1982; Stringer et al. 1998; Manzi et al. 2011; Faivre et al. 2014; Lari et al. 2015). Estimates for the Boxgrove hominin's stature are ≈175 cm and the estimate for body mass ranges from 76 kg - 90 kg (Trinkaus et al. 1999; Froehle et al. 2013). Estimates of the Sima sample including both males and females show a mean height of 164 cm, and body mass of 69.1 kg (Arsuaga et al. 2015). One particularly large individual from the Sima sample had an estimated body mass of 90 kg, making it at the heaviest end of estimates for MP hominins (Froehle et al. 2013). The mean stature of the Sima sample of males (n = 19) is 169.5 cm (SD = 4.0 cm) which is slightly taller than those of Neanderthals, slightly shorter than that estimated height of the Boxgrove hominin, and significantly shorter than estimates for early modern humans (Stringer et al. 1998; Arsuaga et al. 2015). Overall MP hominins appear tall and robust, with some particularly large individuals (Trinkaus et al. 1999; Gallagher 2013). The European evidence for robusticity is supported by the tibia from Broken Hill (Zambia), which is similarly robust to other MP hominins, though with a gracility potentially reflecting the tropical climate (Trinkaus 2009). The Sima sample also provides the best indication of the MP hominin hand, showing that as a population they were possibly preferentially right-handed (Lozano et al. 2009), with a morphology similar to Neanderthal and modern human hands (Arsuaga et al. 2015). The shoulder girdle and upper arm of the Sima hominins have a mix of traits, with humeral torsion similar to modern human populations, which may reflect that an adaptation for throwing was in place by this time (Arsuaga et al. 2015; Larson 2015). Dated to MIS 6, the Tourville left arm bones reflect trauma that the authors hypothesise could be connected with throwing activities (Faivre et al. 2014).

Roebroeks (2006) suggests that as large-bodied hominins, these groups would have been at even higher trophic levels than modern humans, which would have resulted in large ranges and low population densities. It is argued by many that the northern latitudes of Europe did not see significant and lasting occupation by hominins until about 600,000 to 500,000 BP, known as the 'modified short chronology' (Dennell & Roebroeks 1996; Roebroeks 2001; Roebroeks 2006; Hosfield 2011). With evidence of hominins dating between ca. .78 to 1 mya, Happisburgh 3 is the earliest evidence of occuption in northern Europe with conditions appearing to reflect a cooler later interglacial (Parfitt et al. 2010). The site of Pakefield (UK), dated to MIS 17 or 19, represents full interglacial conditions and an extension of Mediterranean ecologies exploited by hominins during the Early and early Middle Pleistocene (Parfitt et al. 2005). Particularly from the middle of the European MP onwards, an increasing number of sites demonstrate that hominins were inhabiting a range of environments (Roebroeks 2006; Hosfield 2011). High levels of meat consumption, particularly in colder periods and higher latitudes look to have been a significant aspect of the ability of hominins to colonise these higher latitudes during cooler periods, which may have been connected to brain growth and cooperative hunting (Roebroeks 2001; Roebroeks 2006). Focusing on the Eurasian MP record, behavioural interpretations of the period rely upon a compromised record, which has frequently failed to preserve what must have been significant use of organic materials. However, technological behaviours, particularly during the second half of the MP, include use of fire, evidence of hunting and butchering large mammals, multiple lithic industries, and the use of organic materials such as bone and wood. These are briefly outlined here.

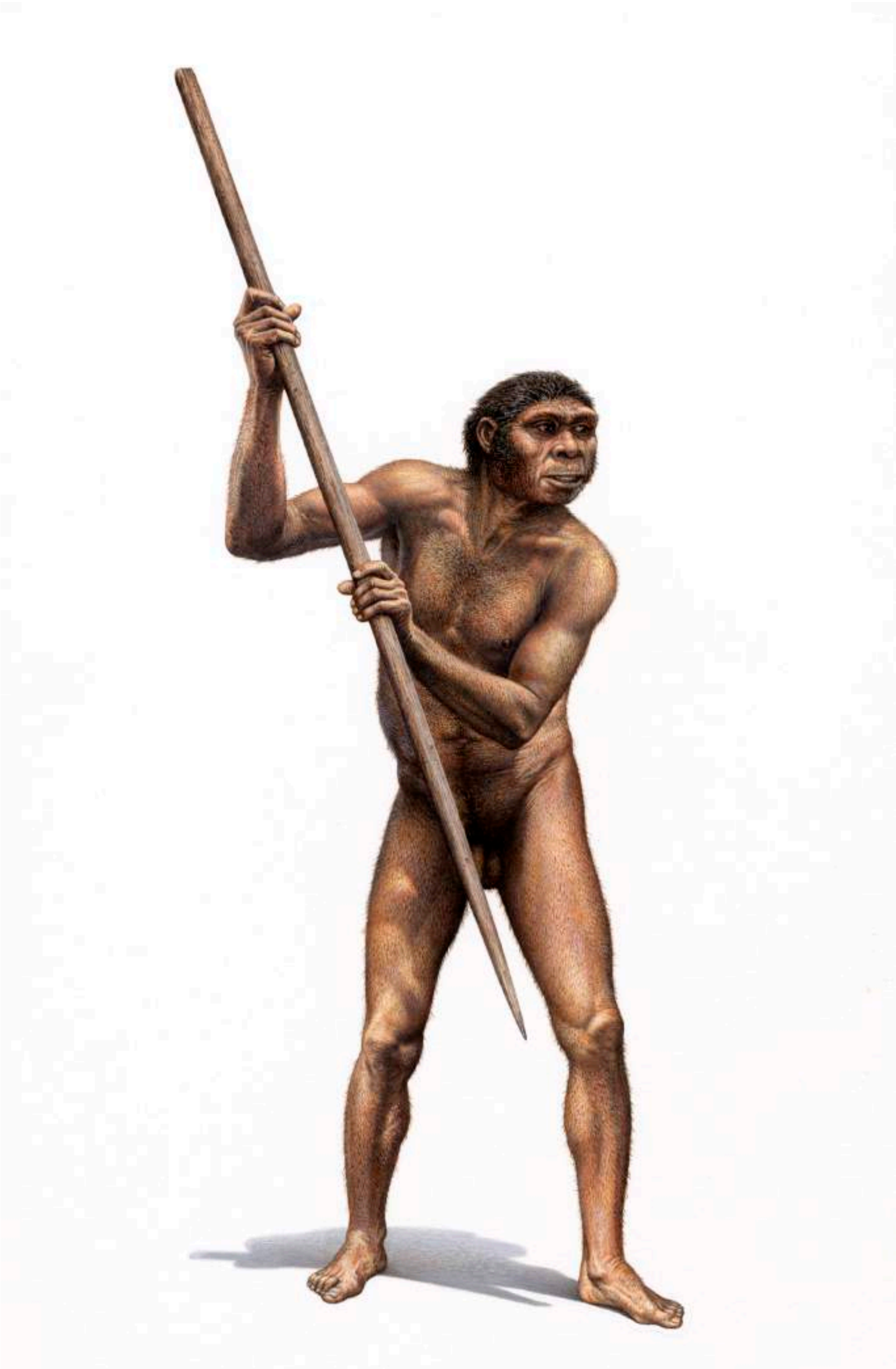


Figure 2.6. Artistic reconstruction of *H. heidelbergensis* with an untipped wooden spear. © John Sibbick / The Trustees of the Natural History Museum, London, permission to use granted

It is generally well-accepted that the organic components of material culture are grossly under-represented in the archaeological record, and this is particularly true for the Pleistocene. Wood preserves particularly poorly compared with other organic materials such as bone, antler, ivory, horn and shell (Hurcombe 2007, pp.142-43). Nevertheless, Pleistocene sites containing wood do exist, particularly from the Middle Pleistocene onwards (Appendix 1, Table A1). The organic tool technologies include not only the wooden spears that form the focus of this thesis, but additionally handaxes and other tools manufactured from bone (e.g. Gaudzinski et al. 2005 and references therein), bone retouchers (e.g. Van Kolfschoten, Parfitt, et al. 2015 and references therein), use of antler in soft hammer lithic reduction (Parfitt & Roberts 1999; Pope 2003; Pope & Roberts 2005), and wooden tools of uncertain function including possible throwing sticks, clamps/handles and digging sticks (e.g. Thieme 1997; Clark 2001; Conard et al. 2015; Schoch et al. 2015).

Most significantly for this thesis alongside the well-known Middle Pleistocene and early Late Pleistocene examples of wooden spears from Clacton-on-Sea, Schöningen and Lehringen, possible wooden spears - including possible spear shafts and broken wooden spear tips - have also been claimed for Kärlich-Seeufer (Germany), Cannstatt I, (Germany), Torralba (Spain), Monte Verde (Chile), and Wyrie Swamp (Australia) though several of these, and in particular the objects from Kärlich-Seeufer, Cannstatt, and Torralba are disputed as humanly modified (see Appendix 1, Table A1 for references; Schoch et al. 2015). These and other possible examples are discussed more in Chapter 4. Globally, indirect evidence of the use of organics for technologies in the Early and Middle Pleistocene (Keeley & Toth 1981; Keeley 1993; Domínguez-Rodrigo et al. 2001; B. Hardy & Moncel 2011), and limited evidence of consumption of plant foods at sites such as Gesher Benot Ya'aqov (Goren-Inbar et al. 2002) dating to MIS 18 and Payre, France spanning MIS 8 to early MIS 5, is a reminder that the significance of plants for food, medicine and raw material for tools, fire and bedding during this period remains poorly understood (Bigga et al. 2015; K. Hardy & Kubiak-Martens 2016).

The ability to make and control fire represents a momentous achievment for hominins, providing warmth and light, and paving the way for use in cooking, self-defence, tool manufacture, and hunting (e.g. Stahlschmidt et al. 2015b; Hosfield 2016 and references therein). It is now well-accepted that hominins were using fire during the MP, but with the clearest evidence in Europe not appearing until MIS 11 (Gowlett 2006; Preece et al. 2006; Roebroeks & Villa 2011). Recent analytical approaches ruling out fire for sites where it has previously been claimed, such as for Schöningen, demonstrate the importance of considering other causes for discolouration to wood and sediments that may mimic hearths and burnt wood (Stahlschmidt et al. 2015b).

Lithic tool manufacture from the European MP includes varied industries including those with bifacial tools, core-and-flake technologies, flake tools, and pebble/cobble tool technologies (e.g. Roberts & Parfitt 1999; White 2000; Schreve et al. 2002; Carbonell & Mosquera 2006; Hosfield 2011; Ashton et al. 2014; Serangeli & Conard 2015; Ravon et al. 2016a; Ravon et al. 2016b). Some disagreements still exist about whether these different technologies can be attributed to species, cultural or functional differences, and given chronological contemporaneity during the second half of the MP, different explanations include variation in raw material availability, function, and/or culturally distinct technologies produced by different groups or species (e.g. Ashton et al. 1994; Ravon et al. 2016a; Ashton et al. 2016). Towards the end of the MP, particularly from MIS 9 onwards technological shifts are widely apparent, adumbrating the emergence of the Middle Palaeolithic (White et al. 2011; Hérisson et al. 2016).

Non-technological behaviours interpreted from the European MP archaeological and human fossil record include lethal interpersonal violence, possible treatment of the dead, and the organisation of space and creation of structures. The earliest clear evidence for human violence is a Sima de los Huesos cranium showing evidence of an unhealed impact wound interpreted as blunt force trauma (Sala et al. 2015). Less certain are claims that a handaxe discovered amongst the human remains at Sima de los Huesos represents some form of ritual or treatment of the dead (Carbonell & Mosquera 2006), which could potentially have ended up in the pit by accident, rather than being purposefully deposited. However, there are features of the handaxe suggesting possible symobolic behaviour including its colour - a reddish-brown - as well as the fact of it being the only evidence of technology amongst the collection of hominin remains. Given arguments that later Neanderthals practiced symbolic behaviours (d'Errico et al. 2010) the evidence could represent early precursors to behaviours which later intensified. Recently, Bruniquel Cave (France) has been shown to have annular constructions made of stalagmites deep in a cave, associated with hearths, and dating to ca. 176.5 BP (Jaubert et al. 2016).

A few sites that are extraordinarily rich in archaeological material give remarkable insights into MP hominin behaviours, and of particular note are Boxgrove and Schöningen, key sites relating to the research aims in this thesis. Whether Schöningen represents a something new in terms of behavioural shifts, or rather a coalescence of behaviours seen from earlier MP sites is a matter for discussion and is revisited in Chapter 9. The main behaviours implied at the site including predation and systematic butchery of large mammals, the use of organics for tools, repeated use of a landscape, social cooperation and abilities for planning and communication to undertake such behaviours. But these can all be argued to be in evidence elsewhere and at earlier dates (Oakley et al. 1977; Roberts & Parfitt 1999; Rabinovich et al. 2008; Rosell et al. 2015; Zutovski & Barkai 2016). What Schöningen does provide is an extremely well-excavated site with extraordinary preservation conditions, providing a direct association of lithic and organic technologies including the earliest complete spears, with faunal remains bearing traces of butchery and evidence of primary access by hominins, given an unprecedented picture of patterns of human predation during the second half of the MP. Shaw et al. (2016) argue that the MP is no longer such a muddle, and this is certainly true for the second half of the MP, although a dearth of sites from the first half of the MP make the first half of the MP more difficult to interpret.

2.2.2 Hunting in the Middle Pleistocene: evidence for hunting, prey physiology and prey behaviours

Any discussion of human hunting must clarify what is meant by that term, which is explored here alongside the earliest evidence. This section reviews this as well as prey behaviours, underpinning a review of predator-prey relationships (2.2.3).

2.2.2.1 Evidence for hominin hunting behaviours in the Eurasian MP

This thesis partially follows Voormolen's (2008b, p.128) definition of hunting as 'the exploitation of faunal products facilitated by tactical intentional killing', although the systematic butchery of animals, which Voormolen's original defintion also includes, is not considered here to be a requisite for hunting because unsystematic butchery may also follow from a hunting episode, and therefore additional alternative means of consumption, particularly for smaller prey. Power scavenging is defined as humans 'confronting carnivores and forcibly driving them from their kills' (Bunn 2001, p.201). Because humans lack the physiology necessary for hunting, weapons are implicit for human hunting as well as power scavenging. A clear ethnographic example shows that who humans practiced power scavenging from lions carry weaponry with them even if they are not necessarily used (Stone 2011, from 4:30).

Throughout the animal kingdom, predators have varying strategies in terms of targeting prey within a population. Most predators will either create mortality profiles of prey that are similar to the living population structure ('catastrophic') or they target young and old members of a population ('attritional') (Stiner 1990). Only humans tend to regularly create a third profile called 'prime-dominated' that over-represents healthy adult animals, and thus this pattern is frequently used in zooarchaeological analysis to indicate human hunting (Stiner 1990; but see Gaudzinski & Turner 1999). Humans also can produce catastrophic and attritional mortality profiles for their prey, but it is more difficult to infer active hunting from these as they could represent passive or power scavenging.

Many argue that Early Pleistocene or even late Pliocene hominins in Africa were producing sites which strongly suggest hunting and/or power scavenging (e.g. Bunn 2001; Domínguez-Rodrigo et al. 2002; Domínguez-Rodrigo et al. 2005; Bunn & Gurtov 2014; Bunn 2015). Eurasian MP sites have provided a mixed record in terms of the earliest clear signs of hunting: those with prime-aged prey profiles include Qesem Cave in Israel spanning MIS 11 to 7 (Stiner et al. 2009), level L of Arago Cave (France) dated to MIS 14-12 (Moigny & Barsky 1999), layer TD 10-1 of Gran Dolina (Atapuerca) dated to MIS 9 (Blasco et al. 2013), Bolomor Cave dating to MIS 9 (Blasco & Peris 2012), Cagne l'Epinette (France) in MIS 9 (Moigne & Barksy 1999), Orgnac 3 (France) in MIS 9 (Moncel et al. 2005), and Misliya Cave (Israel) dated to MIS 7 (Yeshurun et al. 2007). Other sites such as the MIS 6 layers in Coudoulous 1 in Quercy (France) have faunal assemblages that demonstrate clear signs of human modification of large mammal remains, but not representing prime-adult profiles (Jaubert et al. 2012). At Schöningen, analyses relating to prey profiles are ongoing, but the presence of sub-adults and adults representing multiple herds has been noted (Voormolen 2008a; Hutson's comment in Hosfield 2016; Julien, Rivals et al. 2015). Overall the evidence shows that during the MP, and particularly during the latter half of it, hominins were top-level predators, capable of hunting large adult prey in prime condition, a pattern which some argue is even evidenced during the Early Pleistocene and early MP in Africa and Eurasia (e.g. Parfitt & Roberts 1999; Bunn 2001; Villa & Lenoir 2006; Pope & Roberts 2005; Gaudzinski & Roebroeks 2000; Rabinovich et al. 2008; Gaudzinski-Windheuser & Roebroeks 2011; Bunn & Gurtov 2014; Starkovich & Conard 2015).

2.2.2.2 Middle Pleistocene prey and modern analogues

Table 2.1 contains generalised estimates of how species relevant to this research project fall into absolute prey size categories (following Bunn 1982). This includes not only MP fauna exploited by hominins, but a few additional examples of extant fauna broadly comparable to extinct species that are referred to in the thesis, as well as fauna used in relevant experimental research (further referenced and discussed in Chapters 6, 7 and 8). Fauna noted to have been exploited with wooden spears in the ethnographic literature will be presented in Chapter 6. Overall European MP hominins predated upon fauna ranging from size class 2 through 6. Estimates for species of *Equus, Bos and Bison* all fall on both sides of size classes 3 and 4 depending upon species, subspecies, sex, individual and whether they are wild or domesticated.

Examples of taxa exploited by hominins during the MP include equids (*Equus mosbachnesis, Equus ferus sp.)* cervids (*Cervus elaphus, Praemegaceros sp.*, *Axis sp.*, *Dama clactoniana, Rangifer tarandus*, *Megaloceros sp.*), suids (*Sus scrofa*), bovids (*Bison priscus, Bos primigenius, Ovis ammon antiqua, Bison schoetensacki),* hippopotamus (*Hippopotamus amphibius*), rhinoceros (*Stephanorhinus kirchbergensis*, *Stephanorhinus hemitoechus*), bear (*Ursus deningeri*) and proboscideans (*Elephas [Palaeoloxodon] antiquus, Mammuthus sp.*) (K. Scott 1986; Tuffreau et al. 1995; Parfitt & Roberts 1999; Gaudzinski et al. 2005; Barsky & de Lumley 2010; Orain et al. 2013; Rodríguez-Hidalgo et al. 2015; Van Kolfschoten et al. 2015). An exception to the pattern of exploitation of large mammals is be Bolomor Cave (Spain) with an occupation spanning from MIS 9 to 5e showing human modification of small prey including for example rabbit (*Oryctolagus cuniculus*), crow (*Corvidae sp.*), and tortoise (*Testudo hermanni*) (Blasco & Peris 2012).

Table 2.1. Size Classes (following Bunn 1982) and estimates of a selection of adult prey including Pleistocene prey as well as some prey discussed in the ethnographic and experimental literature and experiments executed in this thesis (represented as purple text)

Size Class	Mass	Prey	Estimated mass (kg)*
2	23-113 kg	*Capreolus capreolus,* European roe deer *Dama dama,* fallow deer, extant	22 – 51 extant 47-67 Pleistocene: 39–145
3	113-340 kg	*Rangifer tarandus*, reindeer *Cervus elaphus*, Red Deer *Ovis ammon antiqua,* argali *Ursus deningeri*, Deninger's bear	Pleistocene: 43-255 male = 340, female = 255 Pleistocene: 77 – 475 100-173 ~275
4	340-907 kg	*Equus ferus* (Pleistocene) *Equus ferus przewalskii*, Przewaski horse *Equus ferus caballus*, domesticated horse *Equus quaaga (also E. burchelli),* common/plains zebra *Bison priscus*, steppe bison *Alces alces*, moose or elk *Megaloceros* sp., 'Irish elk'	301 – 883 225-350 300-500 up to 350 363 – 1930 202–642 329 – 1228
5	907-2,721 kg	*Bos primigenius*, aurochs *Stephanorhinus hundshemensis*, rhinoceros	389 – 2010 999 – 1691
6	>2,721 kg	*Mammuthus primigenius*, woolly mammoth *Mammuthus trogontherii*, steppe mammoth *Elaphus (Palaeoloxodon) antiquus*, straight-tusked elephant	~3000-8241 ~10,029-10,435 ~11,300-12,308

***Estimates in the literature vary widely as methodologies for estimating sizes of extinct species also vary, and species sizes varied geographically and chronologically. Many prey span two size classes. Estimates of Pleistocene body masses provided where possible. (Sources for estimates: Forsten 1993; Geist 1998; Weckerly 1998; Davies 2002; Burrill 2004; Rivals et al. 2006; Staker 2006; Meloro et al. 2007; Kahlke & Kaiser 2011; Larramendi 2016; Saarinen et al. 2016)**

2.2.2.3 Prey behaviours: social structures and anti-predator responses

Most of what we know about prey behaviours comes from studies of extant species, making imperfect analogies to extinct Pleistocene mammals, and therefore the summaries here in relation to hominin predation should be used with caution. Large mammal behaviours are complex and vary depending upon factors including species, habitat, size, age, sex, season, social group structure and predator. There are many strategies including alertness, vocalisation, silent retreat, flight, aggression, and group defence or mobbing. Predator-prey interactions influence habitat use, with the presence of large cat predators, for example, known to shift feeding strategies and limit food and water intake in response (Valeix et al. 2009). Pregnant, birthing and lactating females may greatly alter their typical anti-predator strategies, including shifting habitat preferences and social structures (Bongi et al. 2008). Furthermore, some species' predator responses are fixed, while others have more flexible and adaptive reactions and are capable of classifying predators and the specific risks they pose (Bates et al. 2007; Thuppil & Coss 2013). Garland (1983) correlated body mass with maximum speeds, finding that in general the larger the body mass, the faster the speed, though the heaviest animals are not the fastest, with the optimal size for speed around 119 kg. Behaviours of a selection of extant prey relevant to analyses including by analogy to Pleistocene prey discussed throughout this thesis are briefly outlined here.

Equids

Of particular relevance to this thesis are MP equids, especially caballoid horses, which have been assigned species names which include *E. caballus, E. steinheimensis, E. mosbachensis,* and *E. taubachensis* alongside others, though these may reflect a single species with the variability expected for horses over time adapting to climatic and environmental change (van Asperen 2012). Equids were a significant prey for humans throughout the Pleistocene, and humanly-modified horse bones are present at both Boxgrove and Schöningen (Parfitt & Roberts 1999; Van Kolfschoten et al. 2015). Fat is a significant component of human diets, with ethnographic sources suggesting it is favoured over meat products (Levine 1998). Equids are particularly nutritious as a food source, containing healthy fats in tissue and marrow, which the former according to the Hadza has a 'soft' consistency, and as such is used to feed newborn babies and in weaning by forest-steppe Kazakh groups (Levine 1998). Horse teeth from Schöningen 13 II-4, the 'spear horizon', were subjected to a mesowear, microwear and isotope analysis and suggest that the horses were mixed feeders with a significant component of browsing in their diet (Rivals et al. 2014), which has interesting implications for hominin hunting strategies of equids during the period as it may reflect differing habitats to those traditionally viewed for equids. Equids are cursorial grazers and because they primarily rely on escape as a defence strategy, they are more vulnerable in closed environments than they are in open settings (Guthrie 2001, p.45). Studies of wild vs. domesticated bovids found that woodland bovid meat contains higher essential fatty acids - 'essential' in part due to their requirement for reproduction - than those grazing in grassland (Crawford et al. 1970); if that pattern were to extend to equids, it could suggest a preference by hominins for browsing equids over grazing equids. However, even if not browsers, equids in grassland ecosystems contain highter essential fatty acids, potentially making them a key resource for hominins in open environments (Levine 1998).

Populations of Przewalski horses in Mongolia have shown a strong preference for resting at the highest elevation in their enclosures, which may relate to their ability to have good views of possible predators (Van Dierendonck et al. 1996). In general equids behave as a group, and compared with stallions or bachelor males mares are highly cautious of settings such as waterholes where large cats may be lurking. As a result harems with young animals are less likely to use habitats offering more cover to felids (Guthrie 2001). Although primarily using flight as a defence strategy, equids with tight social structures, including both the plains and mountain zebras (*Equus burchelli, Equus zebra*) as well as the domestic horse (*Equus caballus*) and Eurasian wild horse (*Equus ferus ssp. przewalskii*) (Fig. 2.7), with characteristic behaviours of feral horses, also act as a group to form a defensive stance (Kooyman et al. 2006). However, strategies do vary by species, and some species including Grevy's zebra, and the African and Asiatic wild ass (*Equus africanus, Equus asinus*) will not form these defensive groups. As Kooyman et al. (2006) point out, this particular defensive strategy may be highly effective against wolves, but would facilitate hunting by humans. Equids are extremely fast runners, reaching up to ca. 70 km/h making flight in open settings a highly effective strategy (Garland 1983).

Figure 2.7. A wild Przewalski horse taken in Khustain Nuruu National Park, Mongolia. By Ludovic Hirlimann from 's-Gravenhage, The Netherlands - Cheval de Przewalski, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=22147897

<u>Proboscideans</u>

Extant elephants are characterised by strong matriarchal herds of varying sizes consisting of females and young, while adult bulls roam solitarily or in small groups with other males. Female African elephants (*Loxodonta africana*) are known to retreat and aggressively vocalise in response to threats (Thuppil & Coss 2013). They will display aggressive behaviours and Asian elephants (*Elaphus maximus*), both lone and in herds, have been shown to do the same, but the response varies by predator (Thuppil & Coss 2013). Elephants have been observed to react aggressively to the Maasai, who spear elephants, while reactions to other humans were to retreat, showing that elephants are particularly able to distinguish between different types of threats and react flexibly (Bates et al. 2007). Elephants are moderately fast runners, up to 40 km/h (Apps 2000, p.120) making flight a reasonably effective strategy but in comparison to predator running speed underscores the significance of mobbing and aggression strategies.

Cervids

The social structures of cervids vary by species, with some living as solitary animals, while others are herd animals. In general, cervids are characterised by hiding or disguising themselves, and display flight behaviours in response to threats (Geist 1998). Moose/elk (*Alces alces*) have an additional response unusual amongst deer, which is that they may attack a predator using both legs and antlers (Geist 1998, p.235). Cervids who live in social groups, in particular red deer (*Cervus elaphus*) (Fig. 2.8) and reindeer (*Rangifer tarandus*) (Fig. 2.9) will leave their home ranges after human disturbance, though less social species like roe deer (*Capreolus capreolus*) and moose/elk (*Alces alces*) tend to remain (Sunde et al. 2009). It is difficult to know for certain the behaviour of the extinct Irish elk (*Megaloceros giganteus*) though it looks likely that they were highly cursorial, and potentially followed similar dietary and life strategies to elk (*Cervus canadensis)* (Geist 1998; Worman & Kimbrell 2008). Cervids are fast runners: moose/elk can run up to ca. 56 km/h (Geist 1998, p.224), reindeer can run 60-80 km/h (Gunn 2016), red deer can reach 72 km/h and roe deer 60 km/h (Garland 1983).

Figure 2.8. Male red deer (*Cervus elaphus*). By Maxwell Hamilton, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=54304920

Figure 2.9. Reindeer (*Rangifer tarandus*). By Alexandre Buisse (Nattfodd) - self-made (http://www.alexandrebuisse.org), CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2625968

Bovidae

The family of bovids includes a diverse group of species, including gazelles, cattle (wild and domesticated), bison and goat-antelope, with a variety of behaviours including solitary animals as well as those with strong social groups. Extant bison (*B. bison*) who live in herds display a variety of antipredator behaviours including fleeing and fighting (Carbyn & Trottier 1988). Body mass, sexual dimorphism and running speed of bovids vary greatly by species. For example, domestic cattle (*Bos taurus*) have been measured to have flight speeds of up to 21 km/h, while bison (*Bison bison*) are cited to have maximum speeds of 56 km/h, and gazelles can reach up to 97 km/h (Garland 1983; Müller & Keyserlingk 2006; Pisarowicz 2006).

2.2.3 Predator-prey relationships: hunting strategies and the importance of environment and landscape

The relationships between hominins and their prey are in some senses no different in scope to those of any predators to their prey, with all predators and prey having strategies aiding their survival. This section explores some of the known human hunting strategies and how that might relate to early hunting.

2.2.3.1 Hunting strategies: social hunting, multiple predation, and attack strategies

A variety of hunting strategies are known to be practiced by human hunters, with a complex interaction between environment, climate, prey size and behaviours, weaponry and number of humans hunting. Social hunting, also called communal or cooperative hunting, is key for understanding human evolution as it indicates a social structure underpinning subsistence behaviours that looks similar to those of recent hunter-gatherers. Social hunting by hominins is often inferred by evidence of humanly-modified zooarchaeological remains of prime-age large mammals, particularly with limited carnivore damage, and/or human modifications underlying such damage, as this indicates primary access to the prey (e.g. Smith 2013; Starkovich & Conard 2015). Prime-age animals, particularly herding ungulates with a flight response and/or extremely large animals are most likely to have been killed by social hunting strategies, whether by humans or other animals (Churchill 1993).

A wide range of animals engage in social hunting, the advantages of which include an increased harvest from kills, either by improving success rates, by enabling the hunting of larger prey and/or facilitating the taking of multiple animals (Gentry Steele & Baker 1993) with ethnographic data showing a strong correlation between hunting large game and group cooperation (Roebroeks 2006). Humans hunt singly as well, and presumably disadvantages of communal hunting include that it increases discoverability by potential prey, and particularly for smaller and solitary prey hunting in singly or in small groups can also be a highly effective strategy, though this is rarely discussed in the literature on archaic human hunting strategies. Social hunting is adaptive because it spreads risk (Hawkes et al. 1991) and increases meat intake, which facilitates sharing large meat packages, increasing fitness for the entire group (e.g. C. Boesch & H. Boesch 1989). Social hunting can be small-scale with two to five members of the hunting group, or large-scale, with five or more hunters (Gentry Steele & Baker 1993), though the degree of planning depth necessary for either is arguable given that species without language practice social hunting. Apart from humans (*H. sapiens*), extant mammalian social predators include hyaenas (*Crocuta crocuta, Hyaena hyaena*), lions (*Panthera leo*), wolves (*Canis lupus, Canis rufus*), dolphins (*Delphinus delphis*), whales (*Delphinapterus leucas, Orcinus orca*), chimpanzees (*Pan troglodytes*) and savanna baboons (*Papio cynocephalus*) (Gentry Steele & Baker 1993). Forest-dwelling groups of chimpanzees have executed large-scale hunts of six or more participants, and success rate correlated with an increase in number of hunters per hunting episode (C. Boesch & H. Boesch 1989). Chimpanzees use communication for organising and running a hunt including drumming and vocalisations, predating on other primates as well as ungulates in size classes 1 and 2, including both juvenile and adult prey (C. Boesch & H. Boesch 1989; Nishida et al. 1979). Evidence for social hunting during the MP has been argued for Eurasian sites including Qesem Cave, Israel (Stiner et al. 2009), Schöningen, Germany (Starkovich & Conard 2015), and Boxgrove, UK (Smith 2013).

Human hunters take single kills as well as multiple kills, called 'multiple predation' (Gentry Steele & Baker 1993). Multiple predation, or the taking of two or more animals in a single hunting episode, includes mass kills from a single hunt and kills taken one after another within the context of a single hunting foray. It is associated with social hunting, and a few species other than humans, in particular wolves, lions, and hyaenas practice mass predation, typically taking between two and five animals in a hunt; lions and wolves have less commonly been known to hunt sequentially (Gentry Steele & Baker 1993). Similar to the taking of large, adult prey, multiple predation is a strategy which increases fitness for the group.

Because hunting strategies encompass social hunting and multiple predation, the term ‘attack strategies’ is used here to refer to the methods with which prey are approached and killed. Attack strategies are defined and described (all after Churchill 1993) to include the following:

1. **Disadvantage hunting**. Disadvantage hunting involves somehow trapping or cornering prey, either using natural features such as mud, snow, swamps, or a cul-de-sac such as a valley or lake margin, or manmade features accomplishing the same goal. Disadvantage hunting has been particularly associated with large prey, and requires the use of landscape features as described above, if there is an absence of domesticated animals such as dogs or manmade corrals, and importantly these features need to co-occur with game animals (Churchill 1993). Both cooperative and solitary hunting strategies can be used with this technique.
2. **Ambush hunting**. Ambushing prey involves the predator hiding behind a natural or manmade feature to wait for the prey to pass, thus surprising the animal and can include animal drives if the animals are directed past the predator(s). Blinds are an example of a feature used in ambushing. This is different from encounter hunting, where an animal can be similarly surprised, but hunters have not been waiting in ambush. Stiner (1990) associated ambush hunting strategies with prime-dominated mortality profiles on the basis of ethnographic data, though this has been disputed because it specifies selectivity of prime-age adults, whereas the Hadza have been observed to use opportunistic, non-selective ambush and encounter attack strategies, resulting in a living population mortality profile (Bunn & Gurtov 2014). An example of non-human ambush predators include solitary felids (van Duyne et al. 2009). Amongst human hunters, ambush hunting is associated both with cooperative hunting solitary hunting, as is disadvantage hunting (Churchill 1993), and ethnographic data on the Hadza suggests that ambush hunting, at least in hot and dry climates, is only effective during the dry season at water holes using blinds (Bunn 2001). Prey size taken with ambush hunting appears to vary by weapon delivery system (Churchill 1993).
3. **Approach hunting**. Approach hunting involves getting close enough to prey to use the weapon without alerting the animal, therefore not triggering behaviours such as the flight response. This strategy is facilitated by natural features allowing concealment, but ethnographic evidence shows that humans are also known to have used crafted shields to facilitate approach hunting (Clarke 2012).
4. **Pursuit hunting**. Pursuit hunting requires the predator to run down the prey, either with speed or endurance running/walking to exhaust the prey. Based on ethnographic data, pursuit hunting without the aid of domesticated animals is particularly associated with hot and dry climates and unlikely in cooler temperate enviornments (Churchill 1993). An example of non-human pursuit predators is canids, including wolves, who will chase

prey to exhaustion (van Duyne et al. 2009). Pursuit hunting is likely facilitated by low levels of shrub and undergrowth while ambush hunting would follow the opposite pattern (van Duyne et al. 2009). It has been associated with the evolution of endurance running in *Homo*, though it has been pointed out that endurance running could also be useful in scavenging fresh animal carcasses (Bramble & Lieberman 2004).

5. **Encounter hunting**. This technique takes advantage of encountering animals in the undergrowth or trees, typically taking an animal if in range and not pursuing it if it manages to flee. The strategy would be especially useful for smaller prey and for solitary or fragmented herds, particularly in forested environments.

Attack strategies envisaged for the Early Pleistocene and early MP include ambush, disadvantage, and pursuit hunting (e.g. Lieberman et al. 2007; Bunn & Gurtov 2014). White et al. (2016) propose the use of ambush and disadvantage hunting by Late Pleistocene Neanderthals, including the use of landscape features. The association between hunting strategies, prey size and weaponry are further explored in Chapter 3.

2.2.3.2 Palaeolandscapes and palaeoenvironments

The effects, limitations and advantages of landscape features, climate and environment on hunting strategies are frequently referred to in the literature, but have not benefitted from a systematic approach to date. True hunting is something that cannot be replicated in a lab, at least in part because the infinite number of variables presented by a real landscape and environmental setting cannot be accounted for. However, our understanding of the 'effectiveness' within an environmental context is important in interpreting what weapons are optimised for, and is taken into account in this thesis when evaluating ethnographic accounts of wooden spears (Chapter 6). Hominin awareness of prey and landscape features must have been a significant factor in predator-prey relationships. Prey animals are aware of dangers of areas such as lakes and waterholes, which they need particularly in arid environments and periods, as well as when they are sick or dying. High points in the landscape that are used by prey animals to scan for predators were also likely used by MP hominins to identify herds or individual animals to target for hunting forays (e.g. B. Scott et al. 2014; Lefort et al. 2016). Vegetation provides hiding places for both prey and predators, affecting hunting strategies as well as weapon choice, while climatic and temperature differences will facilitate or inhibit strategies such as pursuit hunting. Voormolen (2008b) hypothesises that a muddly lakeshore such as that of Schöningen would disadvantage prey, in particular the large number of horses at the site, which would otherwise be likely to react aggressively. As researchers such as those cited above have recently been doing, an analysis of palaeolandscapes and palaeoenvironments in tandem with behavioural ecology of prey exploited and how these factors relate to site location, site type, technologies, and evidence of hunting will continue to help to evaluate possible hunting strategies and weapon choice in absence of direct evidence of weaponry.

2.3 Evidence related to early weaponry from palaeoanthropology, primatology, and behavioural sciences

In addition to the historical references providing a background to more recent research on early weaponry and evidence of MP hominin and prey behaviours, additional data are helpful from fields that are traditionally connected with Palaeolithic archaeology. In particular this section focuses on when archaeology intersects with research from the related fields of palaeoanthropology and primatology. It includes a brief discussion of biomechanical analyses relevant to weapon use (2.3.1); what primate studies have recently added to evaluating early spear use (2.3.2); and connections in behavioural studies between carnivory and collective and/or interpersonal violence (2.3.3).

2.3.1 The biomechanics of weapon use

Connecting early weapon use with physiology is a complex task, and has been explored through multiple avenues of research. Identifying physiological traits enabling weapon use commenced with early researchers including Charles Darwin (1871) already proposing connections between the origins of bipedalism, the ability for long distance running, the morphology of the hand, generalised tool use and the development of early weaponry. With the use of spears as basic thrusting weapons recently observed in a savanna chimpanzee group (Pruetz & Bertolani 2007; Pruetz et al. 2015), which is discussed further in 2.3.2, very early origins for this behaviour seems possible. The ability to throw an object, such as a spear or even a large stone, with the combination of power and accuracy, appears to be unique to our species: although some primate relatives, including chimpanzees and capuchins can and do throw objects (Marchant 1992; Westergaard et al. 2000), they are unable to throw at high velocities and with accurate aim in comparison with our species. Throwing is likely to be highly adaptive for humans, both as a method of self-defence as well as for hunting, and as with most other human adaptations, the origins of this are therefore of interest.

Human bipedalism may have evolved before *stone* tool technology (but see Harmand et al. 2015), and as for expedient and/or organic technologies it appears that these are not derived behavioural traits for *Homo* (C. Boesch et al. 2009; Huffman & Kalunde 1993; Pruetz & Bertolani 2007). Early bipedal adaptations may have emerged in a wooded environment, and hypotheses involving carrying or food acquisition are still a possibility (Richmond et al. 2001). Features present in australopithecines allow movement of the trunk that could have enhanced tool use by improving throwing and clubbing (M. Marzke et al. 1988), possibly connecting postcranial morphology in australopithecines with early weapon use.

While generalized tool use is not a pattern suitable for defining *Homo*, it might be that habitual tool-assisted hunting could be argued to be not such a foolish suggestion after all when considering evidence for obligate bipedalism. Wood & Collard (1999) argue that the fossil evidence shows that *Australopithecus*, *Paranthropus* and *H. habilis* had a mixed arboreal and terrestrial locomotion, with obligate bipedal gaits appearing with *H. ergaster*, and with *H. erectus*, *H. heidelbergensis* (*H. antecessor*), and *H. neanderthalensis* sharing a modern pattern. Whether or not australopithecines used any sort of weaponry in acquiring access to meat and/or marrow is still in disagreement, but it looks increasingly likely that hunting behaviours and/or power scavenging, both of which require weaponry, were emerging by the appearance of *H. erectus* (e.g. Stringer & Andrews 2011, p.191; Bunn & Gurtov 2014).

Generally models of the evolution of weaponry hypothesise that some form of spear thrusting would have preceded launching spears as projectile weapons. Broadly speaking, the debate on the origins of throwing in *Homo* can be divided into two camps: those who think that the human ability to throw large distances with accuracy are limited to *H. sapiens* (e.g. Churchill & Rhodes 2009; Lieberman et al. 2007) and those who believe that the origins of throwing are evidenced much earlier with *H. erectus* (e.g. Roach et al. 2013). Primarily, studies have tended to focus on shoulder and arm physiology, especially humeri, scapulae, clavicles, and ulnae (Larson 2007; Churchill & Rhodes 2009; Rhodes & Churchill 2009; Villotte et al. 2010; Berthaume 2014; Larson 2015; Roach & Richmond 2015a; Roach & Richmond 2015b). Intriguingly, the *H. naledi* fossils, estimated to date between 236,000 and 335,000 BP, have archaic shoulder and upper limb morphologies which are suggested to be adapted for climbing and not for throwing (Feuerriegel et al. 2016; Berger et al. 2017). Berthaume (2014) argues that Neanderthal and early Upper Palaeolithic modern human humeri were just as well adapted for throwing actions as those of recent humans, and interestingly were equally or even possibly more poorly adapted to strains involved in spear thrusting, rejecting the hypothesis that Neanderthals were pooly adapted to throwing and well-adapted for thrusting. Churchill & Rhodes' (2009) study suggesting that Neanderthals were not capable of long distance throwing has by their own admission somewhat unclear results, and the debate looks set to continue. Maki (2013) found that studies including bone remodeling common to ball throwing are not applicable to spear throwing, and suggests that research on the evolution of throwing should focus on the legs and torso, something which is supported by the fact that former javelin athletes often suffer hip arthrosis (Schmitt et al. 2004). The evolutionary origins of thrusting vs. throwing in *Homo* are still under debate, but on balance the palaeoanthropological evidence seems to favor an early origin for throwing as the derived features necessary for high energy storage in the shoulder appear around 2 mya (Roach et al. 2013) coinciding with early indications of intensification of evidence supporting hominin hunting (Bunn 2015).

Similar to bipedalism and the evolution of the shoulder and upper arm, the evolution of the hand, and its connection with weaponry has a long background though direct connections are made more rarely. There are differences of opinion as to whether the morphology of the human hand is an adaptive response to stone-tool use (M. Marzke & Shackley 1986), or whether the human hand morphology evolved previous to the advent of stone tools and/or our genus (Alba et al. 2003). Mary Marzke has published extensively on the morphology of the hominin and human hand and its relationship with stone tool manufacture and use, including experimental work (M. Marzke & Shackley 1986; M. Marzke & Wullstein 1996; M. Marzke & R. Marzke 2000; M. Marzke & Shrewsbury 2006; M. Marzke 2009). Marzke & Marzke (2000) suggest that the 'Olduvai hand', i.e. that attributed most often to *H. habilis*, may have had a capacity for a strong pinch, for precision handling and the squeeze power grip necessary for holding cylindrical tools with enough force for clubbing (Fig. 2.10). Although two-handed spear use is not addressed in the above publications, it is logical that two-handed spear thrusting and throwing both necessitate the *squeeze* form of the power grip. Unfortunately there are no hand bones for *H. erectus*, but it does appear that as early as *H. habilis*, in terms of hand morphology, two-handed spear use may have been a possibility. Modern human hand proportions are key to this grip, with the australopithecines appearing to have manual proportions intermediate between chimpanzees and modern humans (M. Marzke & R. Marzke 2000). In all, the evolution of the modern hand is highly complex, and with a lack of hand bones for many species, there are still disagreements about the timing of certain capacities, in particular the capacity for stone tool use and manufacture. These questions are relevant for weapon use in hunting, both in relation to the crafting of stone tool weapons, crafting of stone tools suitable for making wooden defensive or offensive weapons, as well as for the capacity to hold and/or throw weapons with power and precision.

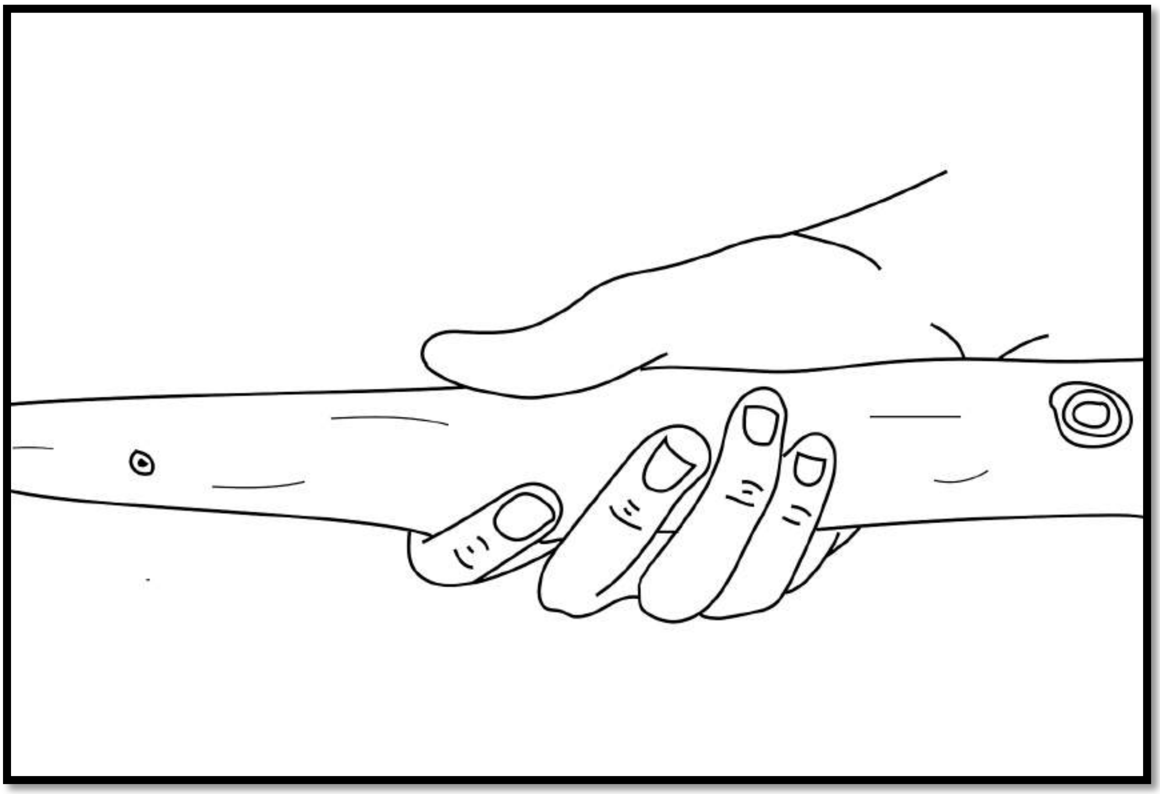


Figure 2.10. Illustration of the squeeze power grip. The squeeze power grip was almost certainly not possible for *A. afarensis*

2.3.2 Contributions from primate studies

Primate studies provide referential models for the origins of human hunting both in terms of their physiological capabilities, as well as behaviours including meat eating, tool use and patterns of violence. In addition to the discussions above on chimpanzee hunting (2.1.3.1 and 2.2.3.1), a few relevant lines of evidence will be added here. Chimpanzees are amongst the primates known to hunt for meat (Fahy et al. 2013); while both sexes hunt, the behaviour is possibly more common amongst males (McGrew 1979), although this is reversed regarding evidence for hunting with weapons (Pruetz et al. 2015). Chimpanzees use tools to rouse animals (Nakamura & Itoh 2008), including the use of sharpened sticks – branches modified using their teeth and hands – to spear and eat small prey (Huffman & Kalunde 1993; Pruetz & Bertolani 2007). This use of crude spears for hunting, along with oft-cited tool behaviours by chimpanzees like termite fishing and nut cracking, suggests that hunting with tools is a plesiomorphy, rather than a derived trait of early *Homo* (Jolly 2009). They also share the meat with the group (Mitani & Watts 2001; Pruetz 2006), and these behaviours altogether provide homologies for human behaviours (Pruetz et al. 2015).

Whilst many argue that differences between chimpanzee and modern human tool use are defined by how much we use tools rather than our capacity to do so (Stringer & Andrews 2011), there are significant physiological differences between humans and chimpanzees, in particular those of a bipedal stance and a derived hand morphology which would restrict chimpanzees from performing certain tool tasks in hunting scenarios, such as forceful two-handed thrusting or throwing spears from a distance. Chimpanzees are incapable of the squeeze form of the power grip, which uses the palm actively to squeeze an object, and reorient cylindrical tools to hold them transversely (M. Marzke & Shackley 1986; M. Marzke & Wullstein 1996). This is different from modern humans, who hold cylindrical objects obliquely across the palm by flexing the fingers, orienting the tool to be in alignment with the forearm adding significant power (Fig. 2.10) (M. Marzke & R. Marzke 2000; M. Marzke 2009). This is specifically explored by Marzke and colleagues in terms of grips for hammer use, similar to clubbing, but grips for spear use are under-studied. Interestingly, when chimpanzees have been observed to hunt with 'spears', their grip has been reported to be a one-handed 'power grip', using the spear to thrust using downward force (Pruetz & Bertolani 2007). Although it isn't specified in the publication, the images provided in a subsequent publication (Pruetz et al. 2015) (Fig. 2.11) show that chimpanzees using spears do not orient them to align with the shaft of the arm, and the grip looks similar to a power finger grip, which does not actively use power in the palm as the 'squeeze power grip' does, potentially limiting the control and power involved in comparison with *H. sapiens* (Fig. 2.12). Spear grips and arm orientations in human spear thrusting and throwing are illustrated in Chapters 7 and 8, contributing data to grips and arm orientation in relation to spear use.

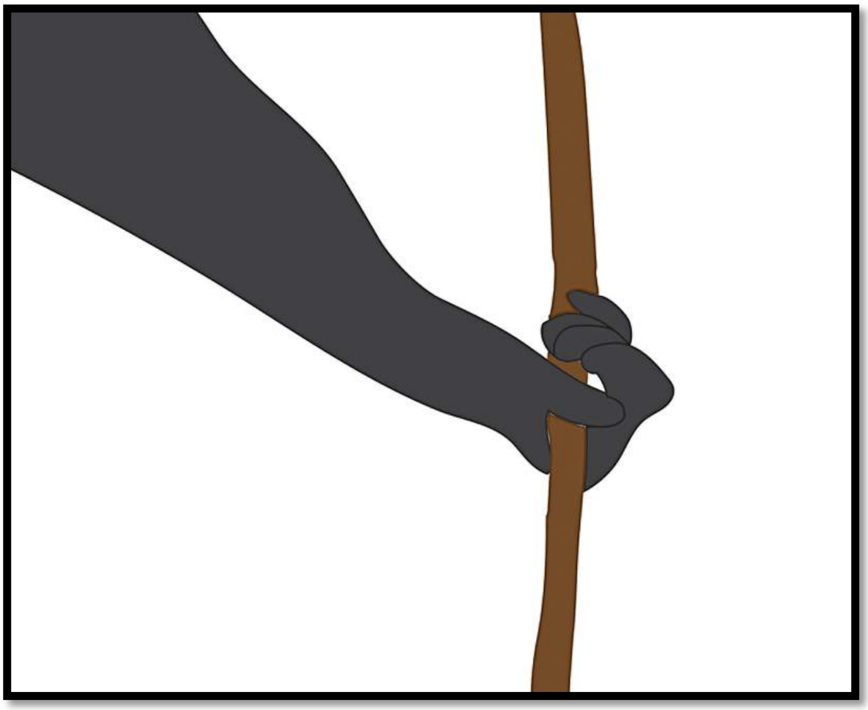


Figure 2.11. Chimpanzee spear grip (drawn after Pruetz et al. 2015 Fig.1, d)

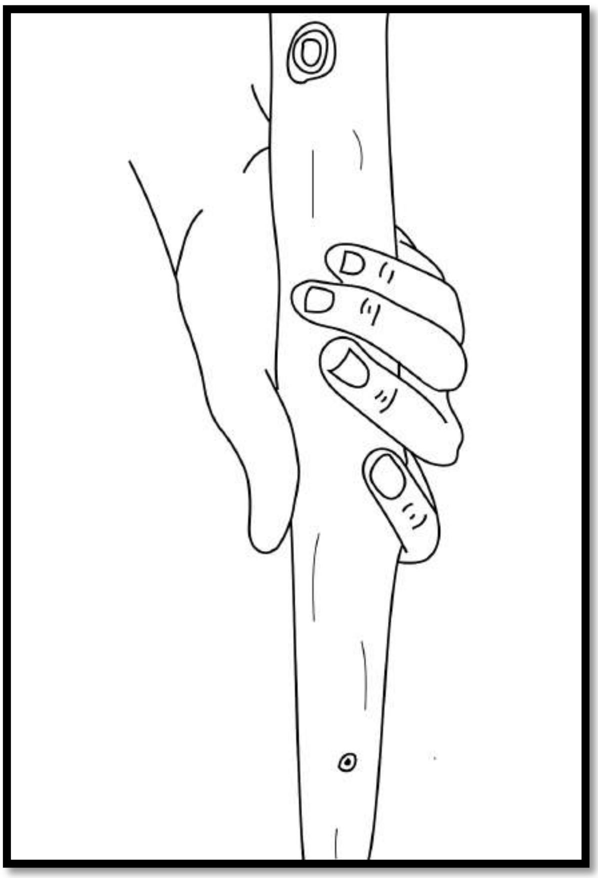


Figure 2.12. Figure 2.10 reoriented for comparison with 2.11. Note the alignment of the forearm and the use of the palm in the squeeze power grip, in contrast with the power grip by the chimpanzee in Fig. 2.11

In terms of patterns of violent behaviour, Jones (Jones 2008) argues that chimpanzee and human groups display similar amounts of collective (group-to-group) violence. However, it appears that the levels of interpersonal (within-group) violence, are much higher amongst common chimpanzee (*Pan troglodytes*) groups than modern humans of similar group sizes (Jones 2008); in contrast, bonobos (*Pan paniscus*) have significantly more peaceful social structures, which may be attributable to differences in behaviours of females between the two species (Furuichi 2011). Patterns of violence amongst chimpanzees and human groups may also correlate with group size (Johnson & MacKay 2015), which has potential links with encephalisation and cooperative hunting as well (Roebroeks 2001; Roebroeks 2006; Gamble 2009).

2.3.3 Behavioural studies: decoupling patterns of violence with human predation

Outside of archaeology and anthropology, a number of models exist for understanding the role of violence and/or aggression in contemporary human societies (Viano 1992b). Models include the ‘culture of violence’ theory, the ‘resource’ theory, and the ‘social learning’ theory (Viano 1992a). An evolutionary theory for aggression is mainly propounded by social anthropologists, but this tends to focus on changes in social structures rather than attributing violence to a deep evolutionary history (Viano 1992a). The sociobiological theory of violence attributes interpersonal violence to some extent to paternal uncertainty, but this is not on the scale as similar claims in ‘The Killer Ape’ theory. In fact in his introduction, Viano (Viano 1992a) clearly expresses hope that many of the challenges regarding violence in contemporary societies can be improved through research – in direct contrast with the idea that violence is inherent to our species.

In 1986 several prominent scientists – amongst them Richard Leakey – convened to craft UNESCO’s Seville Statement on Violence, adopted by the organization in 1989 (Unesco 1991). The statement was written to directly challenge the idea that human violence is biologically determined. It has received criticism, most notably from evolutionary psychologists such as Steven Pinker (Pinker 1998), who argue that violence is a spin-off behaviour, related to other adaptations. Pinker followed this with a popular book *The better angels of our nature: The Decline of Violence In History And Its Causes* (2011) which argues that human violence is in decline. This view of violence in humanity has been met in turn with significant criticism in both the media and by academics, on the basis of ‘murky’ and questionable statistics, a problematic definition of ‘violence’ and a failure to account for innocent lives lost in conflict (Gray 2015; Kelly 2013). Essentially the Seville Statement was meant to address collective rather than interpersonal violence, but the latter is in fact a necessary part of measuring violence when aiming to understand the underlying causes. Looking at patterns of violence, collective violence may be homologous for humans and chimpanzees which suggests that the *human* pattern – whenever it may have evolved – might be a low level of within-group violence and a high level of out-group violence (Jones 2008). Furthermore both intra- and intergroup violence occurs in the animal kingdom amongst both carnivorous and herbivorous animal species. As these debates on human violence continue, we must continue to separate questions of violence with those on the origins of predatory behaviours in our genus, and this applies until we begin to see patterns of violence, rather than isolated occurences such as are seen in the Middle and early Late Pleistocene. Although questions about weaponry innovations and use are not entirely able to be separated from those of collective and interpersonal violence, particularly in later periods for which there is signficantly greater evidence of such behaviours, the limited evidence of violence in the MP in contrast with relatively good evidence for hunting means our focus needs to continue to be on the effectiveness of weaponry in the context of predation. Although some (e.g. Cartmill 1993) continue to equate predation with 'killing', and have moralistic issues with hunting at least in present-day contexts, it is the view here that human predation should be subject to the same moral code as that which we apply to non-human predators (Cromartie 1994).

2.4. Summary of background review

This chapter has summarised the historical background of theories linking the evolution of our genus and weaponry. Middle Pleistocene hominins and their prey were discussed, as well as some features that directly affect hunting strategies and weapon design. Finally, a brief discussion of the evidence regarding human physiology of spear use, and relevant data from primate studies and debates from the behavioural sciences on human violence were also presented, suggesting that human hunting and human violence need to be decoupled, at least for the MP. While wide-ranging, this chapter facilitates the presentation of archaeological, ethnographic and experimental data that forms the main contribution of this thesis. Understanding weaponry is just as intertwined with developments in weaponry during the MP as it is in the LP, where weaponry sits at the forefront of discussions of hominin subsistence or violence in dispersal models (Churchill et al. 2009; Shea & Sisk 2010a). The challenge of this chapter has been to present a historical background that facilitates understanding current theories on early weaponry, followed by a weaving together of evidence from diverse fields of study. This holistic view is important because the earliest weapons are extraordinary objects both in their preservation as well as for what they symbolise in terms of human evolution. The next chapter completes the background review by defining terminology on weaponry, pertinent models on weapon use and evolution, and outlining the theoretical and methodological approaches taken thus far to interpreting evidence for the manufacture and use of untipped wooden spears.

Chapter 3. Evaluating hand-delivered wooden spears and their use: theoretical and methodological approaches

Chapter 3 continues the background review begun in the previous chapter, broadly laying out the limitations of our understanding of the use of wooden spears as objects that carry records of behaviour in both their design and surfaces. MP wooden spears have not been studied in a holistic manner since Oakley et al.'s (1977) analysis of the Clacton spear point, prior to the discovery of both the key sites of Boxgrove and Schöningen, and prior to advances in experimental methodologies. Following a series of definitions (3.1.1), and descriptions and analyses of current models of the development of weaponry in human evolution (3.1.2), this chapter reviews the earliest evidence for weaponry (3.1.3) and outlines some challenges in identifying and evaluating such artefacts (3.1.4). It then explores the theoretical and methodological approaches to these earliest weapons, as well as the hunting lesions that are suggested to result from their use (3.2). The chapter concludes with a brief summary of the key background information presented in the two background chapters (3.3). Overall this chapter provides a broad background on approaches and models in the literature; for the sake of coherence further details and published data needed for direct comparison with original data generated in this thesis will be presented in subsequent chapters.

3.1 Weaponry and human evolution: definitions and models

3.1.1 Weaponry definitions

Definitions of weapon delivery (launching) systems are after Shea and Sisk (Shea & Sisk 2010a; Shea & Sisk 2010b). Simple projectile weapons are those that 'do not involve exosomatic energy storage...launched at targets with unassisted bodily force' (Shea & Sisk 2010a, p.102). This category includes

- hand-thrown spears (also called javelins), whether untipped or tipped
- throwing sticks
- boomerangs

Complex projectile weapons are 'composite, multi-part tools where human energy is mechanically enhanced or stored by a non-projectile part' (Shea & Sisk 2010b) and include:

- Spearthrowers/darts (also called atlatl)
- Bows/arrows
- Blowguns
- Slings

Not usually included in either category is the thrusting spear, which is not a projectile as it does not leave the hand (Knecht 1997a, p.3). Contact weapons, as opposed to ranged weapons, have been a significant component of human weaponry and contact weapons are defined here as those that are used to make contact between the person holding the weapon and a target, without letting go of the weapon. They were often used to dispatch prey that has already been wounded or otherwise disadvantaged, and frequently functioned as melee weapons in collective violence (e.g. Skinner 1911, p.78; Gifford 1931, p.30; Gifford 1933, p.274; Mandelbaum 1940, p.215; Swanton 1946, p.583). Contact weapons include:

- thrusting spears (also sometimes called 'lances'), whether untipped or tipped
- clubs
- pikes
- axes
- knives

This categorisation of weapon systems is important not only for semantic purposes, but also because the biomechanics and weapon mechanics differ significantly. 'Hand-delivered' is used throughout the thesis to refer to both thrusting spears and hand-thrown spears as a group. Thrusting spears are often called 'lances' in the literature, particularly in publications by German researchers (e.g. Münzel & Conard 2004; Gaudzinski et al. 2005; Böhner et al. 2015; Gaudzinski-Windheuser 2016). The term 'lance' is *not* used in this thesis apart from references to where it is labeled as such in the literature because this assigns a mode of use which is potentially controversial given current debates, and additionally this could be too simplistic for multi-purpose tools, i.e. a spear used for both thrusting and throwing. 'Spear' is used when the delivery method cannot be entirely certain, and a delivery method is cautiously assigned - e.g. 'thrusting spear' or 'throwing spear' where appropriate. Similarly, 'javelin' is not used, apart from when it refers to modern javelins and javelin athletes, or references to literature on the development of the javelin throw as a sport.

Finally, 'simple' spears can sometimes refer to sharpened wooden spears in the literature, as opposed to 'hafted' or 'composite' weapons. As the term 'simple' is in use when discussing projectile delivery systems (vs. 'complex'), it is preferable to use a different term to distinguish between weapons with and without a hafted tip or barb. The weapons that comprise this study therefore are sharpened single-piece wooden implements, without lithic or organic tips or barbs hafted or carved into the shaft. These are called 'untipped wooden spears', or just 'wooden spears' in this thesis to make the distinction between spear design and delivery method. This research therefore focuses on examples of hand-delivered (i.e. either thrust or hand-thrown) untipped wooden spears. Fig. 3.1 illustrates that the point of the spear facing away from the body, intended for penetration into a target and sometimes dubbed the 'business end' (McBrearty & Brooks 2000; Lombard & Pargeter 2008; Andrefsky 2009; Costa 2012), is labeled the distal point of the spear following the standard terminology established elsewhere for both untipped wooden, organic-tipped, and lithic-tipped weaponry (e.g. Oakley et al. 1977; Boëda et al. 1999; Wilkins et al. 2014a; Pétillon et al. 2016; Yareshovich et al. 2016) while the back end of the spear, sometimes called the 'butt', is labeled proximal.

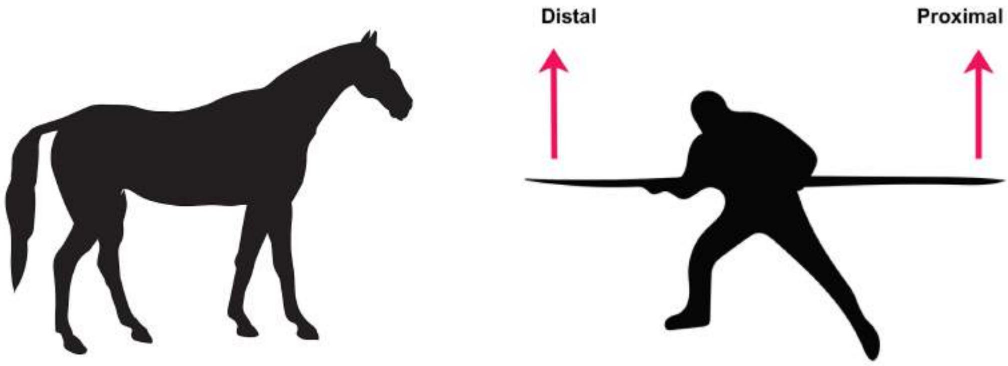


Figure 3.1. Drawing illustrating anatomy of a wooden spear

3.1.2 Models of weapon delivery systems

Changes to and variability in prehistoric weapon systems, whether chronologically, geographically or both, are often used to signify cognitive and/or adaptive shifts in human evolution. Broadly, weaponry is considered to be adaptive because it reflects the ability of humans to increase access to high-quality animal products and compete with apex predators for these resources, and have also been correlated with human dispersal events (e.g. McBrearty & Brooks 2000; Shea 2006; Villa & Lenoir 2006; Shea & Sisk 2010a). Advances in weapon design including hafting and launching systems are also broadly equated with advances in cognition (Wynn 2009; Haidle 2010; Williams et al. 2014; Lombard & Wadley 2016). Although many approach weaponry as a behavioural vector, there are also those who focus on weaponry in order to assess the archaeological record, and do not explicitly extend these data to behavioural interpretations. Perhaps an overarching question in all weaponry studies is whether evaluating the performance and use of weaponry through time and space affects our ability to make conclusions about human behaviours. If the answer is even vaguely affirmative it becomes apparent that establishing performance parameters is an urgent research aim when connecting developments in weaponry with behavioural and demographic shifts in the Pleistocene.

Disagreements exist about the timing of the appearance of various weapon technologies in the archaeological record, but those interested in the development of these technologies and how they map onto human evolution are *generally* in agreement that contact weapons and simple projectiles developed first and are inferior in performance to complex projectiles (Churchill 1993; O'Connell 2006; Shea 2006; Rhodes & Churchill 2009; Shea & Sisk 2010a). This inferiority/superiority dichotomy rests on several attributes, some of which are relatively well-understood but most of which are estimated. A list of important attributes here based on previous work (e.g. Cotterell & Kamminga 1989; Cundy 1989; Friis-Hansen 1990; Ellis 1997; Knecht 1997a; Hughes 1998) include:

- ability to penetrate target based upon design. Includes tip design and material, aerodynamics (if intended to fly), mass (affecting ability to be delivery based on strength, as well as energy at impact), point of balance
- ‘effective distance’, i.e. from what distance can the weapon be reliably expected to hit and sufficiently wound its target
- suitability to prey (size and behaviours); suitability to environment
- versatility
- portability
- durability
- retrievability
- safety to the user
- investment in manufacture
- ease of use and investment in learning

Models on weapon evolution typically illustrate that hand-delivered weapons precede complex projectile technologies in this order: thrusting spears > hand-thrown spears > spearthrowers > bow/arrows (Rieder 2003; Iovita et al. 2016). However, these models are an oversimplification and in some senses reflect 19th century ways of viewing the Palaeolithic, which Trigger (2006, p.153) describes as ‘a unilinear series of stages with little attention being paid to synchronous diversity that might have developed as a result of ecological or ethnic differences.’ This oversimplification primarily relates to representation of simple weapon systems being replaced by complex weaponry, which is not supported by the archaeological and ethnographic evidence. Ethnographic and ethnohistoric data demonstrate that all four weapon delivery systems were in use in recent periods by hunter-gatherers and foragers, with a large variety of tip designs, and Churchill (1993) emphasises not only that multiple weapon systems were used alongside each other, but also that the development of weaponry most likely represents at least in part adaptations to shifts in environments and prey. Some groups used only hand-delivered weapons, with the Tasmanians and Melville Islanders the clearest examples. Of these, the Tasmanians used untipped wooden spears and waddies (a type of club), while Melville Islander spears include both untipped wooden spears alongside spears with carved barbs (Hiatt 1968; Goodale 1971). In contrast the Agta used only bow/arrows (Griffin 1997) while many groups used multiple weapon types (see Hitchcock & Bleed 1997). Archaeological and palaeoanthropological evidence also supports the continuation of hand-delivered spears alongside other weapon systems into the terminal Pleistocene and early Holocene (e.g. Luebbers 1975; Villotte et al. 2010). To illustrate this diversity, these linear models have been reworked here in Fig. 3.2, reflecting the increasing multiplicity alongside complexity over time. This reworked model deliberately ignores additional weaponry for the sake of simplicity, but other weapons and delivery systems and weapons in place prior to the invention of firearms include clubs, throwing sticks, boomerangs, bolas, slings and blowguns, with possible evidence for throwing sticks from the MP (Böhner et al. 2015; Schoch et al. 2015). It also deliberately ignores 'effective distance' of the projectile weapons for the moment, as an assessment of this regarding hand-thrown spears is a key aim of this thesis and is addressed in Chapters 6 and 7.

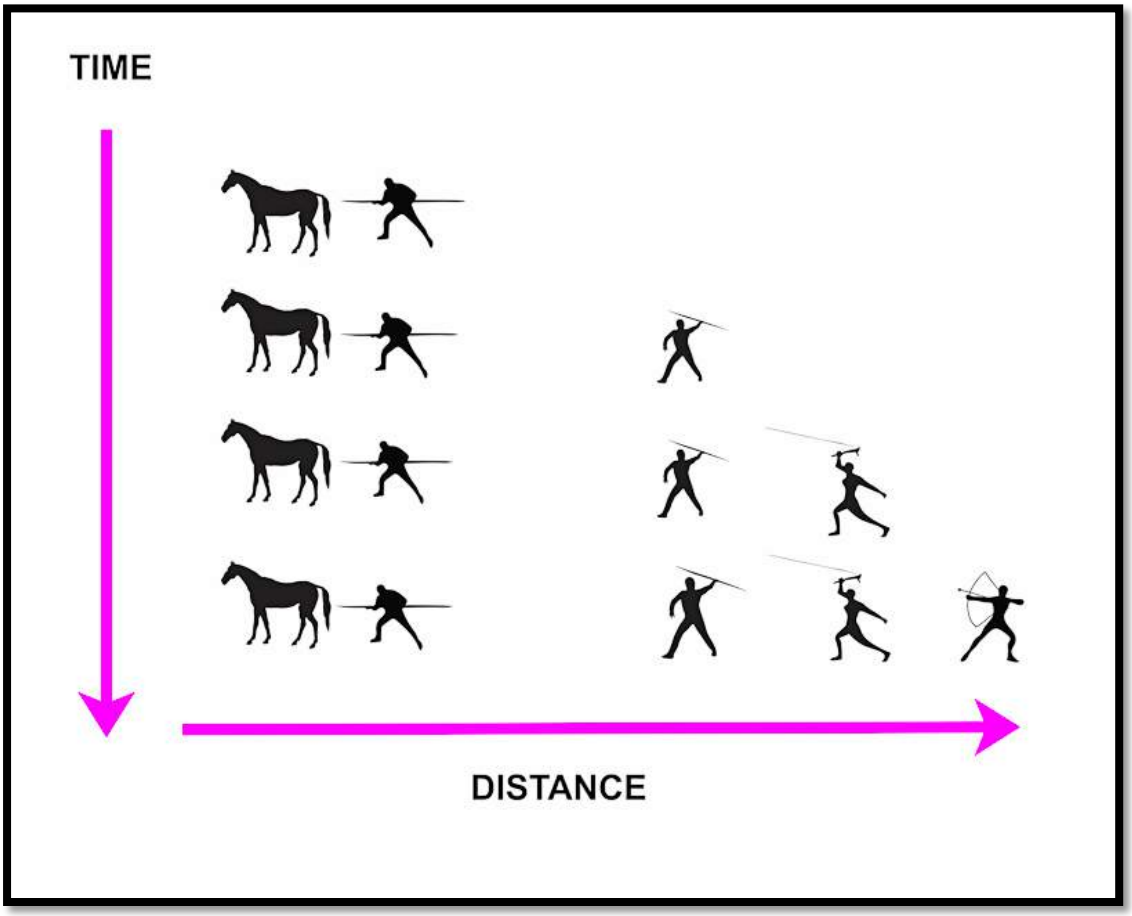


Figure 3.2. A reworked model of the evolution of weapon systems over time. The four main prehistoric weapon systems discussed with frequency in the literature are represented, from thrusting spears at the top followed by hand-thrown spears, spearthrowers and bow/arrows. Each weapon system remains in use as additional complexity emerges

Disagreements about the timing of the innovation of hafting feature heavily in debates about the development of weaponry, in particular in relation to how these innovations map onto the evolution, dispersals and extinction of species (Shea 2006; Gaudzinski-Windheuser 2016). While this thesis is not concerned with the development of hafting and its relationship to composite weaponry, characterisations of the performance of untipped wooden spears in relation to composite weapons require testing. Providing data regarding the effectiveness of wooden spears as hunting weapons is a key aim of this research, and while not making direct comparisons with composite weaponry, it informs these debates.

Finally, there are implications for understanding the development of delivery systems, i.e. whether hand-thrown spears are close-range or 'true' projectiles (e.g. Shea 2006), as greater distances are widely agreed to confer advantages, in relation to both safety for the user(s) and hunting strategies. The arguments and evidence on the mechanics and biomechanics hand-delivered weaponry, effective distances, and proposed disadvantages are further explored throughout this thesis.

3.1.3 Early evidence of weaponry

Direct archaeological evidence for weaponry in the Early Pleistocene is at present nonexistent, with no known reliable examples from Eurasia or Africa. Indirectly, woodworking residues on Acheulean handaxes from Peninj, Tanzania, dating to ca. 1.6-1.5 mya suggest that hominins were using stone tools to craft wooden tools of some kind (Domínguez-Rodrigo et al. 2001), which may have included clubs or wooden spears but may also suggest other tool types such as digging sticks.

In addition to the wooden spears and potential hunting lesions which are the focus of this thesis, MP artefacts cited as evidence for hunting weaponry come from sites in Africa and Europe. The claim for the earliest hafted lithic weapon points is from the site of Kathu Pan 1 in South Africa, of which stratum 4a, dated to ca. 500,000 BP has yielded lithic points proposed to tip weapons, with replicas tested as thrusting spears (Wilkins et al. 2012). However, this stratum has been dated with a single OSL date to 464 ± 47 ka, and is immediately capped by stratum 3, with a much younger OSL date of 291 ± 45 ka, leaving some questions about the integrity of this earliest date range for hafted spear points (Underhill 2011). Lithic projectile points, proposed to have been designed to tip hand-thrown spears on the basis of microfracture features, also come from the Gademotta Formation archaeological site complex in the Ethiopian Rift, dating to >279,000 BP (Sahle et al. 2013). European evidence includes a possible throwing stick from Schöningen, as well as lithic points possibly functioning as spear armatures, such as those found at Biache-Saint-Vaast (France) dated to MIS 6 or 7, and Bouheben (France) and La Cotte de Saint Brelade layer 5 (Jersey), both dated to MIS 6 (Villa et al. 2009), as well as evidence of hafting by ca. 200,000 BP (Mazza et al. 2006). The recognition of impact scars on Middle Palaeolithic lithic points from Eurasia is beginning to gather interest with archaeological contributions to debates on the development of throwing in *Homo* providing much-needed evidence of this important behavioural shift (e.g. (Villa & Lenoir 2009; Villa & Soriano 2010; Shea et al. 2001; Sisk & Shea 2009; Rios-Garaizar 2016; Rots 2016).

3.1.4 Identifying and evaluating prehistoric weaponry

There has been a research bias which has favoured replication of complex projectiles and left a comparative gap in understanding of hand-delivered weaponry. As an example, of chapters in a recent volume on weaponry (Iovita & Sano 2016b) of those dedicated to a specific weapon technology, the vast majority of these relate to those associated with *H. sapiens*, with a small selection focusing on technologies thought to relate to archaic hominins. This is at least partly in response to a Late Pleistocene archaeological record that is rich in potential projectile points. Spearthrowers have numerous publications aimed at understanding performance, damage/wear to points, hunting lesions, and mechanics (e.g. Raymond 1986; Cattelain 1997; Geneste &

Maury 1997; Hutchings & Brüchert 1997; Pargeter 2007; Letourneux & Pétillon 2008; Bradfield & Lombard 2011; Pétillon et al. 2011). Bow/arrow technologies have profited from a similar intensity of research (e.g. Bergman et al. 1988; Fischer et al. 1984; Bergman & Newcomer 1983; Cattelain 1997; Geneste & Maury 1997; Baugh 2003; Pargeter 2007; M. J. Smith et al. 2007; Sisk & Shea 2009; Waguespack et al. 2009). In comparison with these presumed later weapon systems comprising innovations both in delivery systems and weapon design, the performance of hand-delivered spears remains poorly understood, in spite of the fact that ethnographic studies have repeatedly indicated that hand-delivered weaponry has continued to be in use alongside complex weaponry, and formed an important component of toolkits for both hunting and warfare (this point is further explored in Chapter 6). In Palaeolithic archaeology, the dearth of research into the earliest weapon systems from the Lower and Middle Palaeolithic is in part due to the relatively 'empty' archaeological record in terms of artefacts signaling weapon use, particularly in comparison with the rich Upper Palaeolithic and Holocene record, which have not only weapon armatures but complete composite weapons and numerous examples of hunting lesions (Noe-Nygaard 1974; Gaudzinski-Windheuser 2016).

'Functional study' is a term typically used to describe use-wear and residue analysis (e.g. Bradfield 2015; Fullager 2016; Rots 2016). However, in prehistoric weapon research experiments relating to weapon performance in terms of effectiveness on and wounding of prey are also often evaluating function (e.g. Huckell 1982; Guthrie 1984; Friis-Hansen 1990; Waguespack et al. 2009; Salem & Churchill 2016; Wilkins & Schoville 2016), and are increasingly used as a method for interpreting the archaeological record (Iovita & Sano 2016a). The use of tip cross-sectional area (TCSA) was one such method for identifying the function of lithic points in the archaeological record (Hughes 1998; Shea 2006; Wadley & Mohapi 2008; Shea & Sisk 2010a; Costa 2012) but further studies have found this method to be somewhat unreliable (e.g. see Hutchings 2016; Milks, Dinnis, et al. 2016; Clarkson 2016). Naturally none of these approaches are capable of accurately representing weapon use in 'real life' hunting scenarios, but the borrowing of methods and use of research from ballistics and impact engineers who work within the military and forensic sectors - a key approach in experimental research for this thesis - goes a long way to providing useful data and methodologies relevant to evaluating prehistoric weaponry. Such studies will continue to develop in sophistication, and provide promising methods for making both large-scale and smaller-scale cross-cultural and macroevolutionary comparisons between weapon delivery systems and design, underpinning hypotheses about the relationships between prehistoric weaponry and human evolution with empirical data.

3.2 Theoretical and methodological approaches to evaluating hand-delivered wooden spears

This section details previous approaches to interpreting the use of wooden spears, including first a broad overview of approaches to assessing the function of untipped wooden spears (3.2.1) as well as the identification of hunting lesions resulting from their use (3.2.2). Relevant ethnographic (3.2.3) and experimental (3.2.4) approaches are outlined, with further details on these studies presented in relevant chapters later in the thesis. The experimental section in particular details some useful definitions of methodologies and materials used in prehistoric weapon research and from ballistics and impact research on present-day weaponry, providing context for methodological choices made in experimental work in Chapters 7 and 8. Details regarding previous approaches to the manufacture of wooden spears are found in Appendix 1.

3.2.1 Relating morphometrics to function of wooden spears

The design of spears are thought to relate directly to their function, including mass and point of balance (PoB, also called centre of mass or centre of gravity) which affect flight mechanics, biomechanics and kinetic energy at impact, while tip design affects penetration and damage to spears. Morphometrics of untipped wooden spears have been published in varying levels of detail (Movius 1950; Oakley et al. 1977; Luebbers 1978; Thieme & Veil 1985; Dillehay 1997; Thieme 1997; Thieme 1999a), but often comparisons are based on problematic and small datasets and no cross-comparison of all known examples has yet been undertaken. In spite of this, claims regarding their function and mode of delivery to date relate to design features, including length, diameter and location of maximum diameter (Oakley et al. 1977; Rieder 2003; Villa & Soriano 2010), tip morphometrics (Guthrie 1984), whether spears are double pointed or have an untapered proximal end (Thieme & Veil 1985; Thieme 1997; Schoch et al. 2015), where their point of balance (centre of mass) lies (Palter 1977; Thieme & Veil 1985; Cundy 1989; Thieme 1997; Rieder 2007; Gaudzinski-Windheuser 2016), and their total mass (Palter 1977; Berger & Trinkaus 1995; Shea & Sisk 2010a).

The comparative dataset of ethnographic examples created by Oakley et al. (1977) and cited in relation to the function of archaeological examples of untipped wooden spears (Churchill 2002; Schmitt et al. 2003; Allington-Jones 2015) has a number of problems which need resolving (further discussed in Chapter 6). Therefore, expanding Oakley et al.’s (1977) research with further comparative datasets is useful in re-assessing both the Clacton and Lehringen spears as well as evaluating the more recent finds from Schöningen. Testing the claims regarding relationships between morphometrics and performance of untipped wooden spears is key to empirically evaluating broader claims about their lethality in comparison with innovations in Late Pleistocene weaponry.

3.2.2 Approaches to identifying hunting lesions

Part of understanding the use of archaeological wooden spears involves evaluating artefacts proposed to possibly represent damage to bone resulting from weapon impact. Studies of ‘Projectile Impact Marks’ (O’Driscoll & Thompson 2014; Duches et al. 2016), also called ‘hunting lesions’ (Noe-Nygaard 1974; Gaudzinski-Windheuser 2016) assess impact trauma to bone from weapons. The term ‘hunting lesion’ is used here, as this encompasses trauma to prey regardless of mode of delivery. The practice of identifying hunting lesions on archaeological faunal remains is not a particularly new area of research (see Letourneux & Pétillon 2008 Table 12; Gaudzinski-Windheuser 2016; Duches et al. 2016). However, research has focused almost exclusively on Upper Palaeolithic and Mesolithic sites, and is not comparable to the extensive amount of research conducted on the identification of projectile points – both lithic and osseous - in the archaeological record. Nanna Noe-Nygaard (1973; 1974) provided a few studies of hunting lesions on Mesolithic faunal remains from Denmark, which were mostly thought to have resulted from lithic projectiles (Noe-Nygaard 1973; Noe-Nygaard 1974). She suggested that dimensions of punctures on faunal remains tend to correspond with sizes and shapes of known Mesolithic weaponry, generally having a maximum length of 15-20 mm (Noe-Nygaard 1974). A few punctures she observed were two to three times that size (exact data not provided) and she speculates that these may have been caused by barbed points, harpoons, flint-edged spears or wooden spears, also known from Mesolithic sites. She described unhealed entrance wounds as displaying a smooth surface, with the exit side having ‘splinters’ or ‘scars’ (Noe-Nygaard 1974, p.221). Healed wounds, from which the animal survived, have a smooth surface and she suggests that these give no indication of the weapon’s direction. Noe-Nygaard (1974) plotted healed and unhealed punctures on archaeological scapulae on a schematic scapula demonstrating that successful shots tend to focus on a particular location (Fig. 3.3). The placement of unhealed punctures relates to the location behind the scapula of a major artery and/or the heart, and therefore the effectiveness of an impact in terms of lethality for a hunted animal is relatable to the location of the impact (Noe-Nygaard 1974). A hit to an animal with even a high-velocity projectile may not be fatal if it is located on the edge of the scapula blade.

There are few ethnographic references to or examples of healed or unhealed hunting lesions from weaponry (but see Christie 1924 cited in Oakley et al. 1977, p.21), making experimental approaches the only viable method for comparative analysis. Experimental studies represent a relatively new approach to the identification of weapon damage to zooarchaeological remains from Pleistocene sites. The study of such damage, particularly in relation to wooden spears, and how damage characteristics may overlap with other taphonomic marks to bone has relatively little experimental work underpinning identification (Duches et al. 2016; Gaudzinski-Windheuser 2016). Similar research aiming to identify ‘Diagnostic Impact Fractures’ on lithic material used as weapon tips has been plagued with problems of equifinality (Sano 2009; Rots & Plisson 2014) and the search for ‘diagnostic’ features in terms of hunting lesions must take this into account. O’Driscoll & Thompson (2014) conducted a review of experimentally produced hunting lesions from lithic weaponry with the goal of developing a methodology for describing the marks and creating a consistent nomenclature. This system has been adapted for this thesis to account for making comparisons with wooden spears as well as other modes of dynamic impact, alongside developing descriptive and metric analytical approaches for making comparisons both between different types of weapon impact damage and other damage. Identification of hunting lesions is a promising avenue of research, but much is needed in the way of development of methodologies, including a clearer understanding of the nature of fracture patterns and how these patterns relate to energy at impact, weapon material and weapon morphology. Duches et al. (2016) produced a 3D analysis of hunting lesions, in this case from the Late Epigravettian, alongside a descriptive analysis. This is a promising approach, particularly for distinguishing potential lesions from other taphonomic agents but is more useful for larger datasets than those that are available for the MP.

Gaudzinski-Windheuser's (2016) review of Pleistocene and Holocene hunting lesions shows the large range of variability depending upon the age, type and size of the prey as well as the weapon tip and delivery method. The review also points out issues of equifinality, in that impact marks from weaponry can overlap and be confused with carnivore damage and taphonomic alterations to bone, and concurs with others (e.g. Leduc 2012; Pétillon et al. 2016) that these marks are rare archaeologically in comparison with experimental evidence, which may in part be due to zooarchaeologists' limited recognition of this type of damage. A conclusion of the review includes that the evidence on hunting lesions suggests a relatively late development of lithic technology, implying a long period of use for wooden spears. Only two possible hunting lesions from the MP have been identified at the time of writing this thesis, and these are from the British sites of Boxgrove and Swanscombe. While further hunting lesions have been identified from the period may exist in zooarchaeological collections, problems with the lack of established qualitative and quantitative methodologies for evaluating such lesions need to be addressed, a key objective in this thesis.

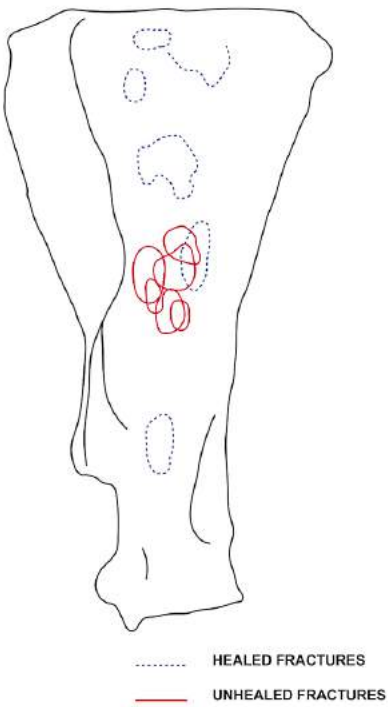


Figure 3.3. Healed and unhealed fractures over standardised blade of hunting lesions from the Upper Palaeolithic site of Stellmoor and Mesolithic hunting lesions, redrawn after Noe-Nygaard 1974 Figure 22, B

3.2.3 Ethnography and wooden spears: a thorny relationship

3.2.3.1 Reliability of the ethnographic record for the interpretation of Middle Pleistocene weapons

This section addresses some of the pitfalls of the use of ethnographic research in relation to evaluating MP weaponry, while acknowledging the continuing if qualified benefits of such data. The use of indigenous material cultures and behaviours as proxies for prehistoric behaviours coincides with the origins of archaeologically-oriented research, and many 19th and 20th century researchers saw recent hunter-gatherer groups as 'living fossils' of prehistoric people (Gosselain 2016) . There has been a noticable shift away from a heavy influence of these studies in the subfield of prehistoric weaponry, with increasing reliance on experimental research. Three edited volumes spanning nearly half a century of research illustrate this point. The first is *Man the Hunter* (Lee & Devore 1968a), which was oriented towards understanding the role of hunting in human evolution, and was the first attempt to synthesise evidence of the origins of human predation. The volume reflected positivist research agendas of the time, and almost entirely consists of ethnographic studies with few direct connections to the archaeological record. Discussion of weaponry is markedly rare in the volume, with a focus instead on relating hunting behaviours to social organisation, demographics and ecological considerations. Jumping forward nearly 30 years, Heidi Knecht's edited volume titled *Projectile Technology* (1997b) dedicated one part of five to ethnoarchaeological investigations, with chapters in that section focused on questions such as design and function of weaponry, associated hunting strategies, and choice of weaponry on the basis of variables such as prey and environment. This is reflected in other studies at the time (e.g. Churchill 1993), which directed data from the ethnohistorical and ethnographic literature at the archaeological record. Fast forward another 20 years, and in the most recent collection of research on Palaeolithic weaponry, *Multidisciplinary Approaches to the Study of Stone Age Weaponry* (Iovita & Sano 2016b), none of the chapters are dedicated solely to ethnographic research, though several reference ethnographic data (e.g. Lombard & Wadley 2016; Milks, Dinnis, et al. 2016; Whittaker 2016; Yareshovich et al. 2016). It is clear that there has been a significant shift away from a reliance on ethnography, with current research programmes increasingly using these data with caution, and contextualising them accordingly. This is undoubtedly due in part to the limitations that ethnography and ethnoarchaeology have in interpreting the archaeological record including the use of weaponry and hunting strategies (e.g. Wobst 1978; Lieberman et al. 2007; Gosselain 2016) and particularly in relation to those periods prior to and around the emergence of *H. sapiens*. Looking specifically at wooden spears, much of the ethnohistorical data pertaining to their use consists of accounts which were recorded unsystematically, and particularly in the case of the Tasmanian Aboriginal populations, those recording the data such as George Augustus Robinson and Joseph Milligan had roles in the disenfranchisement and internment of Aboriginal populations (Flood 1999; Ryan 2012). As such, gross underestimations of population sizes, and misrepresentations of cultures and customs including of their technology, went hand in hand with an agenda to remove them from land coveted by settlers, with these claims about technological simplicity and population size being recycled by subsequent researchers as the main contributing factor to the demise of Tasmanian indigenous peoples (Ryan 2012).

In addition to issues with the collection and use of data, anaologies between recent groups studied and pre-sapiens humans are a further significant step away from evaluating the MP archaeological record. First, physiological and cognitive differences between, for instance *H. heidelbergensis* and *H. sapiens*, remains poorly understood. Furthermore, the uniformitarian principle that recent indigenous groups provide an accurate representation of groups creating the prehistoric archaeological record of our own species is also contested (Hayter 1994; Gosselain 2016). As an example, ethnoarchaeological discussion on the use of spears highlights their use in hunting by the San in the Kalahari who also use guns in certain circumstances, which shifts hunting strategies (Hitchcock & Bleed 1997).

Generally, characterisations of weapon delivery systems and their association with prey and hunting strategies have followed Churchill's (1993) analysis of 96 ethnographic groups; the summary in this paragraph of these characterisations follow that paper unless otherwise noted (see 2.2.3 for definitions of hunting strategies). Significantly, 95% of the groups in Churchill's survey used hand-delivered spears, mostly for terrestrial hunting and primarily alongside other hunting methods. According to Churchill (1993), hand-delivered spears are associated most frequently with disadvantage attack strategies, as well as ambush and pursuit hunting, and to a lesser extent encounter hunting, but no examples are known associating thrusting spears with approach hunting. Hand-thrown spears were associated in the review with all of the attack methods, with disadvantage hunting being the most common. Ethnographically, groups using complex projectiles use them in a larger variety of environments and hunting techniques than hand-delivered spears, which is interpreted as one of the main advantages associated with their use. Spearthrowers are suggested to have been used in distinct ways from hand-delivered weapons, never known to be used with disadvantage, pursuit or encounter attack strategies, while bow/arrow hunting is associated with all of the attack strategies (Frayer 1981; Churchill 1993). Hand-delivered weapons are in general associated with the taking of large prey, and this most strongly correlates with disadvantage methods, though both thrusting and hand-thrown spears are associated with smaller prey as well. Thrusting spears appear to be especially common and versatile, while hand-thrown spears were more rarely used. A critical analysis of Churchill's (1993) review and further ethnographic and ethnohistoric data pertaining to the use of both hand-delivered and untipped wooden spears are presented in Chapter 6.

Ethnographic datasets do still have a role, but their influence on interpretations of the MP record is contextualised and balanced with other approaches. Ethnographic accounts are useful to paint a very broad-brushed picture of the variability of use, and in combination with morphometric studies of examples held in ethnographic collections by museums provide a reference sample for comparative purposes. However, these data must be recognised to be inherently compromised and the results should be weighted accordingly, playing a supporting role to experimental approaches.

3.2.3.2 Methodological approaches to ethnography of wooden spears

Previous methodological approaches applying ethnographic data to MP wooden spears, and implications of the use and abuse of these data are briefly explored here. Ethnographic data have been used in two ways, one of which is to study morphometrics of ethnographic spears to relate to the archaeological record as Oakley et al. (1977) do, and the other is the mining of the ethnohistoric and ethnographic literature for data on their use in relation to mechanics, biomechanics, prey and environments (e.g. Churchill 1993).

Noetling (1911) and Davidson (1934) are early examples of papers specifically examining ethnographic untipped wooden spears, both focusing on the Australian Aboriginal objects, and making statements about a linear evolution from simple to complex weapons, a trend which as discussed has been pervasive in prehistoric weapon research. Adam (1951) evaluated the Lehringen spear by discussing elephant hunting and spear use while Kenneth Oakley and colleagues (1977) used ethnographic data and analogies to make a comparative analysis of the Clacton spear point. Oakley et al. (1977) took a dual approach to ethnographic analogies for the artefact, discussing ethnohistoric and ethnographic publications regarding the use of spears and game stakes by hunter-gatherers while simultaneously examining ethnographic examples of wooden spears, throwing sticks, and digging sticks, primarily for morphometric comparison in making a functional assignment of the broken Clacton spear point. Although there are issues with the dataset that are further explored later in this thesis (section 4.1.1.1), their approach is one of the few that attempts a multi-proxy approach to early weapons, and this approach is broadly emulated in this thesis, expanding upon it with larger datasets and new methodologies, in particular experimental archaeology, while simultaneously evaluating the data and conclusions presented in these earlier publications. The empirical approach of Oakley et al's (1977) reevaluation of the Clacton spear point reflects shifts towards positivist approaches of the time, and the holistic approach and open-mindedness about other possible functions were ahead of their time. In the same year as Oakley et al's paper, Palter (1977) published a study of ethnographic collections of Australian spearthrowers and hand-delivered spears, further adding to data on hand-delivered weaponry vs. complex projectiles. Original research as well as a re-evaluation of the ethnographic literature will be compared in Chapter 6 with data from the key publications outlined above.

3.2.4 Experimental analogies on the use of wooden spears

Experimental research in prehistoric weaponry is a key approach to identify and evaluate the archaeological record, and such studies can be broadly put the categories of weapon mechanics/biomechanics, terminal ballistics and wound ballistics. These are defined here, with a brief summary of background research in each pertaining to hand-delivered and/or wooden spears. Further details on experimental data are explored in later experimental chapters where useful. A general discussion on the theory and different types of experiments in archaeology can be found in Appendix 2.

1. <u>Weapon mechanics and biomechanics</u>. These studies involve evaluating the properties of weapon mechanics and the interaction with human physiology during use. Examples include establishing parameters of use including velocity, force, kinetic energy, flight mechanics, forces and strains on the human body, effects of body mass on performance, and how these interact with overall design and tip morphometrics.
2. <u>Terminal ballistics</u> is defined as 'the behaviour of a projectile after it ends free flight and impacts a target' (Bell 2012), i.e. the study of what happens to the weapon itself during use. In prehistoric weaponry focus has been on fracture patterns on both lithic and osseous tipped weaponry, and constitutes a large percentage of experimental research to date. Macrofracture and more recently microfracture analyses have greatly extended the ability to recognize weapon components in the archaeological record, though such studies have not been without methodological challenges.
3. <u>Wound ballistics</u> in forensic research is defined as the 'study of wound patterns and forms…to determine such things as what type of weapon was used, what movement took place during the struggle, when the wounds were inflicted, and

whether wounds might have been defensive or self-inflicted' (Bell 2012). This approach is relatively new in prehistoric weaponry, and particularly in relation to experimental studies on untipped wooden weapons. In contrast with Bell's (2012) definition of wound ballistics, thus far wound ballistics in prehistoric weaponry has had the objective of better understanding the comparative wounding capabilities of different weapon systems, materials and designs, including the identification of hunting lesions and how these relate to weapon design, delivery systems and hunting strategies.

3.2.4.1 Weapon mechanics

Understanding mechanics and biomechanics of spears is key to evaluating both terminal and wound ballistics. It is generally well-accepted that there is a relationship between form and function in weaponry (Cundy 1989; Hughes 1998; Hutchings 2016) but in addition, form may also have other less-testable origins which may be economic (i.e. related to material properties or availability) or socio-cultural. Although flight mechanics of modern javelins are well-studied (e.g. Campos et al. 2004; Murakami et al. 2006; Vasilios & Iraklis 2013), these studies do not by nature address effective distances, stability in flight, impact velocities, kinetic energy, force, and reliability of early spears, with only a few exceptions to this dearth of research (e.g. Rieder 2001). Thrusting spear use has primarily been experimentally researched from a biomechanics point of view (e.g. Schmitt et al. 2003; Berthaume 2014), the results of which are not directly applicable terminal or wound ballistics studies. As a result, the mechanics during the use hand-delivered weapons are further explored experimentally in Chapter 7.

3.2.4.2 Terminal ballistics

A handful of experimental studies evaluated the potential advantages of materials to tip weapons that are typically found in the archaeological record during the Late Pleistocene such as stone, ivory, bone and antler over wood, the material most commonly associated with weaponry in the MP (Guthrie 1984; Waguespack et al. 2009; Wilkins et al. 2014a; Salem & Churchill 2016). It is often claimed that materials found archaeologically in later periods are functionally superior, but whether that relates to material breakage, lethality (either penetration or other features of capacity for wounding) or some other feature such as size or shape of weapon tips remains unclear. These comparative studies have been influential; claims that innovations in terms of weapon design signal cognitive advances and/or represent economic advantages are frequently made but also often unsubstantiated with experimental evidence. There are no known experimental studies that specifically focus on the terminal ballistics of wooden spears.

3.2.4.3 Wound ballistics

Focusing on experiments aimed at understanding the wounding potential of wooden weaponry, Guthrie (1984) conducted an experiment comparing wounds on moose carcass caused from different organic projectile point materials and designs and found that simple conical points with smaller diameters penetrated more deeply, location on the animal had large effects on depth of penetration (DoP), and that in comparison with other organic materials, wood penetrated less deeply, and suffered more breakage. G. Smith (2003) conducted an experiment that tested wooden spears on a lamb carcass to investigate resulting bone damage, finding that they penetrated this small size prey as both thrusting and hand-thrown spears, causing damage to scapulae, ribs, vertebrae, humerus, and the pelvis with the majority of the damage focused on the ribs. The experiment reported 'high degrees' of penetration using the spears, but this is not quantified, and the resulting scapula damage is also not quantified (G. Smith 2003). More recent examples include the use of ballistic gelatine to evaluate DoP and wound tracks (e.g. Waguespack et al. 2009; Wilkins et al. 2014a; Salem and Churchill 2016). Waguespack et al.'s (2009) experiment concluded that wooden arrows penetrate marginally deeper than stone-tipped arrows, while Wilkins et al. (2014a) found the opposite pattern when testing heavier spears at lower velocities. Wilkins et al. (2014a) used the gelatine to analyse wound tracks and found that stone-tipped spears created larger wound tracks than wood, concluding that the functional advantage of stone lies in its ability to create larger permanent wound cavities. Salem & Churchill (2016) came to similar conclusions testing wooden and stone-tipped arrows at higher velocities. These results are particularly useful in understanding economic advantages of wood vs. stone/osseous points. However, for reasons relating to the use of ballistic gelatine described further below, measures of DoP from these studies may not reflect their actual ability to penetrate an animal, and perhaps even more problematically the studies compare weapons with differently sized and shaped tips, making it unclear whether differences in the size and shape of wound tracks relate to material properties, shape, or size.

There are few data on measuring lethality on different size categories of animals, and how they relate to weapon types. DoP is a key variable in evaluating lethality: most researchers cite a figure of at least 200 mm (20 cm) for lethality on a large mammal (e.g. Hughes 1998 p. 351; Waguespack et al. 2009; Wilkins et al. 2014a; Salem & Churchill 2016). However, looking at the original research studies that are cited, these also suggest that 150 mm (15 cm) can be lethal, depending upon location and prey. The following quotes come from the literature most often cited for lethal DoP on a large ungulate:

> …the point and haft were buried to a depth of about **15 cm** (6 inches) into the rib cage and **it actually cut into the heart**. It would have been **a lethal wound** to a live animal within a very short time.
>
> (Frison 1974), emphasis added

versus

> What is the critical depth of point penetration for a hunter's purpose?...Obviously the carcass is not a homogenous mass and this critical penetration depth is quite variable. However points at depths of 10 cm (4 in.) for instance would seldom have caused enough damage for the hunter's purpose…Generally at 20 cm (8 in.) and greater the point would have caused major damage in many different regions to the central axis of the body.
>
> -Guthrie 1984, p. 282

Frison (1974) tested on an adult cow (*Bos taurus)*, while Guthrie was testing on an adult moose (*Alces alces*), with both species falling into size class 4 (Table 2.1). Measures of ≥150 mm into the rib cage to even very large mammals can be considered to potentially result in rapid organ failure, as these could collapse the thoracic cavity, and/or puncture heart and lungs. Therefore DoP must be used carefully and measures of 150 mm (15 cm) should also be considered as potentially lethal, particularly on smaller prey to that of Guthrie's (1984) study, with such DoPs likely to at the very least incapacitate animals facilitating further shots or thrusts. Clearly as no systematic studies have been undertaken, more research evaluating these oft-cited estimates of DoP and how these relate to prey size, physiology and hunting strategies would contribute to the utility of establishing a standard measurement.

Hits to the thoracic cavity are particularly lethal, with this being the choice target zone for hunters, being frequently illustrated as such by Upper Palaeolithic cave artists (Guthrie 1984; Friis-Hansen 1990; Guthrie 2005), containing the major organs that are accessible with impacts through the ribs. Other target areas include the abdominal cavity, though the likelihood of a lethal shot is lower as the skin is less taut and the organs in this area are not critical. Guthrie (1984) and Frison (1974) both found that skin tautness and thickness in the thoracic area almost certainly affected penetration, something also evidenced in forensic research (e.g. Knight 1975). As shots of 150 mm into the thoracic cavity can be lethal on a size 4 animal, impacts of ≥150 mm in the thoracic area to a size 3-4 animal such as a horse (Table 2.1) are defined in this thesis as a 'lethal' DoP, with the caveats mentioned above.

Targets in experimental work with weaponry include animal carcasses or carcass parts, and/or the use of ballistic gelatine. Inter- and intra-species variations in the physiology of prey affect the penetration of weaponry. Of particular concern are differences in skin/hide thickness, muscle thickness and density and bone mineral density. The thickness of skin/hide affects the effectiveness of penetrating weapons (Datoc 2010). Skin/hide thickness in mammals differs by species, by location on the body, and by sex and seasonal changes, which relate at least in part to interspecific aggression (Jarman 1989). Larger prey also tend to have thicker muscle tissues, affecting effectiveness of weaponry (e.g. Frison 1974; Frison 1989; Badenhorst 2012).

Bone mineral density (BMD) is another variable. Not only do bone densities vary by species, and by bone, they are considerably lower for juveniles, increasing the ability of projectiles to penetrate bone (Letourneux & Pétillon 2008). BMD affects penetration not only because less dense bone increases the ease of penetration, but also because resistance of more rigid bone tissue results in more surrounding tissue damage due to compression waves (Rozen & Dudkiewicz 2011). Generally BMD is utilised in terms of survivability in order to evaluate density-mediated attrition in a given sample, but it is also of value when assessing cause of damage in relation to mode of impact and location on the element. BMD is fairly similar between bovids, cervids and equids (Lam et al. 1999). Pooling the means of the groups of taxa and scan sites, scapulae blades have higher BMD_1 than ribs, humerus, and femur (Table 3.1) (Lam et al. 1999).

Table 3.1. Pooled means of BMD1 values across three taxa (calculated from data in Lam et al. 1999, Table 1)

Element	Pooled mean of BMD_1	n
Scapula	.62	15
Rib	.50	15
Humerus	.45	15
Femur	.40	21

The locations of scanned sites for scapulae and ribs are illustrated in Fig. 3.4. These elements were selected for presentation here as they make up the bones representing the majority of the target area on ungulates and are referred to in further discussions of experimental and archaeological hunting lesions, hammerstone damage and carnivore damage (Chapters 5 and 8). For scapulae the BMD_1 mean value is lowest across all three taxa at scan site SP5, and in equids is equal to or less than half of the values for the other four scan sites, making this area particularly vulnerable to all types of impact damage (Table 3.2). In equids the rib scan sites RI1 and RI2 have the lowest values, making this area most vulnerable to damage, though the pattern is different for cervids and bovids, with the lowest values at scan site RI5. Finally, in order to illustrate variability in terms of areas thickness of bone on an equid scapula, which is different from BMD, a horse scapula was laid over a lightbox (Fig. 3.5).

Table. 3.2. Mean values and sample sizes for BMD_1 of scapulae and ribs , reproduced from Lam et al. 1999 Table 1. Further data including SD values and values for other elements can be found in the original source

Scan Site	Equid	Bovid	Cervid
RI1	.36, n = 12	.48, n = 12	.47, n = 11
RI2	.39, n = 10	.47, n = 12	.49, n = 11
RI3	.50, n = 10	.65, n = 12	.62, n = 12
RI4	.55, n = 12	.61, n = 12	.65, n = 12
RI5	.51, n = 12	.41, n = 12	.40, n = 10
SP1	.64, n = 8	.68, n = 8	.66, n = 7
SP2	.67, n = 8	.71, n = 8	.73, n = 7
SP3	.55, n = 8	.74, n = 8	.73, n = 7
SP4	.66, n = 8	.65, n = 8	.69. n = 7
SP5	.28, n = 8	.50, n = 8	.48, n = 7

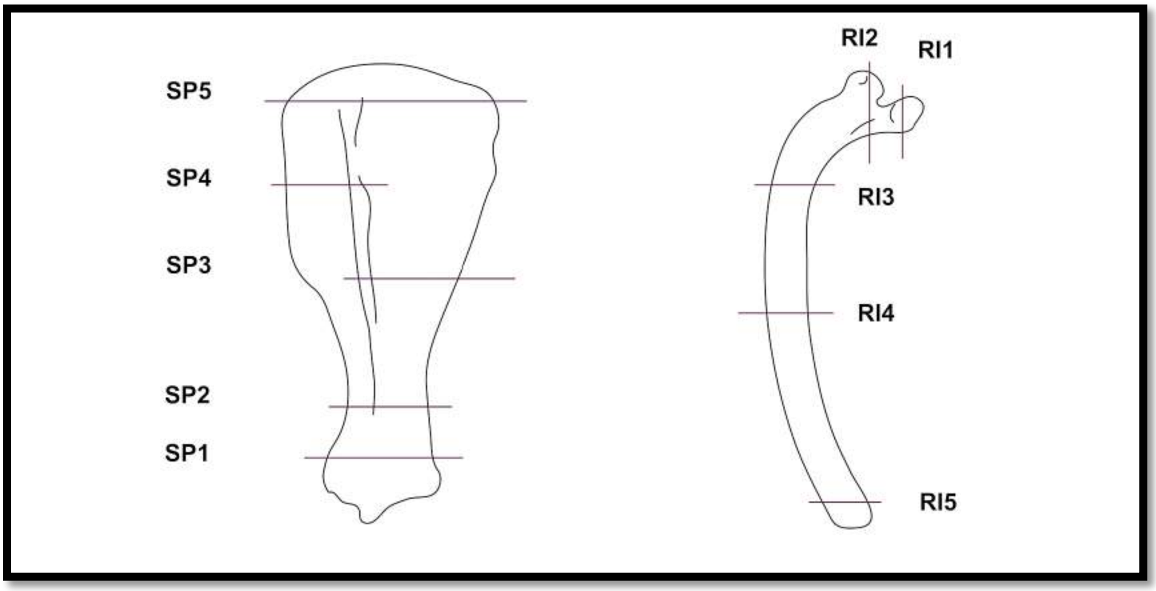


Figure 3.4. BMD Scan sites for the scapula and rib (redrawn after Lam et al. 1999, Fig. 1)

Figure 3.5. A modern adult horse scapula photographed over a light box to visualise the thin areas of bone

Ballistic gelatine (variously called 'ballistics gel', 'ballistics gelatin' and 'ballistic gelatin') is a muscle tissue simulant used in forensic studies, and at concentrations of 10% or 20% is the most typical type of simulant used (Mabbott et al. 2016). Ballistic gelatine consists of powdered animal products and is mixed with water and poured into moulds (Fig. 3.6, left), and then conditioned by refrigeration (Mabbott et al. 2016). It is translucent, facilitating the observation of the path of a projectile (Mabbott et al. 2016). PermaGel™ is a relatively new muscle simulant that is used in ballistic tests, including in sharp weapon studies (Cowper 2015; Cowper et al. 2017) approximating the performance of 10% (by mass) gelatine (Mabbott et al. 2013). PermaGel™ is reusable, translucent, and synthetic and does not require temperature conditioning (as gelatine does). An advantage of using PermaGel™ is the ability to clearly identify wound tracks, facilitating both filming and impact placement (Mabbott et al. 2013).

Ballistic gelatine has come into use in prehistoric weapon studies primarily to provide a homogenous target for comparative purposes, with or without modifications using hide (e.g. Fig. 3.6, right) and/or bone (Waguespack et al. 2009; Milks 2010; Wilkins et al. 2014a; Iovita et al. 2014; Milks, Champion, et al. 2016). As a target, it is particularly useful when attributes of the weapons such as point morphometrics vary. It is also useful in making comparisons between wound tracks (e.g. Milks 2010; Wilkins et al. 2014a; Salem & Churchill 2016). Importantly, experiments using unmodified ballistic gelatine (e.g. Wilkins et al. 2014a; Salem & Churchill 2016) do not reflect the ability of weapons to penetrate an animal, and measures of DoP presented can only be used for comparative purposes, and not as a reflection of the ability of that weapon to penetrate to a lethal depth (contra Rieder 2001; Waguespack 2009; Salem & Churchill 2016). A significant limitation of the use of ballistic gelatin in prehistoric weapon testing relates to the poor understanding of how it compares with animal tissue at low velocities and energies, as the only relevant studies comparing simulants relate to high velocity projectiles. Mabbott et al. (2016) compared 10% and 20% concentrations (conditioned at 4º C) with pig muscle, finding that the 10% concentration was a good match at high velocity impacts, indicating that the concentration and method of manufacture including conditioning is important. Observations in experimental work for the author's Masters dissertation compared ballistic gelatine at 20% concentration with a fallow deer carcass (*Dama dama*), and high speed video footage demonstrated that at hand-thrown spear velocities (15-26 m/s) lithic-tipped spears tended to bounce out of the gelatine, which did not occur when impacting the deer carcass (Milks 2010). Further work on comparing ballistic gelatine with PermaGel™ and animal tissue would help understand how these simulants behave in comparison with animal targets at low velocities. In certain contexts, particularly when a homogenous target is essential, the simulants provide a good medium but they are not directly analogous to an animal. Good practice is to clarify what the concentration is, and whether it has been temperature conditioned, but this is not always reported in archaeological research, while it is the norm in ballistics research (e.g. Jusilla 2004; Kneubuehl et al. 2011;). When 'effectiveness' in terms of DoP is being evaluated, an animal carcass best replicates the performance of prehistoric weaponry, and for evaluating hunting lesions this is essential, at least in terms of evaluating the ability of a particular weapon to create damage to bone, as hide, muscle, connective tissues and fat will inevitably absorb energy that would otherwise be directed only at the bone. If using ballistics gelatine, this difference in energy absorbtion would need to be accounted for.

Figure 3.6. Left: making ballistic gelatine in a cement mixer. Right: a block of ballistic gelatine modified with hide (Both from experiments in Milks 2010)

Few published experiments provide an appropriate reference sample for analyzing hunting lesions from untipped wooden spears, with limitations of these reviewed in Chapter 5. Potentially, marks to bone from carnivore activity, intraspecific combat, trampling or impact by humans from hammerstones may mimic hunting lesions (Guthrie & Koenigswald 1996; Duches et al. 2016; Gaudzinski-Windheuser 2016). Although experimental work on marks from hammerstone impacts during marrow access exist (Pickering & Egeland 2006; Galàn et al. 2009), these studies tend to focus on long bones for marrow access, and impacts to flat bones may not produce the same damage patterns. Further reference collections for impact marks from wooden spears from systematic experimental work, as well as marks from carnivores, hammerstones and other agents would be helpful in analysing faunal collections from relevant periods. This thesis aims in part to begin to establish such a reference collection, and additionally develops a method for quantitatively analysing damage which is inclusive of hunting lesions and butchery damage for comparative purposes. The methods and results of this analysis are in Chapters 5 and 8.

3.3 Summary

As proposed at the beginning of Chapter 2, the evaluation of the performance of wooden spears and their role in human evolution necessitates an approach that takes account of multidisciplinary research. Prior to Chapters 4 through 8 which present new datasets and methodologies regarding archaeological and ethnographic wooden spears, archaeological hunting lesions from the MP and experimental approaches, the background data and models as presented and argued in Chapters 2 and 3 can be briefly summarised as follows.

The MP is a period of shifting hominin behaviours, with the current evidence supporting an increase in sites from the middle of the MP, and a gradual transition from Lower Palaeolithic to

Middle Palaeolithic technologies (Hérisson et al. 2016). Hominins in the European MP appear to have been tall and robust, and by the second half of the MP, when we see the first evidence of weaponry in the archaeological record, they apparently possessed a wide range of technological behaviours including fire, sophisticated and varied organic and lithic toolkits, inhabited a range of environments and repeatedly exploited particular landscapes. Possible additional behaviours include the structuring of space, ritual treatment of the dead, and interpersonal violence. Clear hunters and/or power scavengers of medium and large terrestrial mammals, the hominins also show hints, particularly in southern Europe, of the beginnings of exploitation of smaller prey.

Primate studies have made useful contributions to evaluating the potential behavioural repertoire of Pleistocene hominins. With homologous behaviours of chimpanzees and *H. sapiens* including meat eating acquired through both solitary and cooperative hunting, and tool use including the use of crude weapons in hunting, it is likely that the last common ancestor also engaged to some degree in these behaviours. Zooarchaeological evidence of hunting and power scavenging may date as early as the Early Pleistocene, and is clearly in evidence by the middle of the MP in Eurasia. Both strategies imply the use of weaponry. Archaeological evidence of weaponry, though rare, begins to appear in Eurasia and Africa during the second half of the MP, and intensifies in the Late Pleistocene. The earliest weaponry in Eurasia is the fragmented Clacton spear point from MIS 11, and the earliest complete weapons originate from the site of Schöningen, dated to MIS 9. Weapon delivery systems and weaponry continue to become more complex through time, though simple weapon systems and untipped weaponry remain in place throughout human prehistory and recent periods showing an increased multiplicity and variability in weaponry over time, not a simple replacement.

Methodological approaches underpinning theories about the mechanics, terminal and wound ballistics, and marks and breaks from manufacture and breaks of hand-delivered untipped wooden spears are in their infancy, and are underdeveloped and unsystematic when compared with approaches to Late Pleistocene hunting technologies. An approach that is systematic, holistic, and empirically-based is necessary to move forward hypotheses pertaining to the adaptive, behavioural and cognitive claims regarding the effectiveness of the earliest weapons and the development of weaponry in human evolution.

Chapter 4. Archaeological wooden spears: morphometrics and traces

To the maker of man – THE STICK
-Wendell Oswalt (1973)

4.1. Introduction

Chapter 4 is the first of two chapters focusing on archaeological material covering the record of the use of Middle and Late Pleistocene wooden spears. The sample of archaeological examples of untipped wooden spears is small in comparison with almost every other category of Palaeolithic artefacts: from the entire Middle Pleistocene (MP) there are 11 well-accepted complete spears or spear fragments from the sites of Clacton-on-Sea (n = 1) and Schöningen (n = 10) though there are additional possible examples discussed below (Oakley et al. 1977; Schoch et al. 2015). Excavations at Schöningen are ongoing and not only may further spears emerge but additional wooden fragments are yet to be analysed (Schoch et al. 2015). Although additional possible examples have been proposed from a number of MP sites, none have preserved well enough to be certain of their anthropogenic origin and/or function (Schoch et al. 2015). From the Late Pleistocene, further examples of wooden spears exist, with the most well-known being that from Lehringen (Germany), where one complete spear was excavated in the middle of the 20th century, and where a second spear had possibly been present (Thieme & Veil 1985). Three additional examples from much later in the Pleistocene include two wooden spears from Monte Verde II in Chile as well as one from Wyrie Swamp in Australia (Luebbers 1975; Dillehay 1997). These terminal Pleistocene and early Holocene examples underpin what will be demonstrated in Chapter 6 on the basis of ethnographic data, which is that wooden spears were geographically widespread, often in use alongside complex and composite weapon technologies. While there are clearly limits of inference, an analysis of wooden spears is timely to facilitate intra- and inter-site comparisons in order to begin to build a picture of their design and use.

The persistence of the use of hand-delivered wooden spears not only by MP hominins but by Late Pleistocene Neanderthals, and *H. sapiens* clearly indicates that these spears had advantages over other weapon types. Although hafting is considered a significant step in cognitive evolution (e.g. Wadley et al. 2009; Wynn 2009), manufacturing a wooden spear is thought to require modularity of mind, with a long operational sequence including advance planning, knowledge of raw material location and material properties (Haidle 2010). Evaluating aspects of wooden spears including design and performance contributes to evaluating changes in cognitive evolution during this critical period in human evolution. The conundrum that wooden spears are simple in comparison to composite and complex weaponry and yet persisted amongst recent hunter-gatherer groups requires systematic comparative research from multiple angles.

Chapter 4 is the first known piece of research collating published and original research data on the current sample of archaeological wooden spears, and is the first comparative analysis of archaeological and ethnographic examples to have taken place since the discovery of the examples from Schöningen. It sets the backdrop for the following chapters looking at potential hunting lesions resulting from their use (Chapter 5), ethnographic data on their use (Chapter 6) and experimental research evaluating performance (Chapters 7 and 8). Chapter 4 (4.1.1) first provides background data on the sites that have yielded archaeological examples. Following this is a traditional morphometric analysis of the distal points of Middle and early Late Pleistocene wooden spears (4.2, 4.3), facilitating a comparison of the archaeological examples (4.3.4) as well as with the ethnographic sample analysed (Chapter 6). The focus on the distal tips was a choice guided by the overarching objective of this thesis - to empirically evaluate the lethality of wooden spears - and an understanding of the 'business end' of these weapons is a key component in lethality, albeit not the only factor (Hughes 1998). A more complete study of design was not possible due to limited access to archaeological examples, but where available published measurement data provide further means of assessing design and function.

4.1.1 Background on sites and artefacts

This section provides site excavation history and context for a selection of proposed wooden spears from the Middle Pleistocene, and reviews the evidence of terminal Pleistocene and Holocene examples with an overview of previous assessments of the spears from each site of the main sites of Clacton-on-Sea, Schöningen, and Lehringen (Fig. 4.1). The section also briefly reviews sites with artefacts previously suggested to represent wooden spears or spear fragments, but which are not well-accepted as such (see also Figs. 4.1 & 4.2, and Appendix 1 Table A.1).

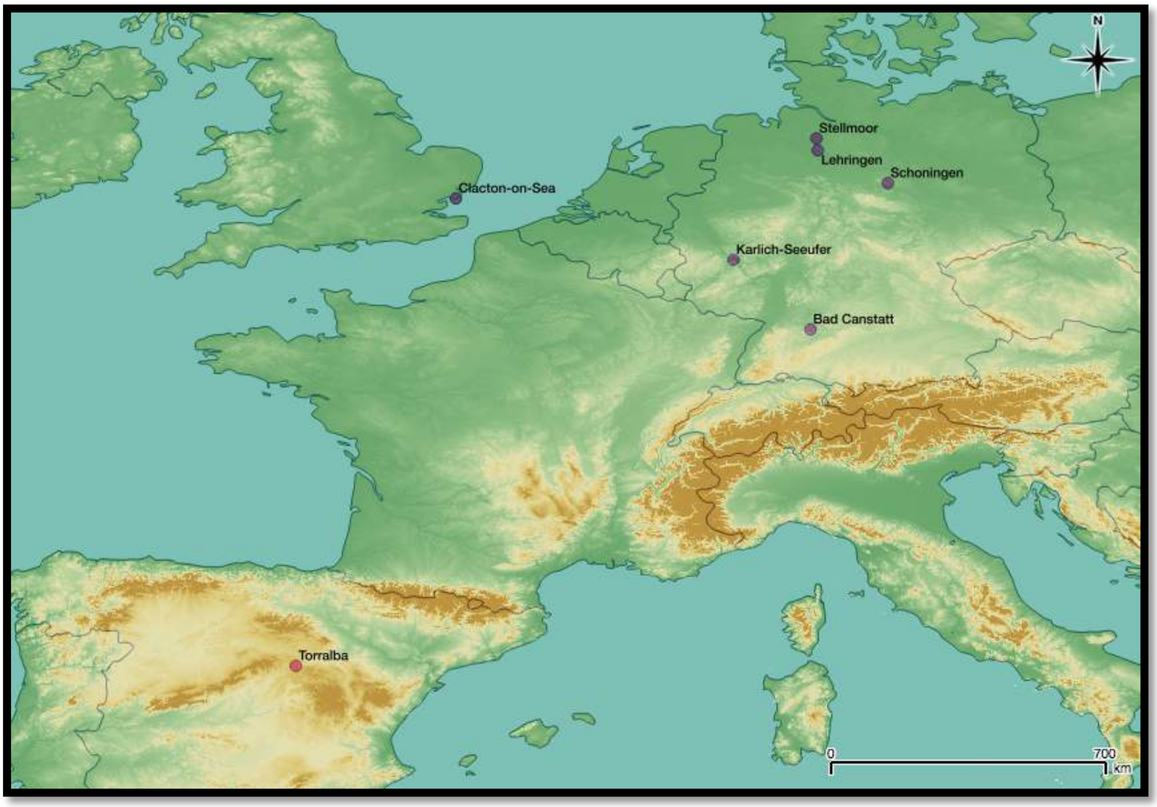


Figure 4.1. Map of European sites mentioned in Chapter 4

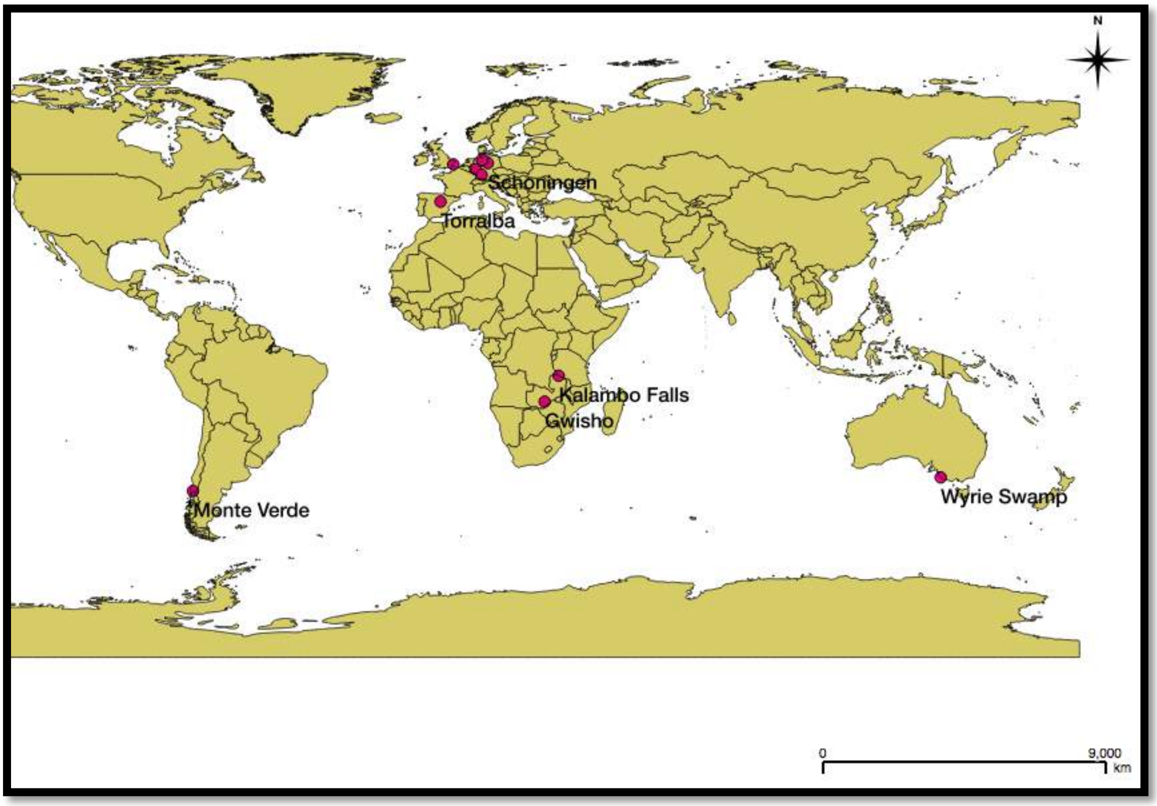


Figure 4.2. Global map of sites mentioned in the text. Please see Fig. 4.1 for the detail of the European sites and associated place names.

4.1.1.1 Clacton-on-Sea, Essex (UK)

The broken yew artefact variously known as the 'Clacton spear Point', the 'Clacton spear' and the 'Clacton point' (e.g. Oakley et al. 1977; McNabb 1989; Allington-Jones 2015; Fluck 2015) does not originate from a systematically excavated archaeological site, but rather is one of a collection of humanly modified artefacts associated with flora and fauna from MP deposits at Clacton-on-Sea, Essex (UK) (Fig. 4.1). The artefact was removed from fluvial deposits (called 'freshwater beds' in Warren 1923) outcropping on the foreshore of the West Cliff in Clacton-on-Sea (51.783374, 1.146638) by Samuel Hazzledine Warren in 1911 (Fig. 4.3) (Warren 1911; Warren 1923; Oakley et al. 1977; White 2000). Warren was a keen and meticulous amateur geologist, whose observations and research, particularly at Clacton-on-Sea, made a significant contribution to the chronology of the British Quaternary as well as Lower Palaeolithic archaeology (O'Connor 2006), recording geological contexts for finds with enough precision as to broadly understand the archaeological context for the Clacton spear point.

The important deposits at Clacton were first identified by John Brown (Brown 1838; Brown 1840; Brown 1841) who described both mammalian and shell fossils, indicating mixed marine and freshwater deposits. When Warren began investigating the area, the West Cliff locality was the only one known to have significant deposits. Warren investigated the wider region identifying further deposits at Lion Point, Jaywick which provided the main sequence for interpreting the West Cliff exposures where fluvial deposits were overlain by estuarine deposits (Bridgland et al. 1999). Four different locations are known to have had significant Pleistocene deposits including the cliffs and foreshore, Lion Point (Jaywick), the golf course (Clacton-on-Sea Golf Club) and the now-developed area under what had been Butlins Holiday Camp (Fig. 4.3). Excavations took place at the golf course near Jaywick in the 1930s and 1970s with the main finds being lithic artefacts in fresh condition (Oakley & Leakey 1937; Singer et al. 1973). Boreholes have been taken at various times from the 1950s through 1980s from behind cliff (behind West Marine Parade), from the foreshore, and under the former site of Butlins Holiday Camp prior to development (see Bridgland et al. 1999). The foreshore, along with the cliffs now covered over with landscaping, and further deposits in the area are today a Site of Special Scientific Interest.

The deposits formed as channel features cut into Palaeogene London Clay and subsequently were infilled with fluvial deposits by the Thames-Medway River after the Thames had been diverted during the MIS 12 glaciation (Bridland et al. 1999). Bridgland et al. (1999) regard the archaeology at Clacton as coming from downstream deposits directly relatable to those at Swanscombe from the same interglacial, MIS 11. The dating of Clacton to the temperate interglacial of MIS 11 is on the basis of aminostratigraphy, palynology, mammalian biostratigraphy, plant macrofossils and sea-level change records (Bridgland et al. 1999; Roe et al. 2009).

Lithic artefacts include flakes, flake tools, and cores. According to Warren (1951) the lithics at Clacton included no bifaces, which had led to it becoming the type site of the 'Clactonian' industry (Breuil 1932). The existence and nature of the 'Clactonian' has been the subject of debate regarding contemporaneity with and differentiation from bifacial Acheulean technology (e.g. Ohel 1977; Ohel et al. 1979; McNabb & Ashton 1992; Ashton et al. 1994). An absence of bifaces at Clacton helped underpin a drawn-out controversy over whether the 'Clactonian' represents 'cultures' that for example had an absence of bifacial technologies, whether sites with different lithic technologies represent different activity areas, or whether there are raw material constraints. Subsequent excavations produced possible handaxe thinning flakes and bifaces from deposits at the golf course and Lion Point (Singer et al. 1973; Wymer 1985 cited in Bridgland et al. 1999). McNabb & Ashton (1992) make a convincing case that there were in fact bifaces from both the gravels at Lion Point as well as from the West Cliff deposits. A tool type often associated in discussions about the Clacton spear is the 'Clactonian notch', which is defined as a 'flaked flakes with sharp, durable and slightly concave edges, ideal for planing and whittling wood' (Ashton et al. 1992). The Clactonian notch has been suggested to possibly be intended for use as a 'spokeshave' for shaping wood tools including spears, and has been experimentally used for such (McNabb 1989; Ashton et al. 1991). In addition to the broken spear point, Warren (1951, p. 129) published some photographs of bone tools previously identified by Breuil, which have been subsequently studied and look to possibly be a type of percussor, though their specific function is as yet unclear (Simon Parfitt, pers. comm.).

Mammal remains from the Clacton deposits show the presence of cervids, equids, proboscideans, rhinoceros and bovids, suggesting a temperate interglacial climate (Warren 1923; Singer et al. 1973; Bridgland et al. 1999). Warren (1951) mentions cut marks on mammalian fauna but these are not illustrated or discussed further. A study of plant macrofossils from Clacton deposits show a mix of woodlands and scrublands associated with the Upper Freshwater Beds (Bridgland et al. 1999). Although it is not clear whether chronologically the pollen analysis relates to the context of the Clacton spear point, spruce (*Picea* sp.) was present in the profile (Bridgland et al. 1999) suggesting that although spruce - the wood that nearly all of the Schöningen spears were manufactured from - may have been available during MIS 11 at Clacton, the Clacton spear point was manufactured from yew. This suggests that yew was a preferable material due to mechanical properties including density and elasticity.

Figure 4.3. The surviving Clacton channel sediments as of 1999, with the location of sites, including the West Cliff. (From Bridgland et al. 1999, p.111)

As for the context of the broken spear point, Warren (1923, p.613) wrote that ‘The wooden spear was dug out of bed r; it lay almost horizontally, but with the thicker and heavier end slightly depressed’ (Fig. 4.4). Although the context is not secure by modern standards, the location and nature of the sediments from which the broken point come is clear enough that lack of context cannot be used to dismiss the object (contra Villa & Lenoir 2009). Warren’s investigations suggest a good level of organic preservation, with additional natural unmodified wood, nuts and other organic matter in the fluvial deposits (Warren 1911; Warren 1923).

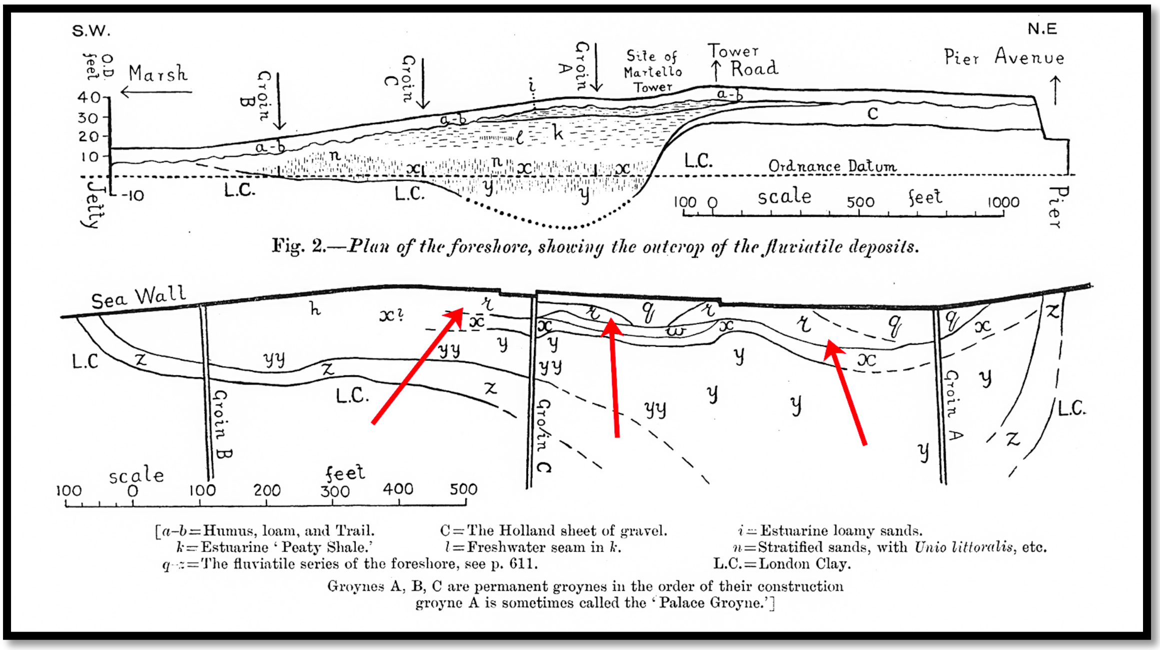


Figure 4.4. Drawing of the West Cliff, with arrows showing the location of ‘bed r’ (modified after Warren 1923, p.610)

Figure 4.5. The Clacton spear point (Photo by A. Milks)

The broken wooden artefact (Fig. 4.5), which originally had calcareous sediment adhered to the surface, is a humanly-modified branch of a yew tree (*Taxus* sp.), thought to be the distal end of a wooden tool (Oakley et al. 1977). It was originally reported to measure 387 mm (15.25 inches) long and 38 mm (1.5 inches) in diameter at the broken end (Warren 1911, p.xcix), though Oakley et al. (Oakley et al. 1977, p.19) publish the original maximum diameter as 39 mm, which is most likely a small calculation error (Oakley et al. 1977, p.14). A cast made in the year of discovery measured 383 mm long, which translates to 1% longitudinal shrinkage, and by 1974 the length was 367 mm and maximum diameter was 36 mm (Oakley et al. 1977). Compared with measurements published in the year of its discovery the object now measures 5% shorter longitudinally, and 3.8% smaller radially; it has also suffered warping of the tip (Oakley et al. 1977; Allington-Jones 2015). Oakley et al (1977) report that there is no evidence of fire on the object and that the distal 80-100 mm displays some polishing. Several casts have been taken, with the earliest cast from 1911, prior to its submersion in glycerin (Allington-Jones 2015). Subsequent treatment in the 1950s and later included heating and the application of paraffin wax, among other substances (Allington-Jones 2015). At some point the tip of the spear had broken off and was reattached, and additional destructive work included the removal of thin sections for wood identification (Oakley et al. 1977; Allington-Jones 2015). Two post-excavation breaks are visible on the spear today. The key point about the preservation and treatment of the Clacton spear point is that it has resulted in shrinkage and warping, visible particularly on the tip of the original today, and probably mostly as a result of temperature treatments (Allington-Jones 2015). For this reason, casts taken prior to these treatments are more suitable for a morphometric study than the original object. Allington-Jones (2015) suggests that the tip could have become slightly compressed or deformed while in use as a hunting weapon, with the earliest photo showing slight bending (Fig. 4.6).

Figure 4.6. First photograph of the Clacton spear point (From Crawford 1921)

The Clacton spear point has been described by Oakley et al. (1977) as gradually tapering from an area knots about 'one third of the way from the base', and increasing in taper around 100 mm from the distal point (Oakley et al. 1977, p.16). McNabb (1989, p. 251) describes it as having an 'acutely tapering point with straight sides' with the taper becoming 'pronounced 100 mm from the tip' based on Oakley et al's (1977) measurements. Oakley et al. (1977) illustrate the robustness of the Clacton spear point by comparing it with ethnographic wooden tools of various types, as well as with the complete Lehringen spear, showing that the maximum diameter on the broken spear segment exceeds a studied sample of ethnographic spears, but is comparable to digging sticks, and intriguingly is thinner than a throwing stick reused as a digging stick.

The break was described as uneven, with more damage on one side and a long splinter removal stemming from the broken end on the other (Oakley et al. 1977). The splaying of the end was already evident by the time of Oakley et al's (1977) publication, though the earliest photograph shows that it was initially narrower (Fig 4.5). Oakley et al. (1977) suggest the raw material for the spear point was a branch of yew with a similar original diameter to the finished form, and that the spear was broken after the wood was no longer fresh, as such a break would be unlikely to occur on green yew wood. Furthermore, the break is suggested to have been the cause of a significant amount of force, again due to the density and elasticity of yew, although no known experiments have tested this hypothesis. Marks described include parallel striations running obliquely to the grain, chatter marks, and polishing at the tip (Oakley et al. 1977). Experimental manufacture has shown that Clactonian notches make effective tools for shaping spears, while the use of fire would aid the process of shaping (McNabb 1989; Fluck 2015; also see Appendix 1 on further details of manufacturing marks and the use of fire on wooden spears).

Functional interpretations of the artefact have varied. Warren cautiously described it as 'possibly the point of a paleolithic spear' (Warren 1911 p.xcix), which has generally been the interpretation in ensuing publications. Oakley et al. (1977) were the first to systematically examine the artefact, addressing a variety of different aspects of its morphology and macro/microscopic wear, and when comparing the tool with ethnographic and archaeological tools known at the time, concluded it had most likely functioned as a thrusting spear. This functional assignment was partly based on the morphometrics of the point, but also on the basis of the effort expended in carefully shaping the point, which in their view is unlikely for tools such as digging sticks or game stakes. However, there are some problems with the data from Oakley et al.'s (1977) paper. Most significantly, measurement data of 'throwing spears' in the publication combine those from hand-delivered and spearthrower-launched wooden spears. Data from a paper from the same year by Palter (1977) suggests that when separating these categories, the mean length of the Australian ethnographic hand-delivered spears studied (2668 mm) was slightly longer than that of spear-thrower spears (2498 mm). Palter (1977) also demonstrated that the mass of the two categories of spears differs considerably, with hand-thrown spears weighing significantly more than spear-thrown spears. Oakley et al. (1977) also included some questionable examples, such as a child's spear and composite spears, which in a small sample size of 28 would affect the mean. Further details of the ethnographic sample, including a reexamination of Oakley et al.'s (1977) ethnographic data are presented in Chapter 6.

The interpretation of the Clacton spear as a weapon was challenged by Clive Gamble during the hunting and scavenging debate, when he speculated that the wooden artifact functioned instead as a probe for locating frozen carcasses under snow (Gamble 1987). The interpretation of the artifact as a snow probe is mostly now disregarded, probably in part because the find is almost certainly from a mild interglacial period but also because evidence of hunting during the MP, and particularly from MIS 11 onward has strengthened (see Chapter 2), but even if hominins during the period were frequently scavenging carcasses, it appears most likely that such behaviours would have involved power scavenging of fresh carcasses from carnivore kills, for which a robust pointy stick would be very useful. Smith (2010) suggested that the Clacton spear has 'rifling marks' consistent with use as a throwing spear, but such marks on the Clacton spear or experimental examples (Smith 2003) were not illustrated. Most current researchers are hesitant to definitively assign a delivery method to this broken piece due to its fragmented nature but it is broadly accepted as the broken tip of a wooden spear (Berger & Trinkaus 1995; Villa & d'Errico 2001; Schmitt et al. 2003; Villa et al. 2009; Waguespack et al. 2009).

4.1.1.2 Schöningen, Lower Saxony (Germany)

The MP site of Schöningen is located in the southern part of the north German Plain in Lower Saxony (Fig. 4.1). The series of sites with Pleistocene sediments is situated on the outskirts of the town of Schöningen on the edge of a large open-cast lignite mine just east of the Elm forest (Fig. 4.7) (Böhner et al. 2015; Conard et al. 2015). Originally interpreted as infilled fluvial channels (e.g. Thieme 1997; Mania 1998), it now looks likely that Schöningen is in a tunnel valley partially infilled with 45 m of MP through Holocene sediments (Lang et al. 2015). Schöningen consists of a series of different sites with sites 12 and 13 dating to the interglacial MIS 9, situated around a palaeolake with a fluctuating shoreline (Lang et al. 2015).

Figure 4.7. Excavations at Schöningen in the foreground, with the lignite mine in the background. (Photo by A. Milks taken with kind permission of N. Conard)

The sites were discovered as a result of rescue excavation work undertaken by Dr. Hartmut Thieme from 1982 (Conard et al. 2015), who recognized the archaeological potential of the sediments being exposed by mining activities in the area. At the start excavations were conducted to identify and salvage archaeologically rich areas (Böhner et al. 2015). The discovery of artefact-bearing Pleistocene sediments in 1992 produced not only faunal and lithic artefacts but also wooden artefacts - with the first artefacts discovered interpreted as handles of some kind (Conard et al. 2015). Subsequent finds included the 'throwing stick' excavated in 1995 followed by the first of the wooden spears in the same year (Thieme 1997; Van Kolfschoten 2012; Conard et al. 2015). Excavations were initially hampered by the fact that the site was in the ownership of the mining company, and Thieme and his team worked under extremely difficult circumstances. The discovery of the first of the wooden spears at the site highlighted the significance of the archaeology at Schöningen, which helped secure the site for long-term excavation. Excavations now continue for most of the year with a multi-disciplinary and multi-institutional team collaborating on analysis of the site and artefacts (Conard et al. 2015).

The MP artefacts come from several areas, including Schöningen 12 (12A, 12B, 12 II, 12 II DB) and Schöningen 13 (13 I, 13 I DB, 13 II) (e.g. Thieme 1999b; Thieme 2007; Voormolen 2008b; Behre 2012; Van Kolfschoten et al. 2012; Conard et al. 2015). The context for the wooden spears is Schöningen 13 II-4, known as the 'Spear Horizon' (Fig. 4.8). The number II-13 relates to the geographical position, II to the 'channel', and 4 represents the sedimentological level. The details that follow refer to the 'Spear Horizon' of Schöningen 13 II-4. The Spear Horizon covers

3783 m^2 and excavation of this area finished in 2013; an additional area 60 m to the south is thought to correspond to the same levels (Böhner et al. 2015). The Spear Horizon consists of an intersection between lacustrine marl and organic muds, possibly representing a continuously submerged area of a palaeolake (Stahlschmidt et al. 2015a). Level 4 is between 2 and 2.5 m thick consisting of organic lacustrine muds at the bottom covered by lacustrine gyttja which is in turn covered by organic matter, with the organic layers containing the majority of the archaeological material (Böhner et al. 2015). Various models relating to the interpretation of the depositional environment of the Spear Horizon are proposed, including that the artefacts were intentionally disposed of into the lake, that hunting or caching was taking place on lake-ice, that there was a relocation of the artefacts from the lake shore into the water; alternatively, the accumulation could have occurred during a short, dry period (Stahlschmidt et al. 2015a). The explanation that the site might reflect caching of carcasses is problematic, as this would fail to explain the presence of the lithics and spears on site - while it may make sense for the carcasses, the submersion of spears in water would quickly lead to their being water-logged which would negatively affect both the elasticity of the wood and mass of the spears. A model proposing that the hunting and/or butchering was taking place on lake-ice is complicated by isotopic analysis of the horse teeth suggesting that the animals died in different seasons (Stahlschmidt et al. 2015a; Julien, Rivals, et al. 2015). Stahlschmidt et al. (2015a) do not favour the interpretation of a temporarily dry lake shore because the micromorphology points to the sediments being continuously submerged. Alternative scenarios include that the artefacts were slightly displaced in a low energy environment, that the artefacts and butchered fauna were disposed of in the water by the hominins, or that the assemblage accumulated as a result of hunting and/or butchering activities taking place on a frozen lake surface (Stahlschmidt et al. 2015a). The presence of spears in any of these scenarios is complicated if they were not broken or damaged beyond repair prior to deposition, and therefore future analysis of the spears must take break and damage patterns into account.

There is extremely good preservation of organics, including pollen and macro-remains of plants, including not only the worked wood but also natural background wood, seeds, fruit and other plant material (Bigga et al. 2015). Originally thought to date to the same interglacial of MIS 11 as the Clacton spear point (e.g. Mania 2007), recent TL dating gives an estimated age range of 337-300 ka BP, falling into the MIS 9 interglacial (Richter & Krbetschek 2015). Some disagreements remain about the nature and timing of this interglacial, but an assignment to MIS 9 is most likely (e.g. Starkovich & Conard 2015 and references therein). Although originally it was suggested that Schöningen had both hearths and burnt wood (e.g. Thieme 1997; Thieme 2005; Thieme 2007), a reanalysis has found no evidence for use of fire at the site including on one a wood fragments that had been previously suggested to be humanly modified, showing that these objects are stained by sediments rather than burnt (Stahlschmidt et al. 2015b). The authors of this recent study rightly point out the need for modern analytical techniques in assessing wooden artefacts for evidence of charring.

The faunal preservation at Schöningen is equally excellent and large mammals are represented by *Elaphus (Palaeoloxodon) antiquus, Stephanorhinus kirchbergensis, Stephanorhinus hemitoechus, Equus mosbachensis, Equus hydrontinus, Cervus elaphus, Bos primigenius, Bison priscus, Canis lupus, Vulpes vulpes, Homotherium latidens* as well as indeterminate artiodactyls, proboscideans, and cervids (Van Kolfschoten, Buhrs, et al. 2015). These animals represent an environment with a mix of both open and woodland species (Van Kolfschoten 2014). The mammals with evidence of hominin modification include equids, cervids and bovids (*Equus mosbachensis, Cervus elaphus, Bos primigenius, Bison priscus*) (Voormolen 2008a; Van Kolfschoten, Buhrs, et al. 2015; Starkovich & Conard 2015). The faunal assemblage showing modification by hominins is dominated by horses (Voormolen 2008a; Van Kolfschoten et al. 2012; Van Kolfschoten 2014), which make up the majority of sample. The relatively large-bodied horses number at least 46, were between 140 and 161 cm at the withers and have nearly all of the elements represented (Van Kolfschoten 2014; Van Kolfschoten, Buhrs, et al. 2015). Current interpretations favor the explanation that the horses were hunted (Starkovich & Conard 2015); a wide age range of horses are represented, but not enough data are available yet to create a mortality profile (Voormolen 2008a). Isotope analyses of the horse teeth suggest multiple death events, rather than multiple predation of a single herd though as yet it is unclear whether some of the horses died at the same time (Julien, Rivals, et al. 2015). This differs from interpretations by Thieme (e.g. 1997) that the site follows a Pompeii-type model; the re-interpretaiton of the site rests not only on the aforementioned isotope analysis, but also because hominins would be unlikely to be capable of the multiple predation and consumption of such a large quantity of horses in one event (Conard et al. 2015).

Faunal bones indicate cut marks for skinning, filleting, disarticulation, removal of periosteum, and impact marks for marrow access (Van Kolfschoten 2014). Interestingly ten ribs of the horses display evidence of healed fractures, which have been interpreted as evidence of interspecific aggression (Van Kolfschoten, Buhrs, et al. 2015) but impact from wooden spears should also be considered as possible, with healed hunting lesions known from later in the archaeological record (e.g. Noe-Nygaard 1974). There is considerable carnviore damage to the faunal remains, typically showing that carnivores had access to the bones after hominins, supporting evidence of hominin hunting and/or power scavenging (Voormolen 2008; Starkovich & Conard 2015). In addition to the species interpreted as prey, a humerus of a sabre-tooth cat (*Homotherium latidens*) from Schöningen 13 II-4 bears evidence of use as a knapping tool (Van Kolfschoten, Parfitt, et al. 2015; Serangeli et al. 2015). Schoningen 12 II also has a number of other bone tools including horse bones interpreted as being used as percussors and retouchers in lithic tool manufacture and curation, a piece of ivory with signs of use, bone artefacts suggested to have potentially been used as smoothing tools and an inominate bone used as an anvil for knapping (Julien, Hardy, et al. 2015; Van Kolfschoten, Parfitt, et al. 2015). Interpretations of the faunal assemblage point to organised, social hunting and processing of large mammals primarily falling into size classes 3 and 4, although with juveniles represented this probably extends to smaller size classes, while larger aurochs would potentially falling into size class 5, depending upon the size of the individual animal (Table 2.1). Hypotheses that the hominins posessed advanced cognitive skills and complex social organisation rests partly on the evidence for the repeated use of the site and patterns of butchery, implying an understanding of ethology, and the ability to share the landscape and compete for resources with other top-level predators (Starkovich & Conard 2015; Conard et al. 2015).

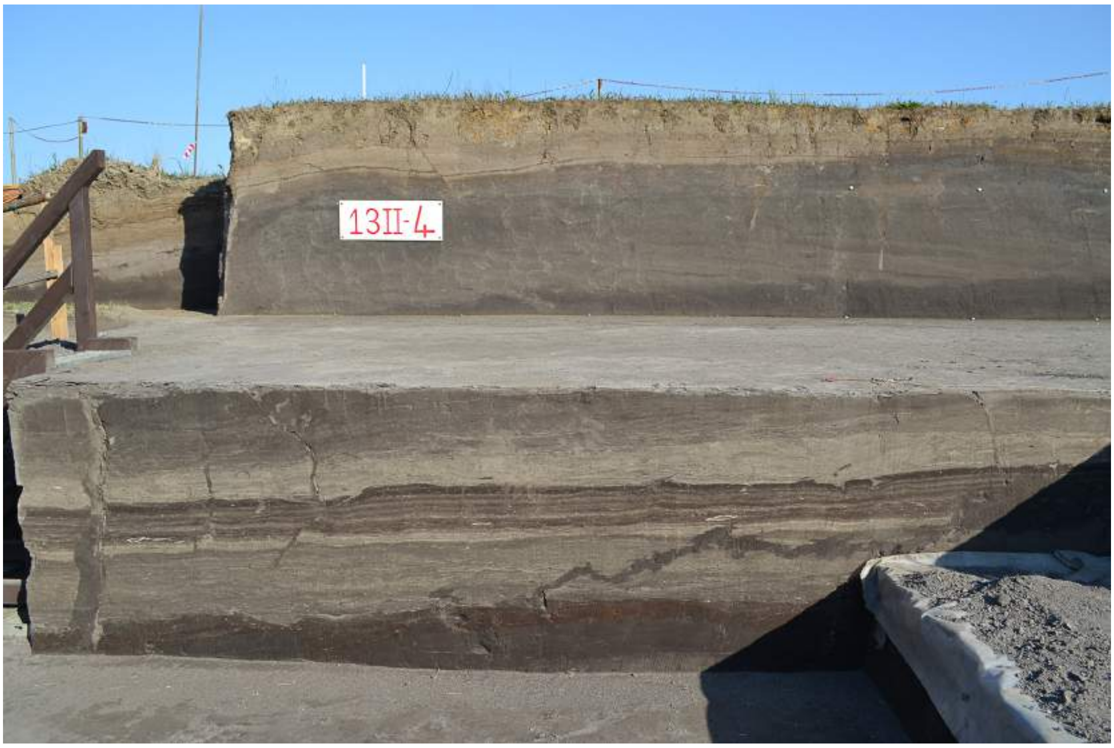


Figure 4.8. Section of 13 II-4, the 'Spear Horizon' (Photo by A. Milks taken with kind permission by N. Conard)

Over 1500 lithics have been excavated from the Spear Horizon and those analysed thus far suggest a transitional technology between the Lower and Middle Palaeolithic, with an absence of both bifaces and Levallois (Serangeli & Conard 2015; Conard et al. 2015). The lithic assemblage consists of flakes, flake tools, and debitage made of local flint, and their relative low density compared with other artefacts suggests non-systematic and opportunistic reduction sequences (Conard et al. 2015). Use-wear shows that the lithics were used for multiple functions, including working wood and plant fibres as well as butchery (Rots et al. 2015). The nature of the assemblage suggests that lithics were brought to the site, and therefore it is unlikely to represent an occupation site (Conard et al. 2015).

The Spear Horizon contains ~740 wooden artefacts, ranging from small worked but unidentified fragments to complete spears (Böhner et al. 2015). As they were under pressure from two to three m of glacial ice, the spears have undergone minor deformation including in cross-section, but their distribution strongly supports that the spears are relatively in a primary context with only a small amount of post-depositional movement (Böhner et al. 2015; Schoch et al. 2015). Thus far the collection includes at least 10 spears and spear fragments (note these are labeled by Schoch et al. 2015 as nine ‘spears’ and one ‘lance’, but this is not followed in this thesis due to issues outlined in Chapter 3 regarding uncertainties around taxonomy, morphology and function).

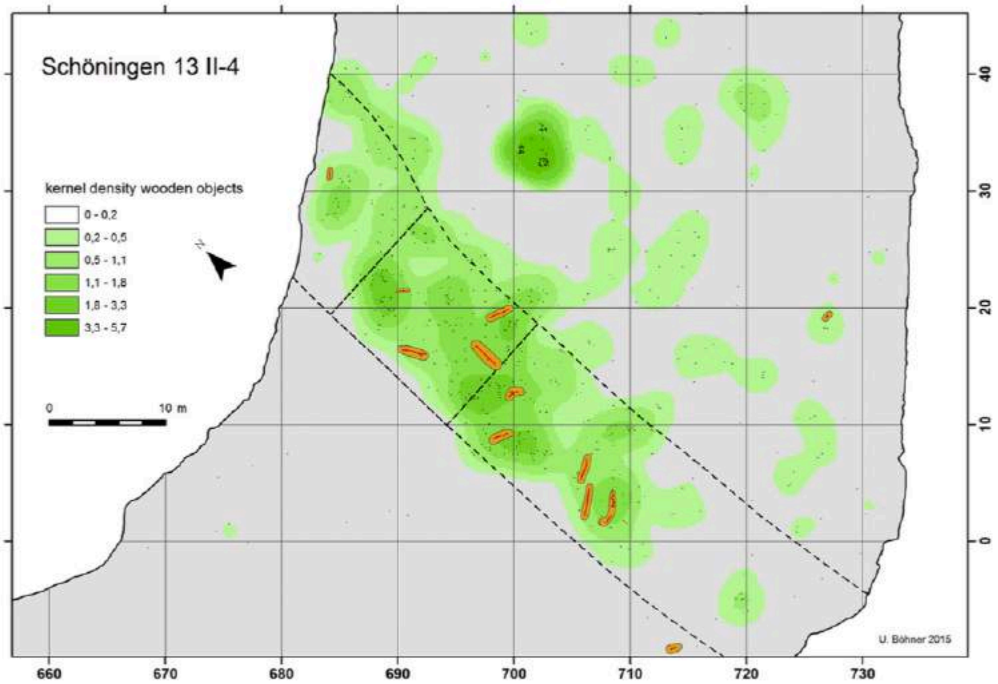


Figure 4.9. Distribution of wooden artefacts in the Spear Horizon. The orange areas represent locations of spears and spear fragments (From Böhner et al. 2015)

Most of the spears are located in an area measuring 10 x 25 m (Fig. 4.9); Some consist of fragments refitting into complete or nearly-complete spears (n = 5), while others (n = 5) consist of spear fragments only (Schoch et al. 2015). It is as yet unclear whether the breaks represent damage from use, trampling or post-depositional processes (Schoch et al. 2015). The complete and nearly-complete spears (Spears I, II, III, V, and VI) range in length from 1841 to 2531 mm, with maximum diameters of the complete examples ranging from 29 to 47 mm, with the maximum diameter of all spears and spear fragments as a group being between 24 and 47 mm (Schoch et al. 2015). The maximum diameter is reported by the authors as always located in the front part of the shaft for all examples except Spear VI, which has been interpreted as a thrusting spear on this basis and on the presence of a natural kink (Schoch et al. 2015). Evidence of working includes stripping bark, working down knots, tool marks along the length of the spears, particularly the distal 250 - 600 mm ends of the spears (Spears I, II, III), and ca. 100 mm of the proximal ends, as well as possible evidence of curation of a broken tip (Schoch et al. 2015). All of the spears taper on both ends, with evidence for working in the form of tool marks at both ends of spears (Schoch et al. 2015), falsifying suggestions that the proximal ends may taper naturally (Shea 2006), and clarifying that this is an intentional design feature. All of the spears and spear fragments have been crafted from slow-growing spruce (*Picea* sp.) except

Spear IV which is of pine. The slow growth is interpreted as representing cool growing conditions, and although it is also possible that slow growth can be related to other growing conditions including the distance of tree spacing, soil quality, and moisture (Tsoumis 1991), the evidence from studies of the palynological, vertebrate, ostracod, molluscs and macro-botanical remains support that the spear horizon corresponds to the end of the interglacial, with a deteriorating climate and mean annual and winter temperatures cooler than present-day conditions (Urban & Bigga 2015 and references therein). The wood for the spears is unlikely to have come directly from the site as few spruce pollen are present, (Urban & Bigga 2015). All of the distal ends of the spears are manufactured from the base of the trees which are typically particularly dense, and the very tip is offset from the soft centre pith, demonstrating an awareness of the properties of wood (Schoch et al. 2015). One intriguing proposal in the most recent paper on the spears is that the 'throwing stick', morphologically similar to the rest of the spears but significantly shorter in length, could represent a child's spear (Schoch et al. 2015). The total number of spears from the horizon may grow, as a collection of wood fragments have yet to be analysed (U. Böhner, pers. comm.; Gaudzinski-Windheuser 2016).

Functional interpretations of the Schöningen spears have generally been that they were designed as throwing spears on the basis of location of the maximum diameter and therefore the PoB, and their similarity in design to modern Olympic javelins including length, mass, and PoB (e.g. Thieme 1997; Rieder 2001; Thieme 2005; Schoch et al. 2015). Spear VI of the collection has a natural kink, is longer than the other spears from Schöningen and has the maximum diameter located in the proximal half of the shaft, and therefore has been interpreted as a thrusting spear (Schoch et al. 2015). Rieder (2001) reports that a replica of Spear II was reasonably accurate when thrown by hand up to 35 m and very accurate between 8 and 15 m, but the method for defining accuracy (e.g. size of the target, conditions for throwing, percentage of hits and misses), is not clearly reported. Additional interpretations mention that the spears could have functioned as both close-range and distance weapons, including for self-defence (Schoch et al. 2015; Serangeli et al. 2015). Relying upon ethnographic evidence, namely morphometric data from the ethnographic literature, Shea (2006) suggests that these were either close-range thrown spears or thrusting spears but this assessment does not account for Rieder's (2000; 2001) experimental work with a replica of Schöningen Spear II, demonstrating its ability to fly. In terms of lethality, the DoP into a gelatine block (% concentration or conditioning not reported) during Rieder's experimental use was reported as 229 mm (Rieder 2000). However, as the gelatine block was unmodified, the concentration is unknown, and does not represent an animal, it does not provide sufficient evidence of this spear's ability to lethally wound a large animal (contra Schoch et al. 2015). Further implications of this and other relevant experiments are further critiqued in Chapters 7 and 8.

4.1.1.3 Lehringen, Lower Saxony (Germany)

The wooden spear from Lehringen (Germany), often called the 'Lehringen lance', was discovered in 1948 as a result of dredging of a marl pit for fertilizer (Thieme & Veil 1985). The site is located on the northwest German plain near the small village of Lehringen in the valley of the River Aller in Lower Saxony, Germany. Glacial activity in MIS 10 and MIS 6 created basins that were infilled with lake sediments and freshwater limestone deposits during MIS 5e (Thieme & Veil 1985; Gaudzinski-Windheuser et al. 2014). These deposits captured the archaeology at Lehringen, with exceptional organic preservation as evidenced by the presence of the spear.

A local school principal R. Alexander Rosenbrock became involved at the site when the bones of a straight-tusked elephant (*Elaphus [Paleoloxodon] antiquus*), were discovered. Various activities contributed to rapid destruction of archaeological contexts, including the further removal of sediments for spreading on fields and looting by local residents (Thieme & Veil 1985). Rosenbrock partially excavated the skeleton and flint artefacts and subsequently discovered the wooden spear, but by the time archaeologists arrived much of the site had been destroyed and the spear had been removed from the sediments (Adam 1951; Sickenberg 1969; Thieme & Veil 1985).

Thieme & Veil (1985) reconstructed the site from a variety of sources. The archaeological record of the site shows that in addition to the remains of the elephant and the wooden spear, a number of additional important data were originally on site. In addition to the ~45 year old butchered elephant, further taxa at the site include beaver (*Castor fiber*), wolf (*Canis lupus*), bear (*Ursus* sp.), rhinoceros (*Stephanorhinus kirchbergensis*), horse (*Equus* sp., *E. hydruntinus*), cervids (*Cervus elaphus, Dama dama, Capreolus capreolus, Megaloceros giganteus*) and aurochs (*Bos primigenius*) (Sickenberg 1969; Gaudzinski-Windheuser & Roebroeks 2011). Primarily these are natural background fauna, but there are cutmarks present on bear and beaver elements (Wenzel 1998, cited in Gaudzinski-Windheuser & Roebroeks 2011). Pollen present at the site includes linden and hazel, and suggests that it can be dated to between 2000 to 3000 years after start of MIS 5e, with the environment interpreted as a densely forested lake basin (Thieme & Veil 1985; Gaudzinski-Windheuser & Roebroeks 2011).

Associated with the carcass were 27 flint artefacts, some which refitted (Thieme & Veil 1985; Gaudzinski-Windheuser & Roebroeks 2011). These artefacts were primarily concentrated around the cranium of the elephant, and it is thought that because the surrounding sediments around the body of the elephant underwent extensive destruction that there were most likely many more lithics around the body of the carcass that were lost, with further small debitage likely not retrieved. The lithic artefacts were in a fresh condition and included both unretouched and retouched flakes, some indicating prepared core technology and possibly biface thinning flakes with use-wear analysis showing butchery traces (Thieme & Veil 1985). The technology is Middle Palaeolithic in nature and due to its location around the carcass looks to have been in a primary context (Thieme & Veil 1985).

There are no drawings or photographs of the spear in situ, but letters and testimonies describing the removal of the spear from the context indicates that it was discovered amongst the ribs of the carcass (Thieme & Veil 1985). Its location and deformation into a C-shape suggests it had been pushed upwards through the abdomen, potentially causing it to bend when the animal fell on the spear (Fig. 4.10) (Thieme & Veil 1985). There was potentially a second spear at the site that may have been removed and discarded before its significance was recognised (Thieme & Veil 1985). The presence of this second spear gave rise to suggestions that the spear may have been used in the context of a pit, but ethnographic hunting, especially of large mammals such as elephants is known to have been executed socially and with multiple spears; therefore the presence of multiple spears in a hunting context, particularly of such large prey, is logical (see Chapter 6).

The spear was made from the worked trunk of a yew tree, with ca. 39 branches removed (Fig. 4.10), with possible evidence of fire hardening at the distal tip (Movius 1950; Thieme & Veil 1985; Gaudzinski 2004). Published measurements (Thieme & Veil 1985) include:

- length: 2390 mm
- diameter near the tip: 20 mm
- maximum diameter: 31 mm (located on Section 11, at the proximal end of the spear)

The spear is now in 13 fragments (note: Section 9 has developed two breaks since Thieme & Veil 1985 publication, pers. obs.) but on the basis of break morphology it is probable that in situ the spear was in six or seven fragments (Thieme & Veil 1985). It has been interpreted as a thrusting spear based on morphometrics, particularly on the basis of the maximum diameter being located at the proximal end of the spear; its location within elephant ribs supports its function as a hunting weapon (Movius 1950; Thieme 1997; Villa et al. 2009; Waguespack et al. 2009; Villa & Soriano 2010). Parts of the spear were post-depositionally deformed by sediments and form a D shape in cross section, rather than a cylindrical shape, but the distal point has not suffered any deformation (Thieme & Veil 1985). The entire surface of the spear has been worked with tools (Jacob-Friesen 1959; Thieme & Veil 1985), and working traces include scraping marks, striations and ‘chatter’ marks that may have occurred from a working edge skipping along the surface during manufacture (Jacob-Friesen 1959; Thieme & Veil 1985). The proximal edge shows polishing which has been interpreted as possibly arising from repeated contact with the ground and probably indicates that the spear had a long use-life (Thieme & Veil 1985).

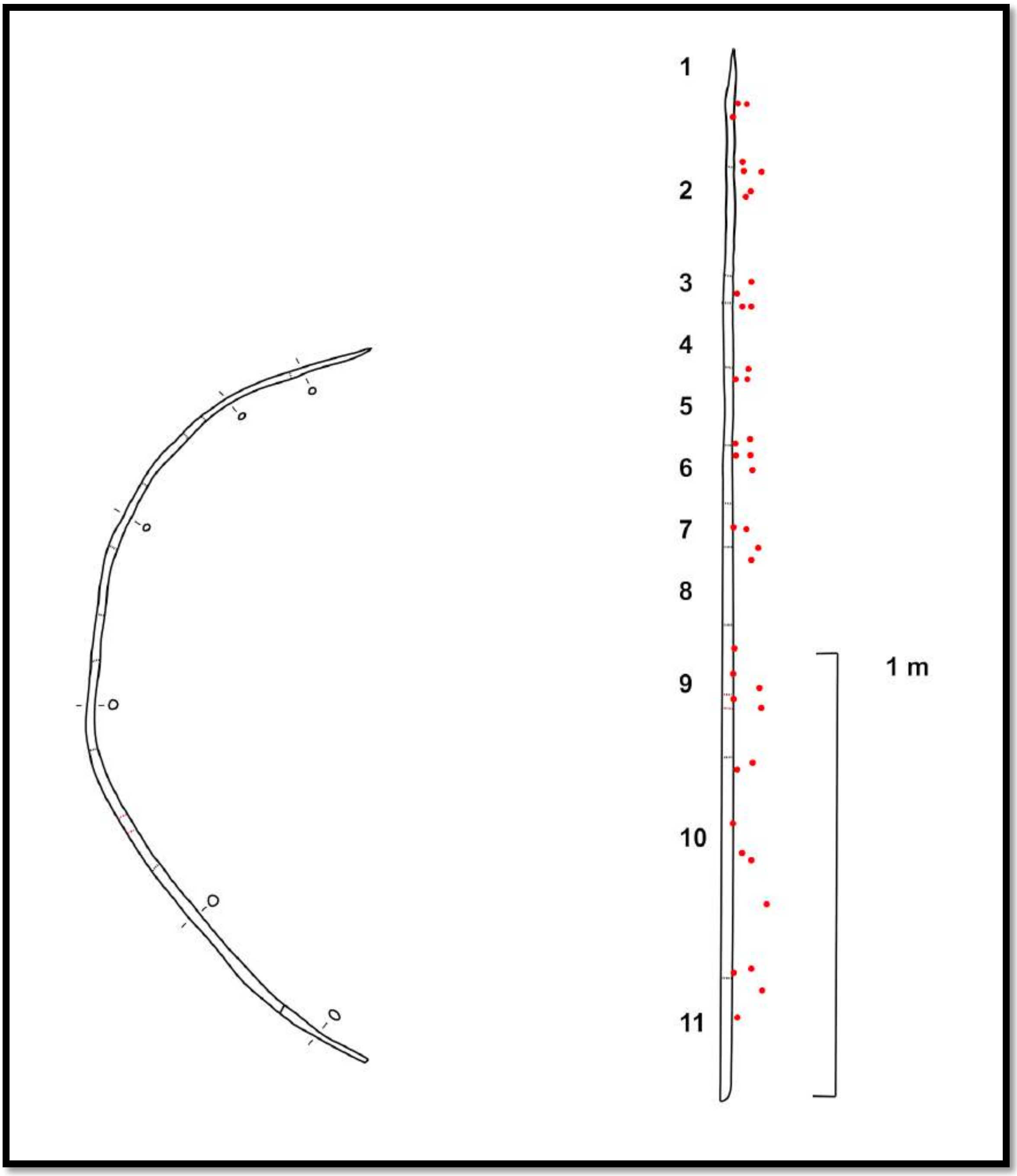


Figure 4.10. Lehringen spear. Left: curved profile as discovered in sediments, with cross-section shapes illustrated. Right: spear sections refitted to original shape. Sections labeled as per the original drawing, with recent breaks on Section 9 illustrated as red lines. Red dots indicate location of knots (Drawn by A. Milks, after Thieme & Veil 1985 Fig. 15)

The distal point is slightly asymmetrical and the pith - the soft core at the centre of a branch or trunk (Hoadley 1990(- is offset from the tip (Thieme & Veil 1985). The tip is particularly finely worked, with branch stems more fully worked down than elsewhere on the shaft. A large removal ca. 55 mm from the distal tip has been interpreted as a result of a mistake during manufacturing (Thieme & Thieme 1985). Veil (1991) describes the distal tip as asymmetrical and hypothesises that this was in order to avoid the pith being the centre of the tip of the spear. The proximal end of the spear is rounded rather than pointed, and has a splinter-like removal extending up the shaft. While the spear has been well described, including measurement data, this thesis adds to the dataset on the Lehringen spear by making a detailed analysis of tip morphometrics in order to make a direct comparison with the Clacton and Schöningen artefacts, as well as ethnographic examples.

Veil (1991) experimentally produced a replica of the Lehringen spear using lithic tools, estimating that it takes between 4.5 to 5.5 hours to make a wooden spear; however Haidle (2010) points out that this estimate regarding spear use does not include the entirety of the production sequence, including raw-material procurement and manufacture of the tools necessary to make the spears.

4.1.1.4 Monte Verde II (Chile)

Amongst the multitude of culturally modified wooden finds at the Late Pleistocene site of Monte Verde II (Chile), recently dated to ca. 14,500 cal BP (Dillehay et al. 2015), are two possible complete wooden spears consisting of refitting fragments, and a further distal fragment of a third possible spear (Dillehay 1997). The objects bear tool facets and evidence of polishing, have symmetrically pointed distal tips, and possibly bear traces of charring, especially at the distal points, which Dillehay (1997) interprets as fire-hardening. They also have possible decorative striations, impressions from some kind of binding, and a notched area which Dillehay (1997) suggests may have functioned as a possible hand grip, proposing a function as thrusting spears. The dimensions of the spears are noted in the body of the text (pp. 156-158) to be as follows:

- Spear A (3 refitting fragments, complete): ~1200 mm long, 70 mm diameter
- Spear B (2 refitting fragments, complete): ~1500 mm long, 65 mm diameter
- Spear C (1 fragment, incomplete): 140 mm long, 52 mm diameter

The possible spears look to have been broken prior to discard, with the two fragments of Spear B discovered in different locations. The proximal ends of the spears are shaped but not tapered (Fig. 4.11). Certain features of these possible spears are unusual, including the grooved section suggested to be a hand grip.

4.1.1.5 Additional Pleistocene and Holocene sites with possible wooden spears

Wooden artefacts that have been suggested to possibly represent wooden spears or fragments of wooden spears but are contested, are known from the MIS 11 site of Kärlich-Seeufer, (Germany), the MIS 7 sites of Cannstatt I, (Germany) and Torralba (Spain), and the MIS 1 site of Stellmoor (Germany) (for further information regarding these objects see Table A.1 in Appendix 1). The human modification of wooden objects from Kärlich-Seeufer has been disputed (Gaudzinski et al. 1996), while a possible spear from Canstatt I did not preserve well making assessment of the artefact difficult (Schoch et al. 2015). The site of Kalambo Falls (Zambia), probably dating to MIS 11, yielded a collection of wooden artefacts which were

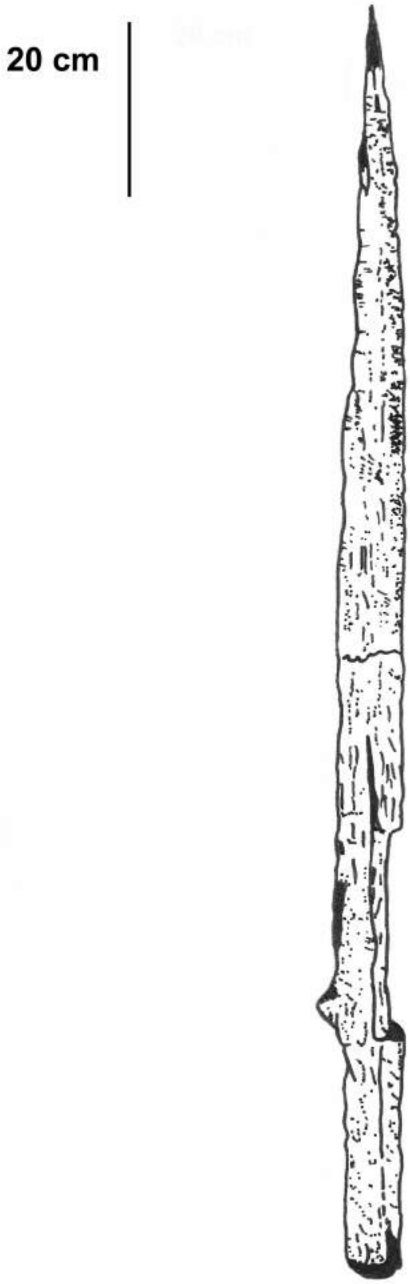


Figure 4.11. Monte Verde, Spear B (Drawn by A. Milks after Dillehay 1997, Fig. 7.29)

subjected to water action; the wooden artefacts bear traces of working and are suggested to possibly include digging sticks, a fragment of a throwing stick, and scraping tools (Clark 2001; Duller et al. 2015). Initially the collection was thought to have a possible spear fragment, but a later assessment has determined that this is unlikely (Clark 2001: Fig. 8.4, No. 2). Two of the Kalambo Falls objects illustrated (Clark 2001: Fig. 8.1 Nos 2 and 3) have possible morphologies similar to wooden spears, but their length is comparatively short so unless they represent broken portions, they are more likely to represent digging sticks or possibly throwing sticks such as that from Schöningen. In general the length and lenticular cross sections of the wooden artefacts illustrated suggests other functions are possible, but this site provides important additional evidence of woodworking in the MP.

A wooden spear comes from a terminal Pleistocene peat bog site in Southern Australia called Wyrie Swamp. The site yielded 25 wooden artefacts dating to between 11,911 ±356 to 10,071 ±167 calBP[1] and included the earliest known boomerangs, two barbed spears that are also the oldest examples of their kind, digging sticks and a 'short simple spear' suggested to be made of she-oak (*Casuarina stricta*) (Luebbers 1975; Dodson 1977; Flood 1999). Photographs of the untipped wooden spear, which measured ~1200 mm in situ, could not be located, and an attempt to study the spear while at the South Australian Museum (Adelaide) was unsuccessful. Unfortunately no diameter measurement is provided for the object, prohibiting its inclusion in the analysis. The Late Stone Age site of Gwisho B (Zambia) yielded multiple types of wooden artefacts, most made of locally available hardwoods including Rhodesian Teak (*Baikiaea plurijuga*) (Fagan et al. 1966). The wooden finds from the site include digging sticks, wooden arrowheads and a possible broken point of a wooden spear (Fagan et al. 1966; Fagan & van Noten 1971). Radiocarbon dates on three of the wooden finds from Gwisho B place the site somewhere between 3998 ±70 and 5487 ± 98 calBP. The drawing of the broken point (Fagan & van Noten 1971, Fig. 11, 7) measures around 140 mm in length and around 25 mm in diameter at its broken end but unfortunately further details of the find are not published and an assessment of the object on the basis of the illustration is difficult. However, the morphology is consistent with the distal points of wooden spears. There is an additional broken artefact (Fagan & Van Noten 1971, Fig. 11, 5) which looks like it could be a spear shaft, with a maximum diameter of 23 mm and smooth, straight sides and beveled breaks on both ends.

4.2 Materials and Methods

4.2.1 Materials

The Clacton spear point fragment and a cast (PA E 1183) were made available for study at the Natural History Museum, London (Fig. 4.12). The cast forms a significant part of the analysis due to the aforementioned shrinkage and deformation at the tip and base, affecting measurements of the original. Measurement data provided for the Clacton spear therefore relates to those taken from the cast. The cast is made of plaster-of-paris and is painted black. The length (383 mm) is 4 mm shorter than the original published length of 387 mm by Warren (1911), which is a difference of 1% and is significantly less than the present day difference of 20 mm (5% difference), with the original now measuring 367 mm (Allington-Jones 2015, and pers. obs.). This corresponds with the length measurement of 383 mm of the 1911 cast published in Oakley et al. (1977). Although the date of the cast studied was uncertain, with the same

[1] Calibration calculated using CalPal (http://www.calpal-online.de) on the basis of published 14C dates in Luebbers 1975

measurements it is most likely to be the first 1911 cast, and predates measurements taken in the 1970s (Allington-Jones 2015, Table 1).

The collection of Schöningen spears were not available for direct study for curatorial reasons. Therefore, 3D spatial model of scans using laser scanning of the distal points of Spears I, II, V, VI and VII were made available were made available by the Lower Saxony State Office of Cultural Heritage (Niedersächisches Landesamt für Denkmalpflege), with the aim of making the first assessment here of the morphometrics of the distal parts of spears to assess how they compare with one another as a group, as well as with other Pleistocene and ethnographic examples. The tip of Spear III is fragmented, IV is missing the tip, and fragments of Spears VIII, IX and X had not been scanned at the time of study. It was agreed to focus on the distal points of the spears in order to facilitate the investigation of lethality in terms of penetration, as well as a comparison with the broken Clacton spear point. The original Lehringen spear also formed part of the morphometric analysis, focusing on the distal tip as detailed morphometrics for this object have already been published (Thieme & Veil 1985, Table 2). Published measurement data were also included in the analysis. Permission was granted to study the spear from Wyrie Swamp, but unfortunately upon arrival at the South Australian Museum (Adelaide), the object could not be located and therefore neither a morphometric study nor analysis of the marks could be made. As so little information has been published for this artefact it was not included in the analysis.

Figure 4.12. The original of the Clacton spear point (left) next to the cast studied (right), showing the shrinkage (Photo by A. Milks)

4.2.2 Methods

Diameter measurements (mm) were taken for a series of six locations, at 10, 50, 100, 150, 200, and 250 mm from the distal point. This facilitates an evaluation of tip design of the front 250 mm of each spear, and extends beyond the critical DoP of >150 mm for lethality discussed in Chapter 3 (3.2.4.2). For the Clacton and Lehringen spears, measurements were taken using a paper tape calibrated to a forensic scale. These measurements were taken for the circumference, from which diameter was calculated (Equation 4.1) allowing for variations in the diameter at any given point as the objects are not perfectly circular in cross section. Measurements of the cast studied correspond well with those published for the 1911 cast (Oakley et al. 1977), with any variation limited to no more than 1 mm. Length measurements are not included for the Clacton spear in the comparative analysis because the object is incomplete.

Equation 4.1. Diameter

$d = C/ \pi$

where d = diameter and C = circumference

Opening angle (Fig. 4.13) was calculated (Equation 4.2) for the front 100 mm of each example to facilitate comparison with experimental results of spear point drop tests presented in Chapter 8 (8.3). Measurements were taken from the scans of the Schöningen distal ends of spears using the 'compute planar section' and measurement tools in MeshLab (Cignoni et al. 2008). Planar sections were created at each designated location from the tip (Fig. 4.14 and 4.15). Due to deformation of the spears from sediment pressure, four measurements were taken (Fig. 4.16) and means of these were used. If a particular location on a spear was clearly damaged, removing a portion of the original surface, these measurements were excluded from the analysis. As some of the Schöningen spear fragments have been postdepositionally longitudinally curved, the planar sections may slightly vary in location from the original distance from the distal end - in other words, they may be slightly closer to the distal end than the original, but differences are in mm and should not have a significant impact on diameter measurements. As an example, Spear II measured in a straight line is 226.4 cm, but the measurement with equalised photographs is 228.8 cm, a difference of 1% in total length of the fragment (U. Böhner, pers. comm.) which also explains the differences in published length measurements for Spears I, II and III (Thieme 1997, Table 1 vs. Schoch et al. 2015, Table 1).

Equation 4.2. Opening Angle (Fig. 4.13)

First solve for slant height:

$s = \sqrt{h^2 + r^2}$

then solve for opening angle:

$a = 2 * \arcsin (r/s)$

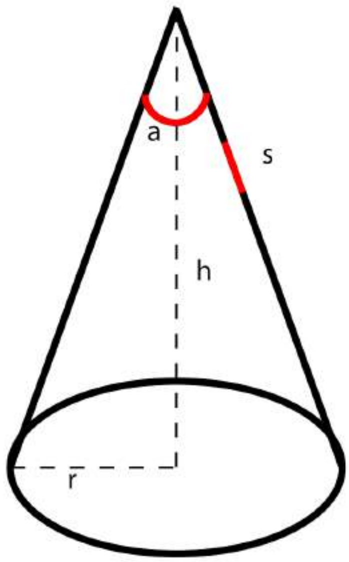


Figure 4.13. Schematic representation of a cone showing location of radius (r), height (h), slant height (s), and opening angle (a)

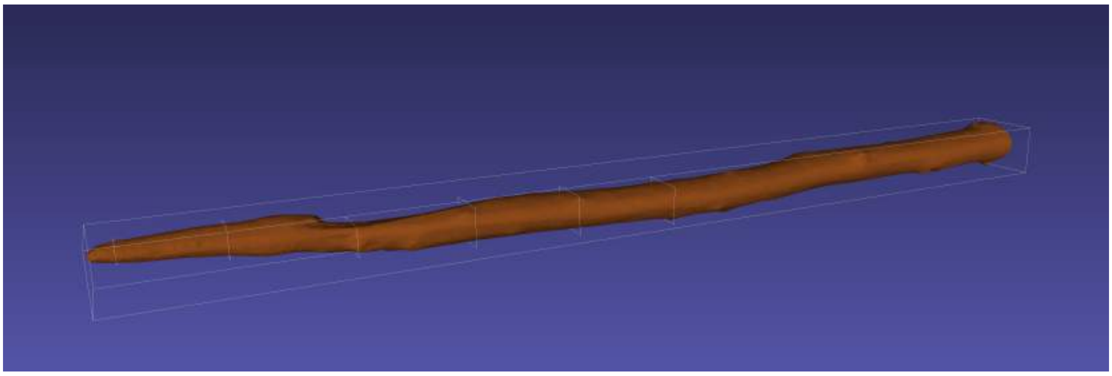


Figure 4.14. Example of scan of distal section of spear, with the planar sections represented as small white boxes within the bounding box

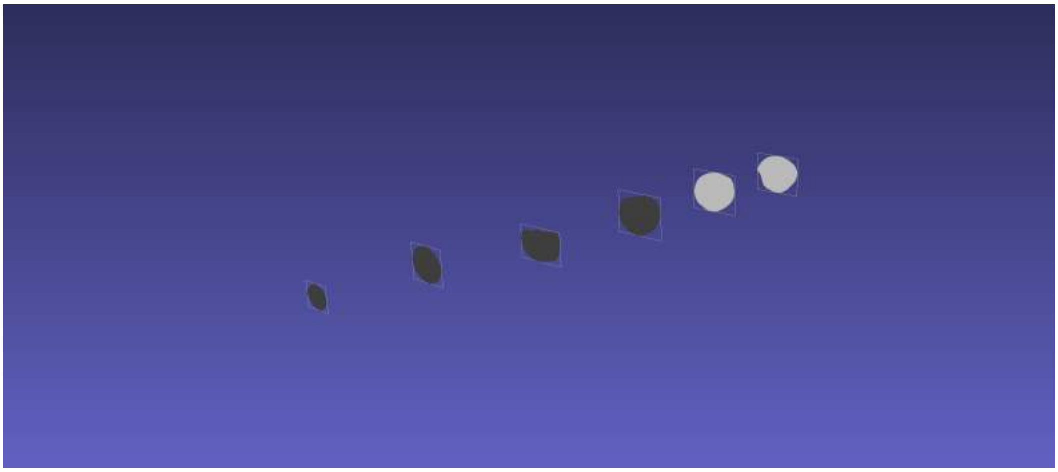


Figure 4.15. Example of the planar sections from a spear shaft

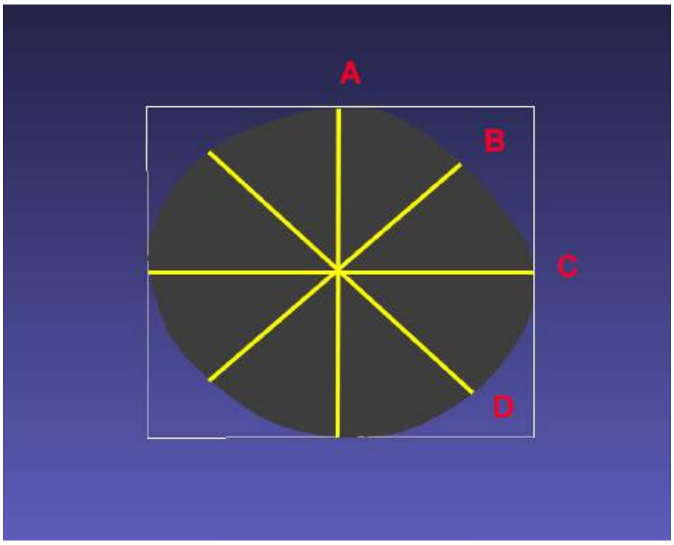


Figure 4.16. Example of a planar section. Yellow lines represent the four diameter measurements taken, from which the mean was used as the diameter

Where available, additional published and unpublished measurement data are included to facilitate comparative analysis (Thieme & Veil 1985, Table 2; Thieme 1997, Table 1). This includes the length and maximum diameter of the Lehringen spear, and lengths, maximum diameters and any locations of maximum diameters presented for the Schöningen spears. Additional measurement data, including lengths determined with the equalised photographs already mentioned, as well as maximum diameters were provided by Prof. Terberger for use in this thesis.

Images and descriptions of a selection of marks and traces on the Clacton spear point and the Lehringen spear (Sections 1, 9, 10 and 11) were also made during study (following terminology in Appendix 1). Macro-images were captured using a digital camera, and microscopic images were made with a Dino-Lite Pro HR (AM7000/AD7000) digital microscope with an internal camera. Where relevant to the shaping of the distal tip and therefore design, these marks are discussed and presented. Additional descriptions and images of traces are briefly presented in Appendix 1. Images of the Schöningen spears presented were produced using the laser scans in MeshLab.

4.3 Results

4.3.1 Clacton Spear

As mentioned in section 4.2.1, the cast measured 383 mm. An area of knots is located between 230 and 240 mm from the distal point, with the location of the maximum diameter of 38 mm at 237 mm. This area has a larger diameter than the shaft on either side due to knots not being worked down completely (Table 4.1). Opening angle of the front 100 mm of the Clacton spear is 15 degrees (Table. 4.1).

Table 4.1. Diameter measurements (mm) and opening angle (degrees) of the Clacton spear point.

DIA at 10 mm	DIA at 50 mm	DIA at 100 mm	DIA at 150 mm	DIA at 200 mm	DIA at 250 mm	Max DIA	Opening Angle
11	16	26	29	34	36	38	15

As described previously (Oakley et al. 1977; McNabb 1989) the taper of the Clacton spear is most pronounced over the first 100 mm from the tip, but it continues to widen until it reaches a series of knots around 230 mm (cast measurements) from the distal point. This suggests that the manufacturer of the point was conscious that the distal section be carefully shaped. There appears to be a technological choice to locate the tip beyond the critical measurement of between 150 mm and 200 mm, crafting the tip to fall forward of the series of knots (Figs. 4.18, 4.19). Relatively wide (around 0.5 mm) and overlapping tool facets with even sides ending in a jam can be seen around these knots (Figs. 4.19, 4.20), with a dense concentration of tool facets not seen elsewhere on the artefact. Running obliquely over the surface of the wide facets are thin parallel striations which are regularly and evenly spaced. These striations are similar to those seen closer to the distal point, and may represent a second phase of working down the spear with a different tool or edge type. Microscopically the striations, which are different to the wide tool scraping facets (Fig. 4.21), were u-shaped. The ‘rifling marks’ mentioned elsewhere (Smith 2010) were not observed.

Figure 4.17. The Clacton spear point (Photo by A. Milks)

Figure 4.18. The Clacton spear point with red arrows indicating the area of knots

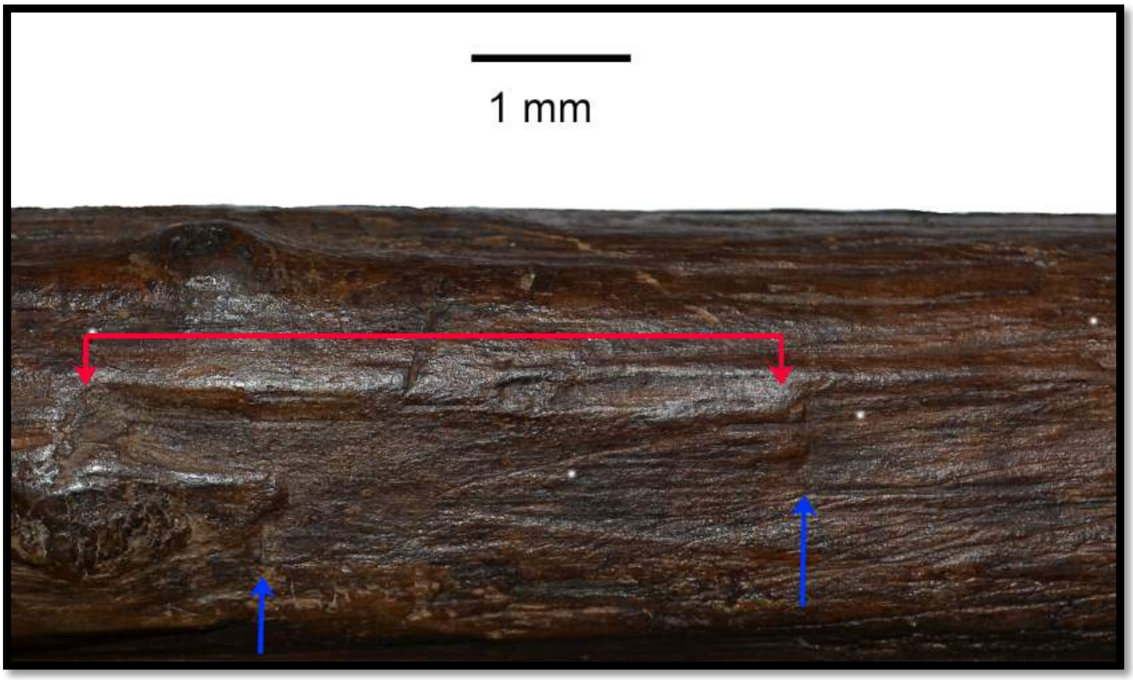


Figure 4.19. Tool facets located near group of knots ca. 210-240 mm from distal point. Red bracket indicates a single facet ending at a jam on the left side. Blue arrows show jams, with facets partially obscured by overlying striations running obliquely over the wide facets

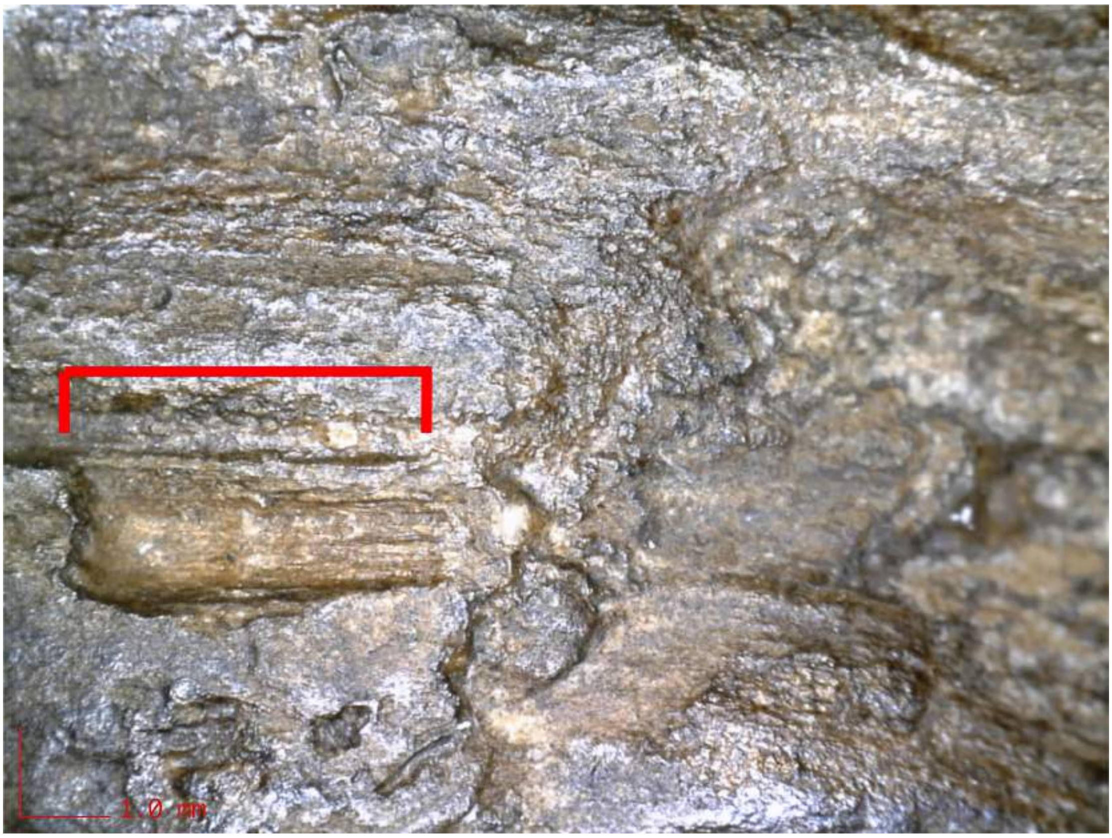


Figure 4.20. Tool facet located near group of knots ca. 210-240 mm from distal point, at 50x magnification

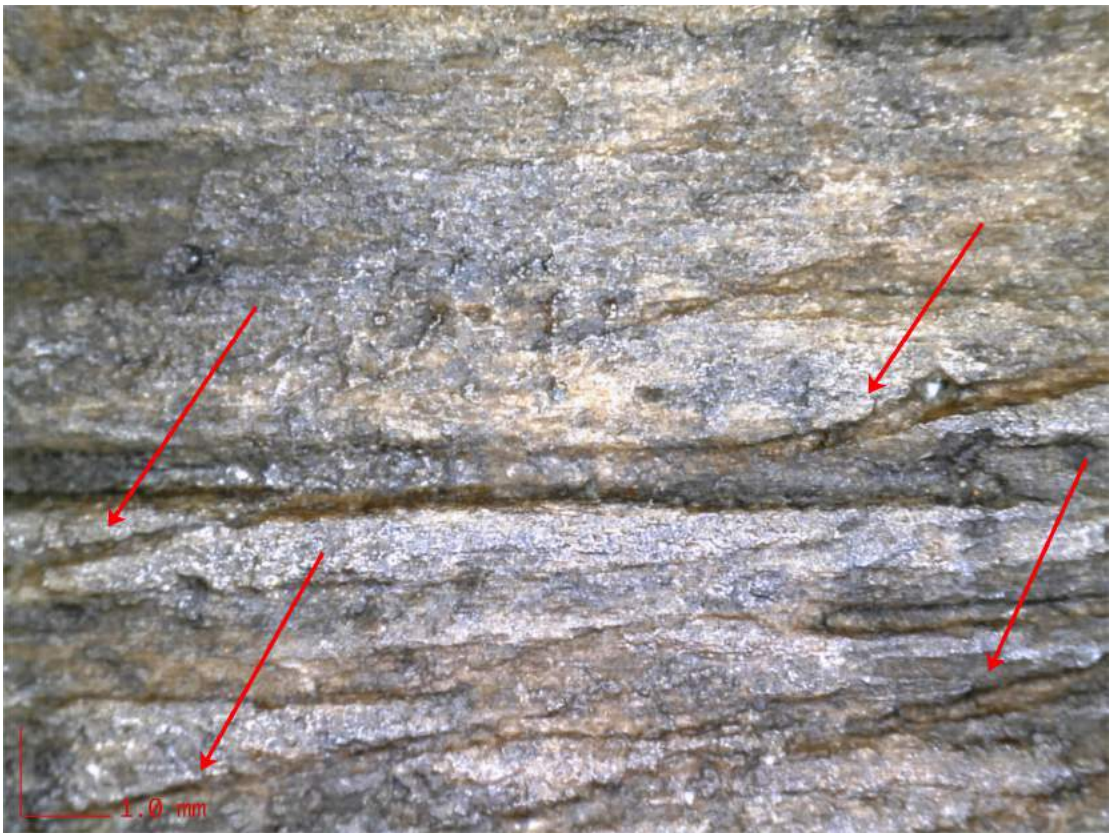


Figure 4.21. Parallel striations on the Clacton spear point, indicated by red arrows, running obliquely to the grain of the wood, at 50x magnification

Figure 4.22. Chatter marks on the shaft of the Clacton spear points, indicated by the red bracket

With the front 200 mm the most significant for penetration, it seems clear that a technological choice was made to work the spear point in such a way that the series of knots could be located behind this critical distance. The knots were not removed, but were heavily worked down with deep tool marks, clearly indicated an effort to smooth this area to some extent. A series of six chatter marks, mentioned elsewhere (Oakley et al. 1977) located between 119 and 140 mm from the distal tip are spaced between 2 and 3 mm apart (Fig. 4.22). These marks are next to a small knot in the wood, again indicating clear tool marks focusing around working out the knots on the surface.

Personal observation and the X-radiographs as reproduced in Allington-Jones (2015) show that the Clacton spear was not worked in such a way as to decentralise the tip, as can be seen on the Schöningen and Lehringen spears (Veil 1991; Schoch et al. 2015). Oakley et al. (1977, p.15) mention a longitudinal split visible at the tip of the spear (Fig. 4.23) but do not discuss the cause of this. The split is also visible on the cast, showing that it is not related to recent deformation of the artefact (Fig. 4.24). It is similar to splits that occured during experimental use in this thesis (Chapter 8) both as thrusting and throwing spears (Figs. A.1.13, A.1.20 in Appendix 1). The split therefore could have been initiated during use. Parallel striations visible at the tip could be from manufacture or potentially could have also occurred during use or could be a result of taphonomic factors. Although the tip damage is not definitive evidence of use, combined with the break the assessment here agrees with Oakley et al.'s (1977) conclusion that the artefact looks to bear evidence of use.

It is difficult to determine the cause of the break on the Clacton spear point with any certainty because experimental evidence is limited. Spear shafts broke during use in all four experiments presented in Chapters 7 and 8 (breaks are illustrated in Figs. A.1.4, A.1.5, A.1.6 and A.1.10 in Appendix 1). However, the wood used (spruce) in experimental use varies from yew in density and elasticity, and therefore inferences of the break to the Clacton spear point are limited. Experimental spear use with yew wood may provide better analogies for the forces and/or kinetic energy at impact necessary to break yew in such a way. Nevertheless, breakage during use remains a viable interpretation. Overall the Clacton artefact fits well with an assignment as a sharp-force weapon point, showing particular attention to shaping the front 150 to 200 mm of the point, which is critical for effective DoP as a hunting weapon. Particular effort was placed in working down a series of knots, and the placement of the distal point >200 mm suggests an awareness of how critical the penetrating section of the front of a wooden spear is.

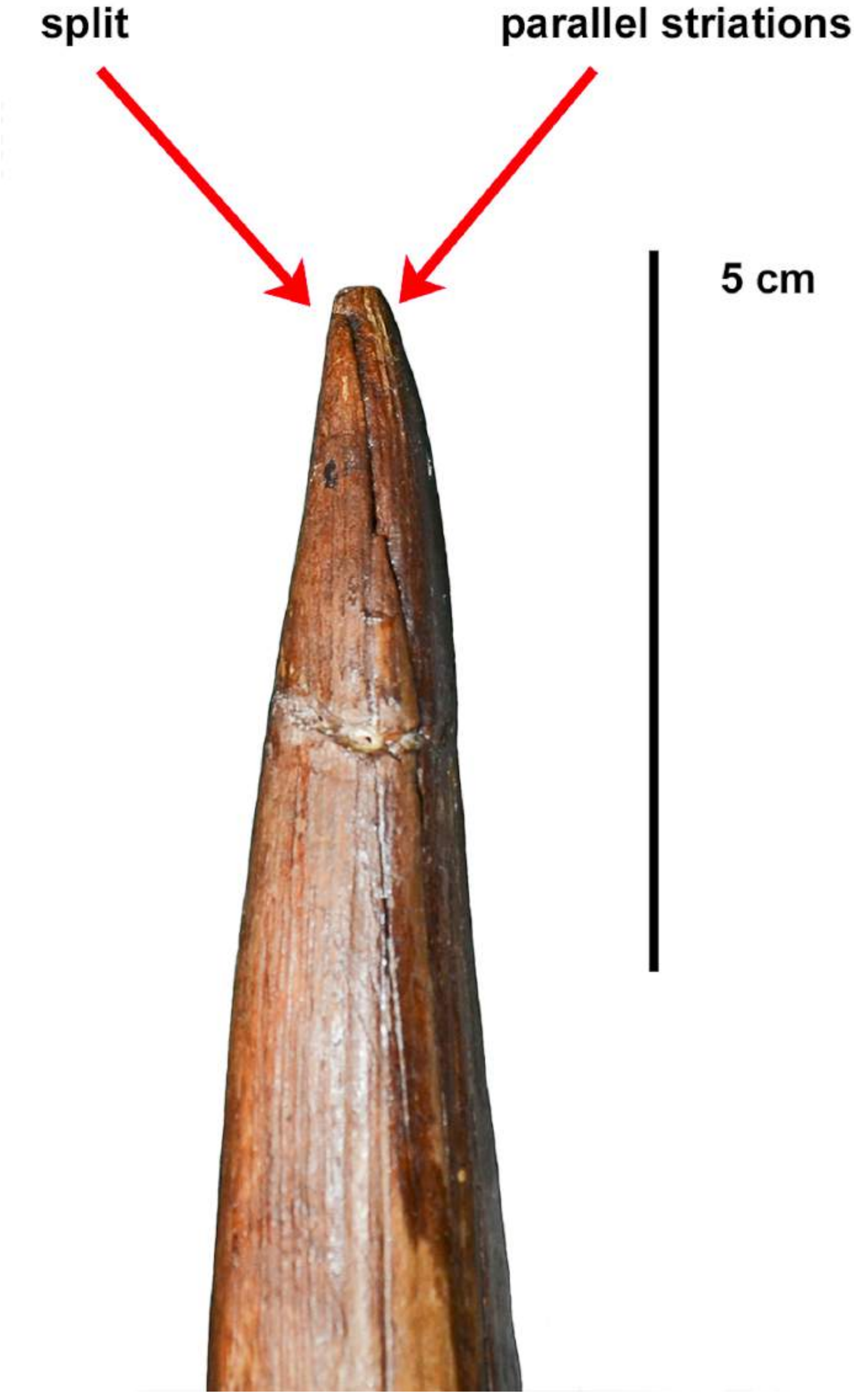


Figure 4.23. Detail of the tip of the Clacton spear point. Left arrow points to the split, right arrow points to the parallel grooves

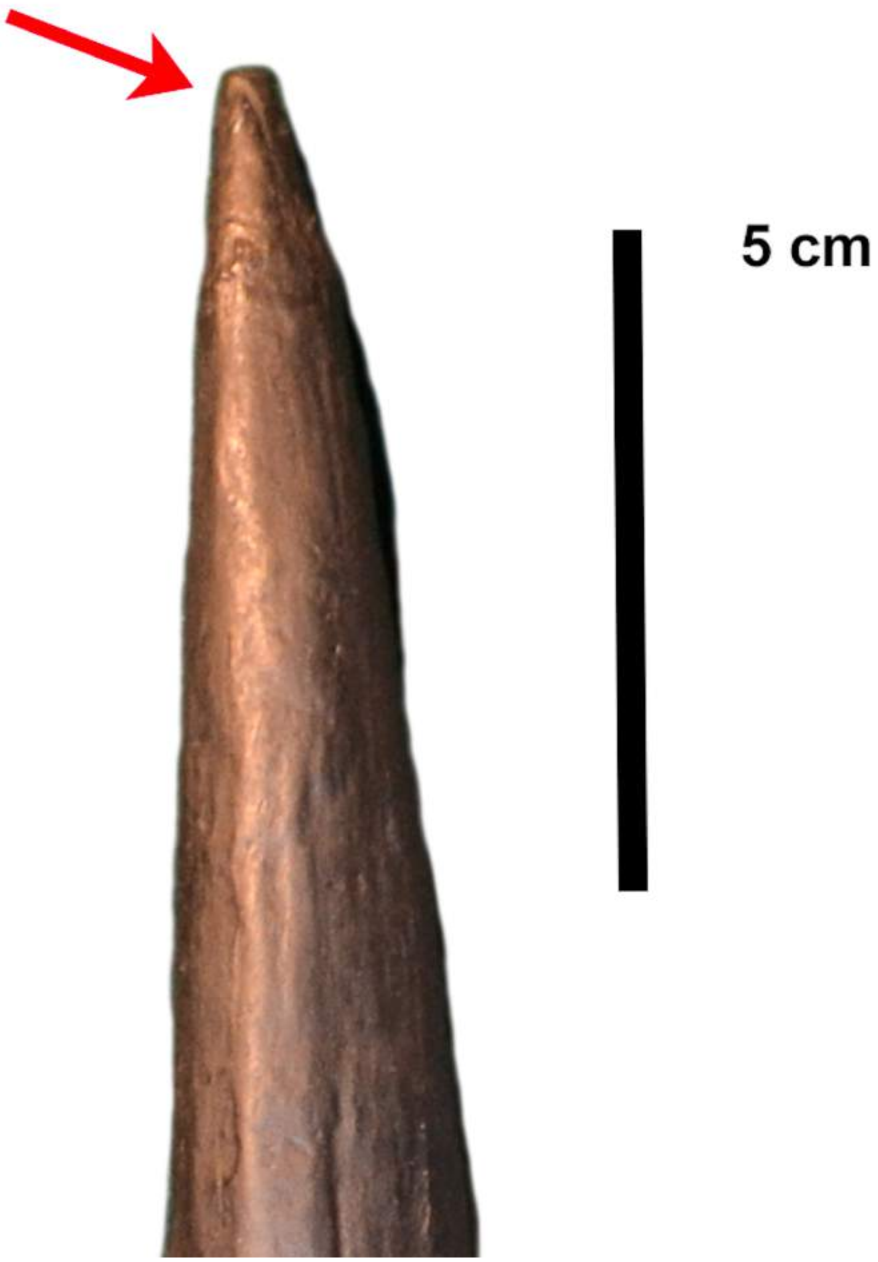


Figure 4.24. Detail of the cast of the Clacton spear point, showing that the split was present at the time of the cast

4.3.2 Schöningen spears

Diameters at each distance along the sample of spears studied (n = 5, Figs. 4.25 through 4.29) show a consistency, particularly when focusing on the measurements at 10, 50 and 100 mm (Table 4.2). Spear VI, suggested to be a thrusting spear (Schoch et al. 2015) has similar diameter measurements at 10 and 50 mm, 100, 150 and 250, to the other spears in the sample, and only at the 200 mm measurement does it have the largest diameter; this demonstrates that although Spear VI has the largest length of the sample, the distal point of the spear was standardised similar to the other spears for penetration purposes. The opening angles at 100 mm ranged from 9 to 10 degrees. Regardless of delivery method (thrusting or throwing), the design of the front of a spear is significant for penetration, and the sample studied here underpins that hominins were aware of this and making a technological choice to shape the distal points of the spears to a particular standard. Spear I, with the largest maximum diameter, has diameter measurements at 150 and 200 mm that fit within the sample, again showing that the distal tips of the Schöningen spears were standardised. Spear II has the narrowest taper overall. Tapers are further compared with the Clacton and Lehringen spears in section 4.4.

Table 4.2. Measurements of the sample of Schöningen spears made available for study

Spear	Length*	Max* DIA	Location Max DIA (%) †	DIA at 10 mm	DIA at 50 mm	DIA at 100 mm	DIA at 150 mm	DIA at 200 mm	DIA at 250 mm	Opening Angle (degrees)
I	2210	47	31	9	14	18	20	21	21	10
II	2288	37	35	6	14	15	16	19	20	9
III	1841	29	16	X	X	X	X	X	X	X
IV	1185	31	X	X	X	X	X	X	X	X
V	2060	30	X	7	13	18	23	26	26	10
VI	2531	40	X	8	13	17	20	28	25	9
VII	2028	30	X	6	13	16	20	22	25	9
VIII	583	26	X	X	X	X	X	X	X	X
IX	256	22x14	X	X	X	X	X	X	X	X
X	1415	24	X	X	X	X	X	X	X	X

*** Indicates Data that were kindly shared by Prof. Terberger for use in this thesis. X = not studied, unpublished or NA. † Indicates data calculated based on published data (Thieme 1997). Blue fill = incomplete: III tip fragmented, IV - tip missing, VII base missing, VIII only tip is present. Orange fill = spear nearly complete or complete. Green fill = damaged area.**

Table 4.3 Descriptive statistics of length and diameter measurements of the sample of Schöningen spears studied

	Length	Max DIA	DIA at 10	DIA at 50	DIA at 100	DIA at 150	DIA at 200	DIA at 250
mean (mm)	2186	35.5	7	13	17	20	23	23
SD (mm)	257.3	7.2	1.3	.5	1.3	2.9	3.7	2.7
CV (%)	12	20	18	4	8	15	16	12
n =	5	6	5	5	4	4	5	5

Table 4.3 shows that all of the distal diameter measurements have lower CV values than the maximum diameter, supporting attention to the morphology of the distal point, and that this was considered more important than the maximum diameter of the shaft, the latter having an impact on overall mass of a spear (further discussed in section 6.7). Lengths are also standardised, with a CV of 12%.

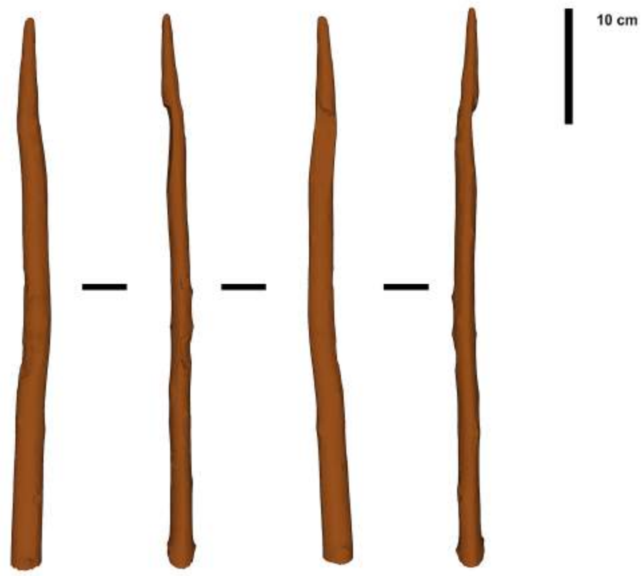


Figure 4.25. Distal 494 mm of Schöningen Spear I

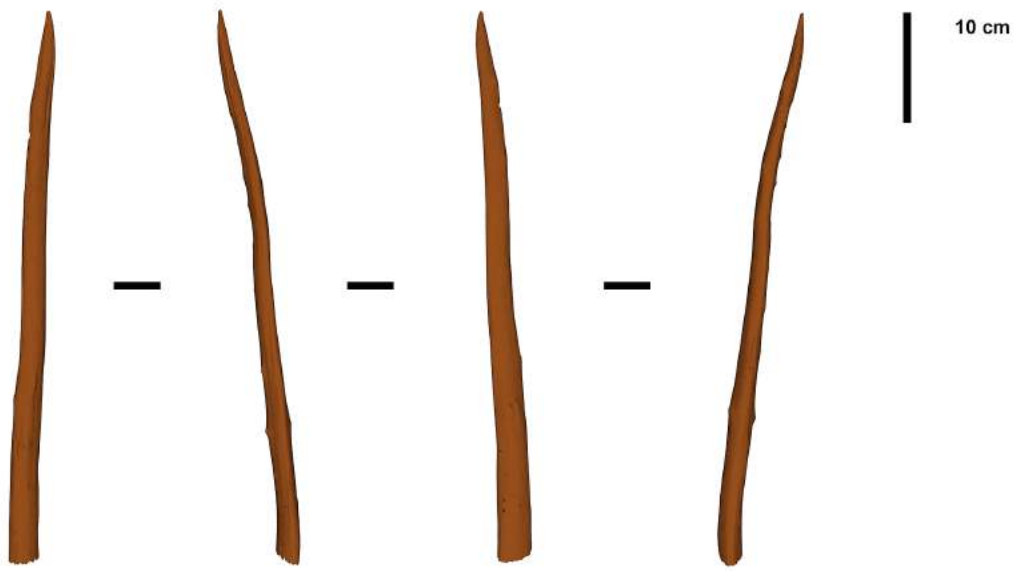


Figure 4.26. Distal 559 mm of Schöningen Spear II

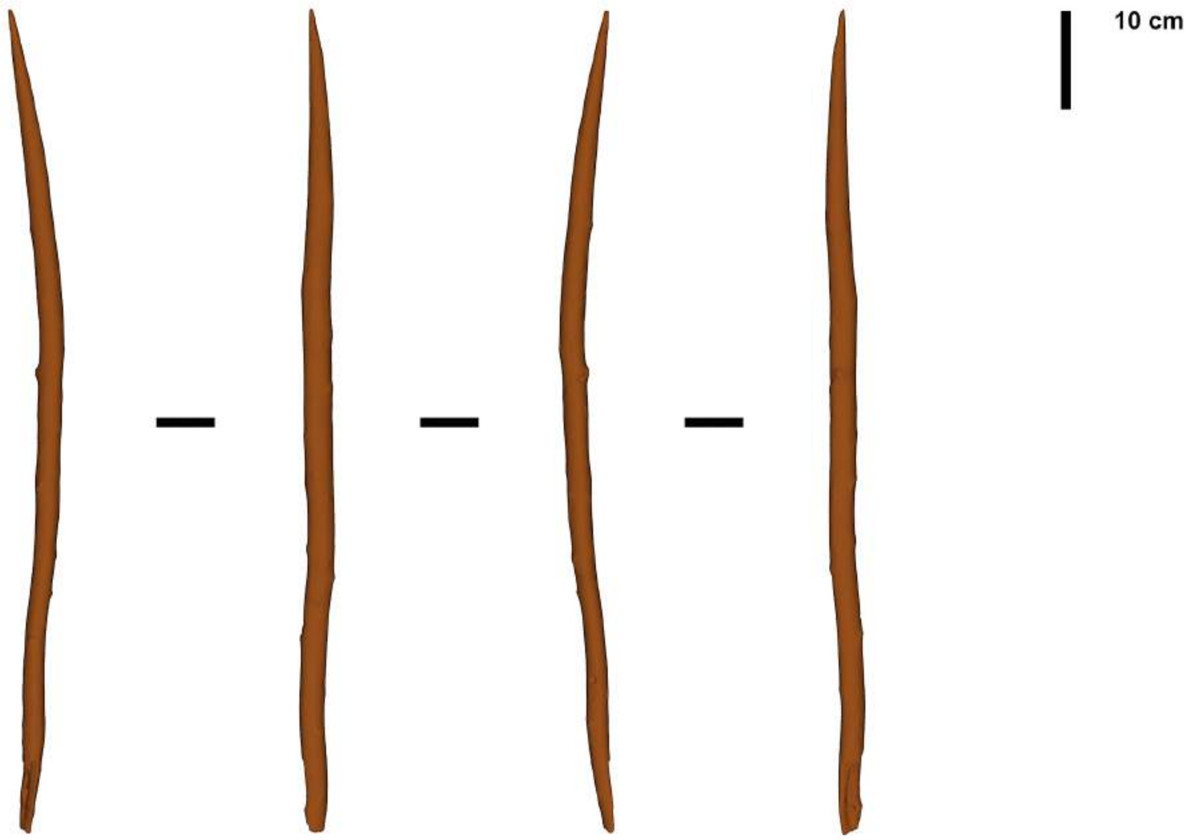


Figure 4.27. Distal 869 mm of Schöningen Spear V

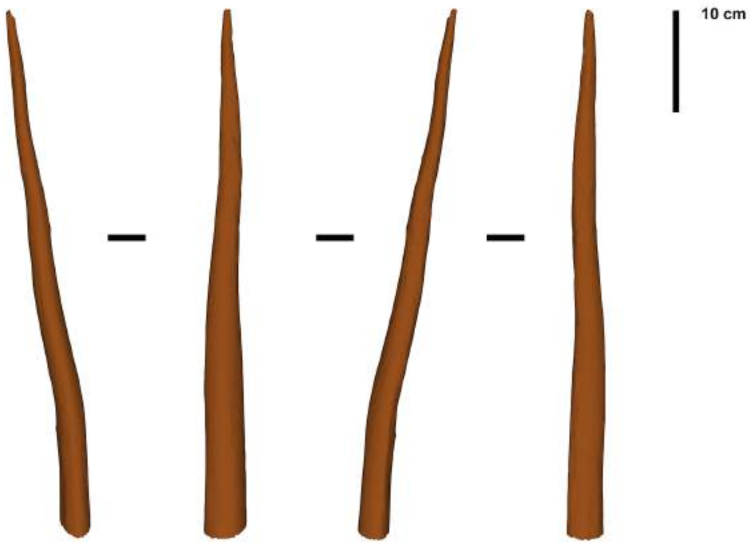


Figure 4.28. Distal 528 mm of Schöningen Spear VI ('Lance')

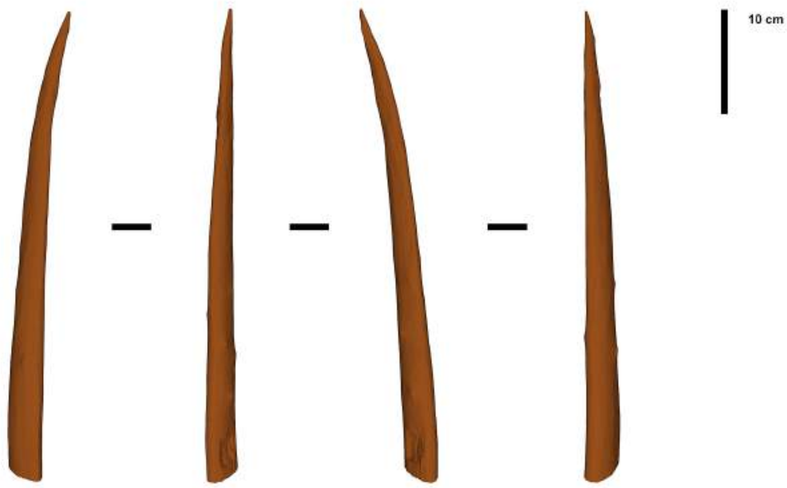


Figure 4.29. Distal 477 of Schöningen Spear VII

Figure 4.30. Left: distal tip of Schöningen Spear V showing beveled tip damage. Right: distal tip of Schöningen Spear VI showing beveled tip damage

Tip damage is evident on at least two of the Schöningen spear scans. Approximately 6 mm of the distal part of Spear V is damaged, with wood removed obliquely to the taper (Fig. 4.31 left) while the damage on Spear VI extends ca. 8 mm (Fig. 4.31 right). The tip damage on both Spears V and VI looks similar to beveled breaks on osseous weapon points (e.g. Bradfield & Lombard 2011; Pétillon et al. 2016) and breaks produced during experimental use as throwing (but not thrusting) spears presented in Chapters 7 and 8 (Figs. A.1.7, A.1.14, A.1.15, and A.1.17 in Appendix 1). Spears V and VI may bear damage from use. An additional maximum of ca. 15 mm can be estimated for the tip of Spear V and an additional maximum of ca. 35 mm can be estimated for the tip of Spear VI, assuming the rate of taper remains constant (Fig. 31).

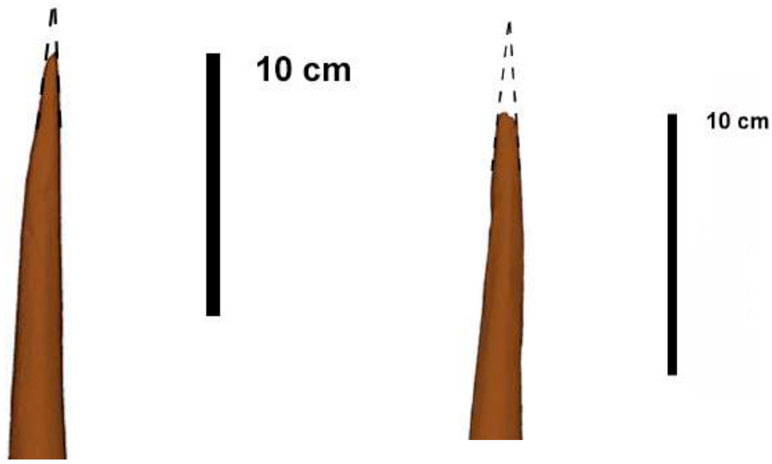


Figure 4.31. Distal tips of Schöningen spears (Left: Spear V; Right: Spear VI) with dotted lines indicating possible original morphology of the tip

4.3.3 Lehringen spear

The distal point of the Lehringen spear is thin and carefully worked (Table 4.4, Fig. 4.32). As has been previously noted (Thieme & Veil 1985) and can be seen in Fig. 4.33, the point is off centre from the soft pith. There are two knots 100 mm from the distal end, which inflate the diameter at this location, and a further knot at 190 mm. These knots are not worked down completely smoothly, and form small raised areas on the shaft, with the knots a particular focus of tool marks along the entire spear (Fig. 4.35) (Thieme & Veil 1985). There is a flatly shaped section resulting from a large removal which has been interpreted as either a manufacturing mistake or intentional manufacturing feature (Thieme & Veil 1985). However, gouging along the surface of wooden spear tips can also occur during use and should also be considered a possibility (e.g. see Appendix 1, Figs. A.1.18 and A.1.19), and indeed given the flat nature of this area, this could reflect curation in the form of smoothing after previous damage from use. Given the polished nature of the proximal end of the spear (Thieme & Veil 1985; pers. obs.), the spear looks to have had an extended use life prior to discard, and curation would be likely. The distal section is slightly warped, which probably occurred postdepositionally. Although it bears tool marks from shaping, the proximal end is not tapered, and localised polishing suggests that this was its morphology during use and prior to deposition rather than reflecting a break during its final use or a postdepositional break (Fig. 4.34) (Thieme & Veil 1985; Veil 1991).

Table 4.4. Diameter measurements and opening angle of the Lehringen spear

DIA at 10 mm	DIA at 50 mm	DIA at 100 mm	DIA at 150 mm	DIA at 200 mm	DIA at 250 mm	Max DIA	Opening Angle (degrees)
8	12	19	18	17	19	31	11

Figure 4.32. Two views of the distal part (section 1) of Lehringen spear

Figure 4.33. Close up of distal end of spear showing medullary canal exposed at tip

Figure 4.34. Proximal end of spear (Section 11)

Figure 4.35. Tool marks around a knot on the distal point (Section 1)

4.3.4 Comparative analysis of the sample of archaeological spears

Table 4.5 presents the measurements for the archaeological sample of wooden spears studied. Generally speaking, the measurements show that the Clacton spear fragment is robust in its diameter comparison with the rest of the sample, while Schöningen spear VI is the longest complete/nearly complete spear in the sample. Comparing length with maximum diameter, there appears to be a relatively weak relationship for the sample of archaeological spears. In contrast with length, neither Schöningen Spear VI nor Lehringen have the largest maximum diameters, with Schöningen Spear I, and the two Monte Verde spears exceeding these (Fig. 4.36). The two spears from Monte Verde stand out for being extremely short and thick in comparison with the rest of the sample. The Clacton spear fragment also has a relatively large maximum diameter of 38 mm, and the length of the fragment is likely to represent only a small portion of the original complete spear. Therefore the maximum diameter on the Clacton fragment is unlikely to represent the original maximum diameter, with the diameter likely to increase along the shaft.

Table 4.5. Summary of metrics sample of archaeological spears

Spear	Length	Max DIA	Location max DIA (%)	DIA at 10 mm	DIA at 50 mm	DIA at 100 mm	DIA at 150 mm	DIA at 200 mm	DIA at 250 mm	Opening Angle (degrees)
Clacton	383	38	X	11	16	26	29	34	36	15
Sch. I	2210*	47*	31†	9	14	18	20	21	21	10
Sch. II	2288*	37*	35†	6	14	15	16	19	20	9
Sch. III	1841*	29*	16†	X	X	X	X	X	X	X
Sch. IV	1185*	31*	X	X	X	X	X	X	X	X
Sch. V	2060*	30*	X	7	13	18	23	26	26	10
Sch. VI	2531*	40*	X	8	13	17	20	28	25	9
Sch. VII	2028*	30*	X	6	13	16	20	22	25	9
Sch. VIII	583*	26*	X	X	X	X	X	X	X	X
Sch. IX	256*	22x14*	X	X	X	X	X	X	X	X
Sch. X	1415*	24*	X	X	X	X	X	X	X	X
Lehringen	2385 †	31 †	~88†	8	12	19	18	17	19	11
MV Spear A	1200 †	70 †	X	X	X	X	X	X	X	X
MV Spear B	1500 †	65 †	X	X	X	X	X	X	X	X

*** Indicates Data that were kindly shared by Prof. Terberger for use in this thesis. X = not studied, unpublished or NA. † Indicates published data, or data calculated based on published data (Thieme & Veil 1985; Thieme 1997; Dillehay 1997). Blue fill = incomplete due to damage. Orange fill = spear nearly complete or complete. Green fill = damaged area. MV=Monte Verde, Sch.=Schöningen**

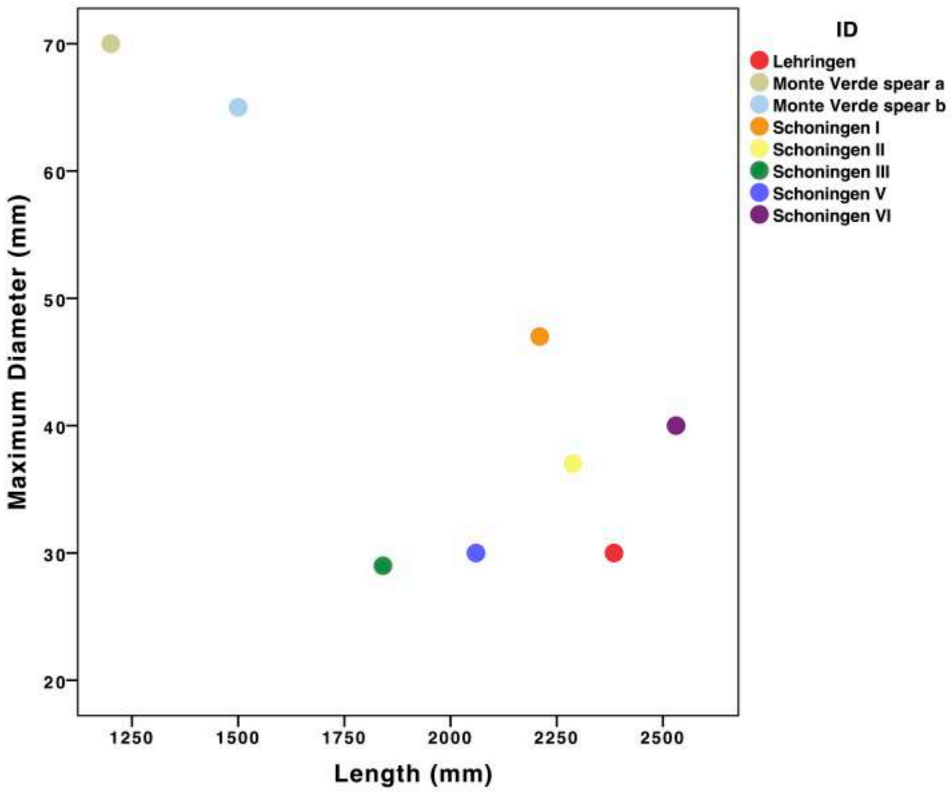


Figure 4.36. Scatterplot comparing length and maximum diameter of the archaeological spears

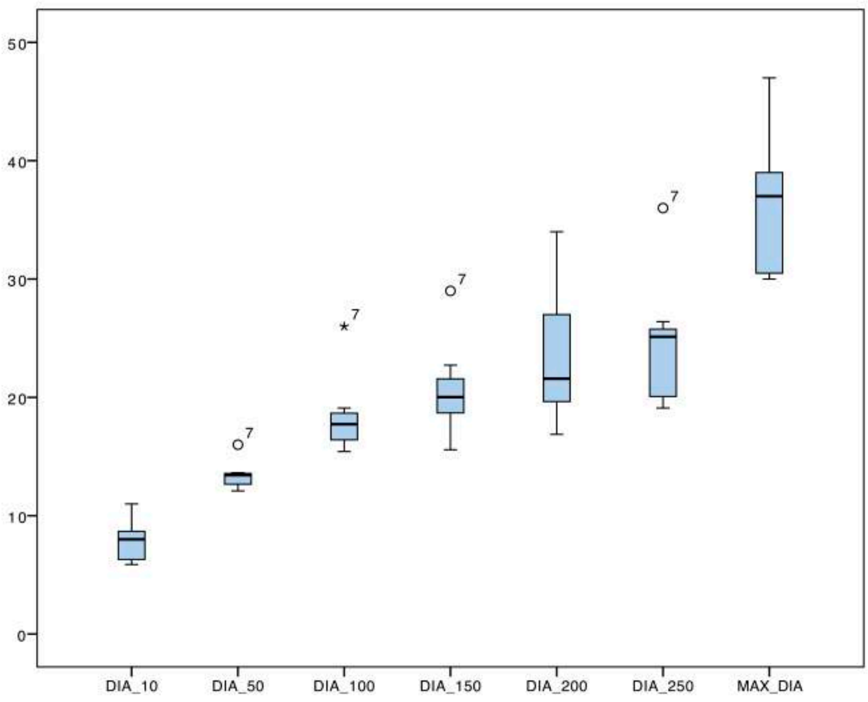


Figure 4.37. Boxplot of diameter measurements of the archaeological sample

The diameter measurements along the distal points (Fig. 4.37) increase at each location, with larger increases at the beginning of tapers. In all cases, the Clacton spear point fragment is the outlier, with notably robust measurements, though the Monte Verde spears may exceed those on the Clacton fragment. The Lehringen spear is gracile in comparison with the sample in all measurements except at 100 mm, where the knots increase the diameter. What stands out when comparing the distal points of spears as a group (Fig. 4.38) is not only the particular robusticity of the Clacton spear point, but also that there appears to be a decrease in diameters over time with Lehringen being the thinnest of the spears. However, the Monte Verde examples appear exceptionally short and robust in comparison with the Middle and early Late Pleistocene examples. The Wyrie Swamp spear was also published as measuring ca. 1200 mm, similar in length to the Monte Verde spears, though the diameter is unknown.

Length does not appear to correlate well with diameter measurements of the distal ends (Figs. 4.39 and 4.40), although with such a small sample size this is inconclusive. There is also a poor correlation between maximum diameters and diameters at the distal points (Figs. 4.41 and 4.42).

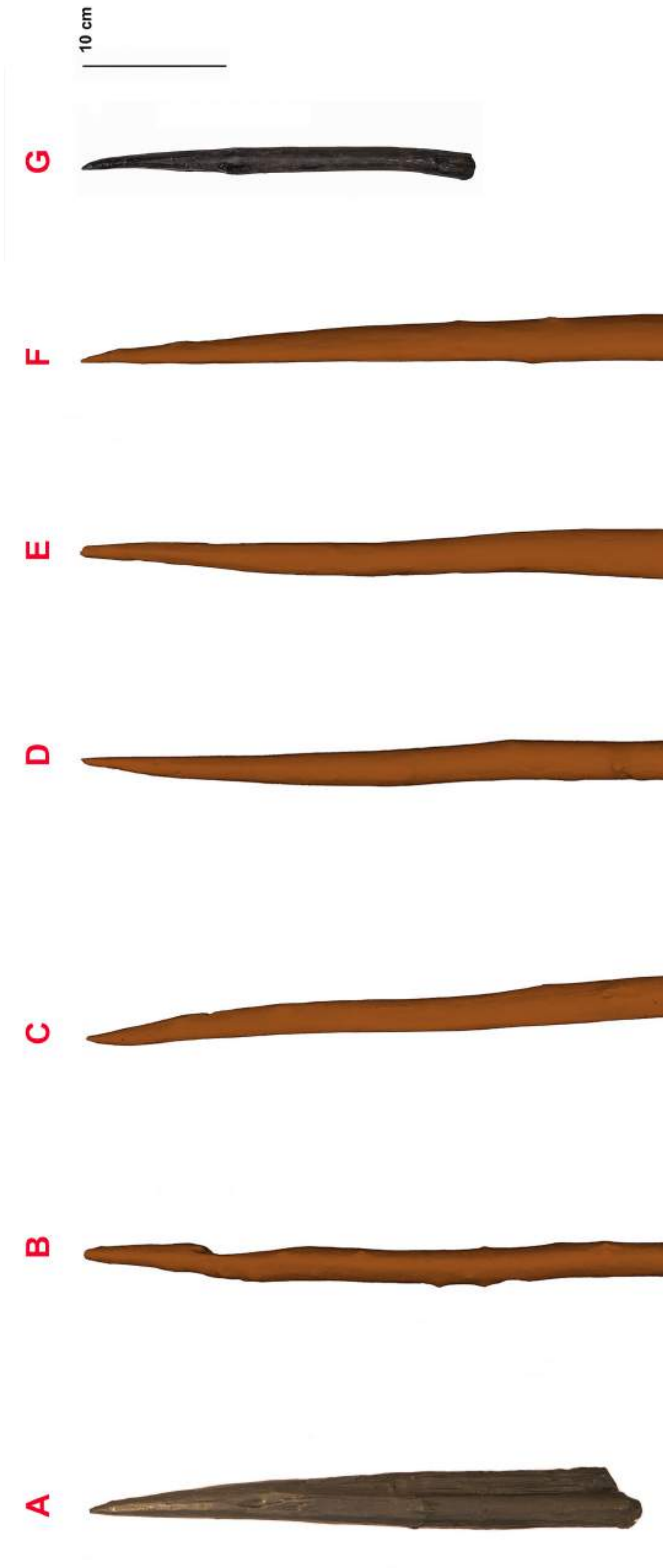


Figure 4.38. Distal tips of archaeological spears. A: Clacton Spear. B: Schöningen Spear I. C: Schöningen Spear II. D: Schöningen Spear V. E: Schöningen Spear VI. F: Schöningen Spear VII. G: Lehringen spear

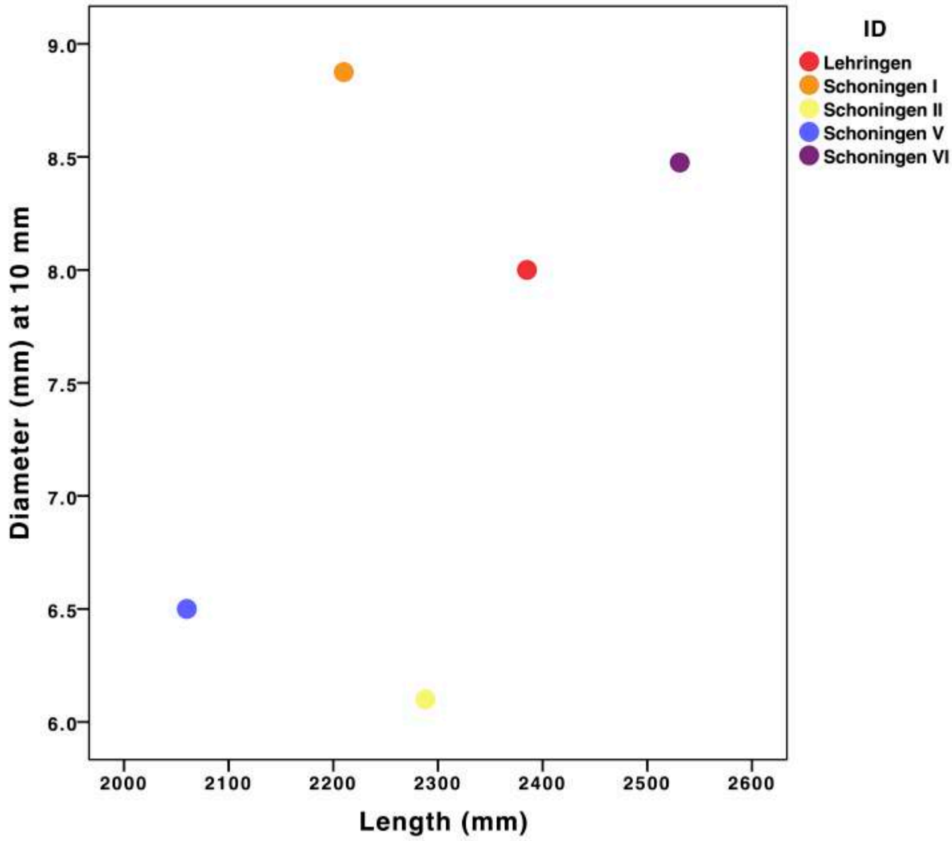


Figure 4.39. Scatterplot of length and diameter measurements at 10 mm

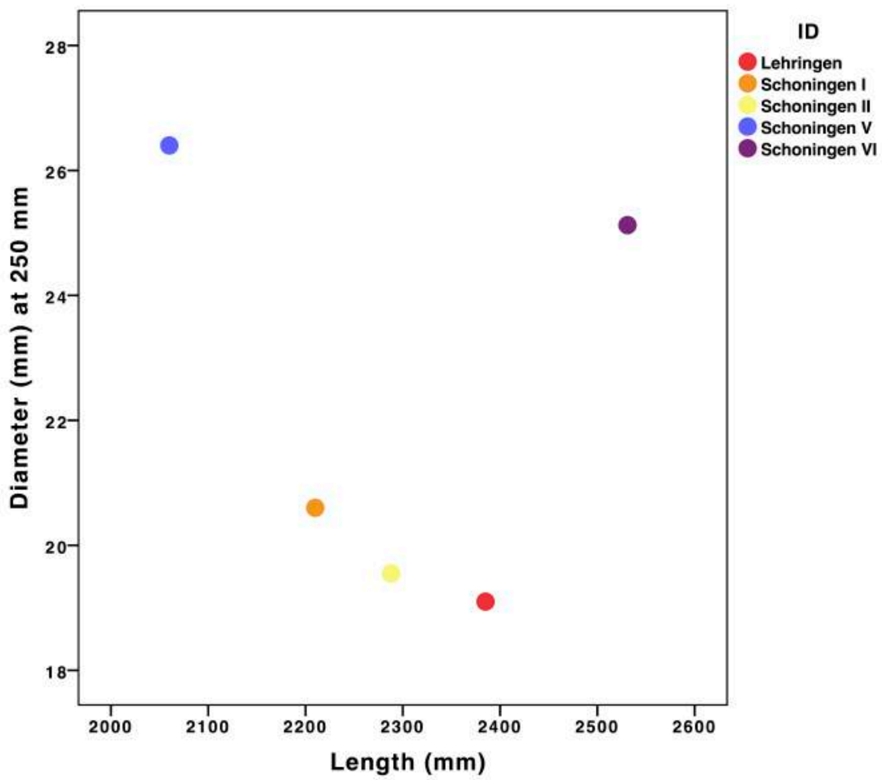


Figure 4.40. Scatterplot of length and diameter measurements at 250 mm

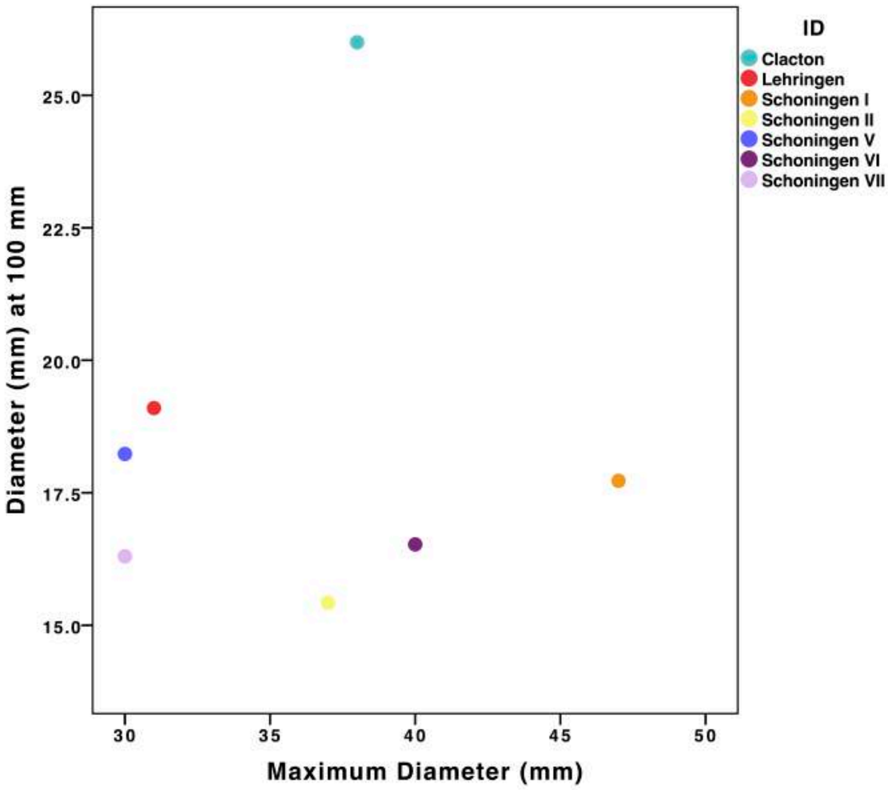


Figure 4.41. Scatterplot of maximum diameter and diameter measurements at 100 mm

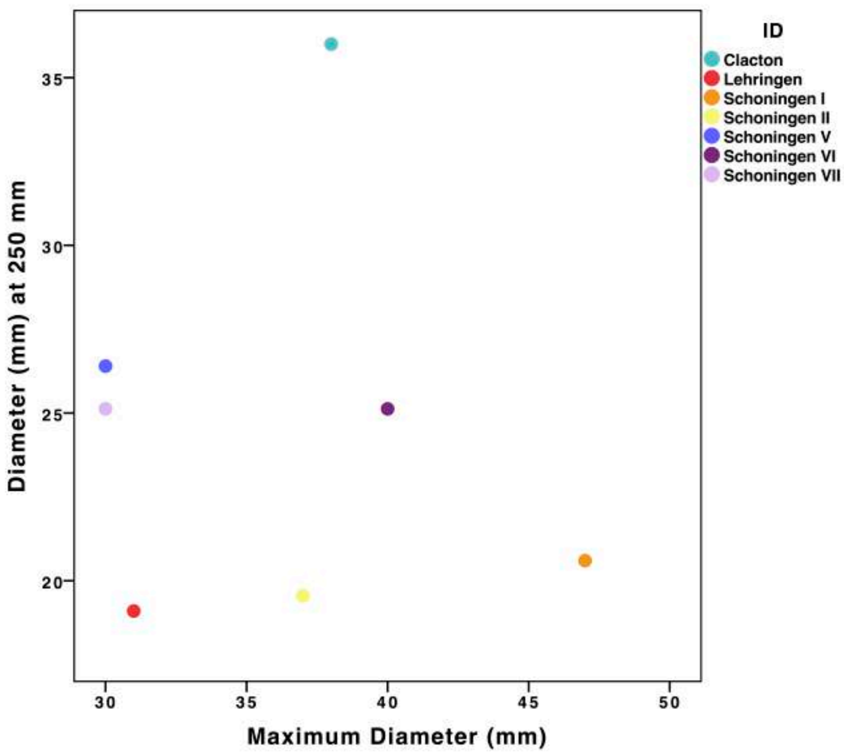


Figure 4.42. Scatterplot of maximum diameter and diameter measurements at 250 mm

Table 4.6 shows that most measurements in this analysis have a similar CV, between 21% and 23%. Maximum diameters vary the most, while interestingly, the diameter at 50 mm from the distal point varies the least. This shows a consciousness in particular of the design of the point in penetration, with higher variation at 10 mm likely to be due to damage at the tips of several of the examples. Diameter at 200 mm - the key point for DoP - has a slightly higher CV, which is due at least in part to a particularly wide cross section at this point for Schöningen Spear VI. Maximum diameter has by far the highest CV value, suggesting that this design feature was less standardised that the length and distal tip morphologies. Length measurements of complete or nearly complete spears are restricted to between just over 1800 and just over 2500 mm in length, and the longest examples are those suggested to be thrusting spears. The results demonstrate that length and distal point morphology are significantly more standardised than maximum diameter. Unfortunately PoB could not be approximated for the sample, particularly lacking data on the location of maximum diameters for the Schöningen spears. This feature relates better to function than other metrics, because location of the maximum diameter relates to PoB, and therefore determines whether a spear is capable of flight (Cotterell & Kamminga, p.172). Further study on the Schöningen spears should therefore include the location of the maximum diameter; further data demonstrating a strong relationship between these measurements on ethnographic spears is presented in Chapter 6 (6.7).

Table 4.6. Descriptive statistics of length and diameter measurements of the available archaeological sample. Spear VII included in Max DIA as only the base is damaged, and this measurement is reported in Schoch et al. 2015, Table 1.

	Length	Max DIA	DIA at 10 mm	DIA at 50 mm	DIA at 100 mm	DIA at 150 mm	DIA at 200 mm	DIA at 250 mm
mean	2002	42	8	14	18.5	21	24	25
CV (%)	23	37	23	9	21	22	25	23
SD	459.2	15.6	1.8	1.3	3.6	3.9	54.6	5.7
n =	8	9	7	7	6	6	7	7

Both the Clacton and Lehringen spears have their taper in part dictated by the presence of knots, which although are worked down, were not removed or completely smoothed. The Schöningen tapers appear long and relatively straight. Although Thieme (1997) suggests the length of the taper on spears I, II and III varies from >250 mm to >600 mm, this cannot be confirmed or further studied here as only the distal parts of the Schöningen spears were available for study. Table 4.7 shows the rate of change in diameter over each section. It demonstrates that in general, this is focused in the front 100 mm of the spears, with Schöningen Spear VI the exception, possibly due to knots in this area inflating the diameter. Overall, the Clacton spear point has the greatest change in diameter, beginning with a relatively thin point, but ending at the break in a robust shaft. Lehringen has the least change, beginning with the narrowest tip, and having the smallest taper. Sch. Spear VI, suggested to be the thrusting spear on the basis of its size and a natural kink, fits well within the group in terms of rate of taper.

Table 4.7. Rate of change of subsequent sections of distal points, indicating the rate of taper

Spear	10-50*	50-100	100-150	150-200	200-250	Overall change (mm) from 10-250 mm
Clacton ¥	5	10	3	5	2	25
Sch. I	5	‡	‡	‡	0	12
Sch. II	8	1	1	3	1	14
Sch. V	6	5	5	3	0	19
Sch. VI	5	4	3	8	-3	17
Sch. VII	7	3	4	2	3	19
Lehringen	4	7	-1	-1	2	11

*** due to difficulties measuring at the extreme tip, the first measurement is at 10 mm, therefore this first section of measurements is 10 mm less than the subsequent sections. ¥ Cast measurements. ‡ These measurements for Spear I are not included because the spear is damaged at 100 and 150 mm. Turquoise fill represents the section of each spear that has the highest rate of taper.**

4.4 Discussion

4.4.1 Reviewing the evidence for wooden spears in the archaeological record

The Clacton, Schoningen and Lehringen spears together show clear and direct evidence of hunting weapons in the European Middle and Late Pleistocene. The earliest evidence, from Clacton, dates to ca. 400,000 BP, and is potentially the work of early Neanderthals, while Lehringen demonstrates the use of these weapons by Late Pleistocene Neanderthals. Monte Verde and Wyrie Swamp provide archaeological evidence of their use by modern humans in Late Pleistocene and early Holocene contexts, while evidence to be presented in Chapter 6 demonstrates the continued use of wooden spears in recent hunter-gatherer societies. Together, there is evidence of the continuous use of wooden spears from at least 400,000 BP, and shows them to be a technology that continued to hold advantages alongside developments in weaponry including hafting and 'complex' projectiles. The possibility that earlier hominins were manufacturing and using wooden spears in ambush hunting at African Early Pleistocene sites such as FLK Zinj currently relies upon indirect evidence such as prey mortality profiles, with researchers calling for further experimentation with wooden spears to better understand bone damage (e.g. Bunn & Gurtov 2014), which is one of the aims of this thesis. The spears from the European Pleistocene contexts all originate from interglacial periods. Both Schoningen and Lehringen provide good evidence of large mammal exploitation with the weapons in their close association with butchered carcasses, contradicting claims that wooden spears are poor weapons for the hunting of large animals (e.g. Lieberman et al. 2007).

4.4.2 Design and functional interpretations of archaeological wooden spears

The suggestion in Oakley et al. (1977) that the Clacton fragment could represent a broken game stake remains an intriguing possibility, but a few things are against this interpretation. For one, there is little evidence of procurement strategies such as pitfalls or traps until the Late Pleistocene (Wadley 2010). Few data exist on the morphometrics of game stakes, making comparison problematic. Oakley et al. (1977) suggest that game stakes would be thicker, ca. 60-100 mm in diameter, but no direct measurements were provided, and examples are reportedly rare in ethnographic museum collections. However, as the maximum diameter on the broken fragment is unlikely to represent the original maximum diameter (see more on location of maximum diameter in Chapter 6), it is probable that the Clacton fragment had at least a slightly larger maximum diameter. Ethnographic evidence suggests that a distinction between spears and game stakes may not be entirely meaningful, with reports of both Tasmanians and Kalahari San using spears crafted for throwing and thrusting as game stakes as well (Hiatt 1968; Hitchcock & Bleed 1997). Similarly the Clacton artefact could have been multifunctional, and either way it looks most likely to have functioned as an aid in hunting large game. An interpretation of the fragment as a snow probe is unlikely, not only because the archaeology from Clacton-on-Sea represents occupation during fully interglacial conditions, but also the morphology of such a tool would logically more closely resemble a digging stick and the point is too carefully worked for this (Oakley et al. 1977). Determining a function for the Clacton spear point as a thrusting vs. throwing spear on the basis of its distal tip robusticity is problematic: both Schoningen Spear VI and the Lehringen spear - suggested to function as thrusting spears - have distal point morphologies that are similar to or more gracile than the Schöningen spears suggested to function as throwing spears. Interestingly, the fact that the lengths of Schöningen Spear VI and the Lehringen spear exceed the others in the sample may support Oakley et al.'s (1977) suggestion that longer spears for spear thrusting are designed to put more distance between the hominin and the animal. Hypotheses that a double taper indicates function as a throwing spear also remain problematic, because this design feature could also have other purposes. For example it could be designed to stop the hand of the trailing limb - which sustains the majority of force during spear thrusting (Schmitt et al. 2003) - from slipping forward along the shaft during spear thrusting, an observation made by participants during the use of a replica of Schöningen Spear II for spear thrusting experiments in this thesis (Chapters 7 and 8). Overall the small group of archaeological spears suggests a standardisation of the design of the distal points, representing an awareness of factors contributing to penetration and therefore effectiveness. The fact that chimpanzees also modify their hunting spears to sharpen them (Pruetz & Bertolani 2007) show the potential for an early awareness of the significance of sharpness for penetration. The robusticity of the Clacton fragment may well indicate that it functioned as a spear intended for use on large and/or dangerous animals, prioritising durability over penetration. Monte Verde offers an unusual contrast to the relatively long MP spears, with two spear-like artefacts that are short and thick, perhaps designed for thrusting rather than throwing, and with a feature that is suggestive of a grip or handle. While there is no a priori reason to discount these as spears of some type, and their robusticity may just reflect morphometric variability of wooden spears, a function as a game stake of some kind should also be considered.

4.4.3 Discard of archaeological wooden spears

One problem pertaining to the spears is the reason for discard. The Clacton example is clearly catastrophically broken, and so reason for discard is clear. At Schöningen some of the spears look to have sustained tip damage, with some of this damage potentially relating to use, and which might have been repairable. These and other breaks require further investigation and comparison with experimentally-used spears to evaluate whether breaks are pre- or post-depositional in nature. The Lehringen spear looks to have been possibly trapped beneath the elephant carcass, making retrieval difficult. At Monte Verde, at least one of the spears was broken prior to discard, as the refitting fragments were discovered in different locations (Dillehay 1997). The Wyrie Swamp spear could have been lost during use, as the swamp site may have functioned as a hunting ground, particularly for birds (Luebbers 1978). The discard and movement of wooden spears in the archaeological record is primarily a taphonomic problem and thus beyond the scope of this thesis, but future study should take into account the possibility of breakage from use when evaluating discard.

4.4.4 Implications for behavioural patterns

That the spears from the sample were used as hunting tools and not simply as an aid in self-defence is supported not only by the shared contexts with butchered large mammals at Lehringen and Schöningen, but also by the break on the Clacton spear point and damage to the tips of the Clacton and some of the Schöningen spears. This possible evidence of use damage requires further study, with breaks produced the experimental use in this thesis providing the first reference sample. The small sample size of archaeological wooden spears is aided by a comparison with ethnographic examples, and this is presented in Chapter 6 of this thesis. Many questions remain about how design relates to function in these weapons, with experimental approaches being the most fruitful means of progressing interpretations of the earliest weapons.

The Schöningen spears represent neither the oldest nor the only complete wooden spears from Pleistocene contexts - though they are the earliest complete spears. Therefore perhaps it is the fact that they form a sample from a single site with an abundance of other organic and lithic artefacts that makes them the most spectacular. Their discovery supports theories that wooden spears were the earliest hunting weapons, by providing additional evidence to corroborate that from Clacton and Lehringen, known from earlier 20th century discoveries. What they also provide, as a collection, is an indication that hominins in northern Europe were socially hunting large mammals from the second half of the MP, although the interpretation of the Spear Horizon as representing a palimpsest slightly undermines this because it is unclear how many spears would have been used in a single hunting episode.

The results of the analysis demonstrate across the entire sample a focus on the distal points of wooden spears that highlights that hominins during the Middle and Late Pleistocene were crafting wooden spears with a clear awareness of the significance that point morphology influences penetration and thus lethality. Although functional assignments are tentative, distal points of spears were carefully shaped and relatively standardised, especially in comparison with maximum diameter. The tool marks around knots, particularly at the distal points, further show a focus of time on smoothing down natural features on the wood that would inhibit penetration. This analysis of the sample unfortunately does not add to the discussion on delivery method, though it does suggest that if previous assignments are correct, that the distal parts of spears were shaped similarly irrespective of delivery method.

Chapter 4 has provided the first analysis of the collection of existing sample of archaeological wooden spears, with a focus on the distal points, and is particularly significant for providing the first analysis of the distal parts of the Schöningen spears both as a collection and in comparison with the Clacton and Lehringen spears. Future analysis should focus on including the entire sample, including the remaining examples from Schöningen, and possibly the Late Pleistocene examples from Wyrie Swamp and Monte Verde. Further evaluation of possible wooden artefacts from throughout the Pleistocene would benefit from a systematic approach utilising 3D microscopic imaging techniques to assess them for human modification. If wooden tools formed a significant but rarely preserved part of toolkits throughout human evolution, such an approach is warranted, as this highlights the significance of such artefacts.

Chapter 5. Middle Pleistocene hunting lesions: a rare phenomenon

> *The methodological dilemma of taphonomical research is illustrated by the fact that a single wooden spear from the German site at Schöningen gives a clearer indication of human subsistence tactics during the Lower Palaeolithic than any number of taphonomically analysed faunal assemblages from the same period.*
>
> \- Gaudzinski & Turner 1999, p.389

5.1 Introduction

After discussing the archaeological evidence of wooden spears and their use in the MP in the previous chapter, this chapter addresses the MP evidence of the other direct evidence of weapon use, which is hunting lesions. The recognition of hunting lesions on faunal remains from prehistoric periods has been in researchers' consciousness for some time, but initially received relatively little attention. This has shifted recently partly as a result of increases in experimental weapon use, though most research is focused on the Upper Palaeolithic and Mesolithic. With the discovery and publication in the 1980-90s of the sites of Schöningen and Boxgrove, linking wooden spear use with potential hunting lesions became more than just an exercise in speculation. A curvilinear fracture on a scapula fragment from the remains of a butchered adult horse at GTP17 (Unit 4b) from Boxgrove was suggested to possibly be the result of impact from a wooden spear (Roberts & Parfitt 1999). It has variously been called a 'puncture mark' (Austin et al. 1999), 'impact point' (Smith 2012) and 'hunting lesion' (Gaudzinski-Windheuser 2016) and has been upheld as a key piece of evidence not only in support of hunting at Boxgrove but also for the wider European MP (e.g. Stringer et al. 1998; Pope & Roberts 2005; Letourneux & Pétillon 2008; Wilkins et al. 2012). Until Smith (2010) brought to light an additional potential hunting lesion on a cervid scapula recovered from the Lower Gravel during Waechter's 1971 excavation season at Swanscombe, the Boxgrove scapula stood alone as the only potential hunting lesion identified from the entire period. The significance of these two artefacts for behavioural interpretations has not been balanced by an empirical approach to the damage, with no quantitative or qualitative analysis yet been undertaken. Without this, interpretations of the artefacts as representing the use of wooden spears by hominins during the MP will remain unsubstantiated. Direct evidence of wooden spears does not enter the artefact record until MIS 11 (see Chapter 4), and therefore if the scapula fragment from Boxgrove were clearly supported by empirical evidence to bear a hunting lesion, not only would it represent the earliest direct evidence of hominin hunting but also the earliest direct evidence of the use of weaponry in the archaeological record. A few small-scale investigations have aimed to show that wooden spears can perforate scapulae, including an experiment in a documentary *The Butchers of Boxgrove* (1996) as well as experimental use of wooden spears on a lamb carcass (Smith 2003). The results of these experiments have not demonstrated the ability of a wooden spear to cut through the hide, muscle and bone of a large adult mammal. Additionally, while experimental work into hunting lesions is currently working towards establishing diagnostic criteria for hunting lesions, other potential causes including human and taphonomic damage also need to be considered (O'Driscoll & Thompson 2014; Duches et al. 2016). Relevant experiments are discussed in detail below (5.1.2), but it is important to highlight at the outset the lack of a systematic empirical approach either directly to these two artefacts or in relation to any pertinent experimental research, and there are still some significant methodological challenges in taphonomical research which present obstacles in identifying agents of modification on faunal remains (Gaudzinski & Turner 1999). This chapter therefore provides the first quantitative and descriptive analysis of the damage to both examples. An experimental programme investigating wooden spear and hammerstone impacts follows in Chapter 8, pulling these lines of evidence together at the close of that chapter (8.5) to make an assessment of the most likely cause of the damage.

The term 'impact damage' which is sometimes used in the published literature in relation to weapon impacts could potentially be confused with terminology for percussion impact during processing of bone for access to marrow and/or bone grease. The terms 'Projectile Impact Mark', 'projectile impact traces' and 'projectile injuries (e.g. M. Smith et al. 2007; O'Driscoll & Thompson 2014; Pétillon & Letourneux 2008) are not used here because they make a prediction of the weapon delivery method and therefore technically rule out the use of thrusting spears. The term 'hunting lesion' is clear in diagnosing the cause of impact, without presupposing a delivery method, and is the term used in this thesis.

This chapter initially covers the site backgrounds of the two MP sites of Boxgrove and Swanscombe (5.1.1). Following this is a brief discussion pertaining to ungulate scapulae, which provides some terminology and information about the function, anatomy, and nutritional value of this bone. This facilitates the next section (5.2), materials and methods, which describes the small but important sample of potential MP hunting lesions and the methods developed for assessing them, followed by the results of the analysis (5.3). A comparative analysis in relation to the experimental programme in this thesis and further datasets is presented in Chapter 8 (8.5), once the experiments have been presented in full.

5.1.1 Background on sites and artefacts

This section presents the two MP sites with proposed hunting lesions, Boxgrove and Swanscome (Fig. 5.1), providing context for evaluating potential causes for the damage on the artefacts.

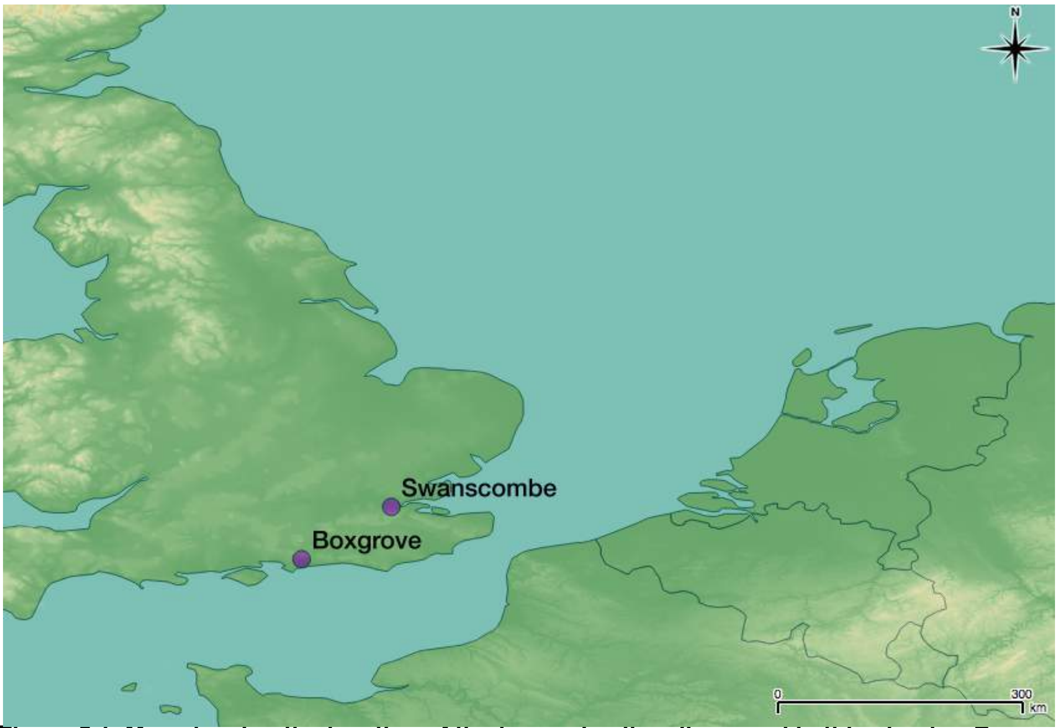


Figure 5.1. Map showing the location of the two main sites discussed in this chapter, Boxgrove and Swanscombe, each producing one proposed hunting lesion from a wooden spear

5.1.1.1 Boxgrove, West Sussex (UK)

The site of Boxgrove is located seven km east of Chichester in West Sussex, (UK) at the edge of the South Downs on raised beach deposits of the coastal plain. Originally called Amey's Eartham Pit, Boxgrove is not a single site but rather a whole series of more than 90 excavation areas, consisting of small geological test pits (GTP) and larger excavation sites, together sampling a 1000 m x 500 m area of much larger preserved palaeolandscape (Roberts 1999a; Pope et al. 2009). Of these localities, this thesis is particularly concerned with GTP17 (Unit 4b) which is located in Quarry 2, and commonly known as 'The Horse Butchery Site' (e.g. Austin et al. 1999; Pope 2003; Roberts 2011; G. Smith 2012; Voormolen 2008a), although evidence from the entire site is relevant in the wider context of hominin subsistence activities.

Interest in the archaeology of the raised beaches began in the mid-19th century when Joesph Prestwich drew attention to the presence of marine deposits at 100ft (40m) above sea level (Roberts 1999a). By the turn of the 20th century the presence of stone artefacts had been recognized and were being actively collected (Roberts 1999a). Quarrying activities of the West Sussex coastal plain, between the River Arun and the River Lavant, exposed MP sediments and when these eventually threatened the in situ Pleistocene archaeology, rescue excavations were deemed necessary (Roberts 1999a). The Eartham Quarry contained the largest exposures, with preservation of archaeology from the western part falling into the parish of Boxgrove (Roberts 1999a).

The Boxgrove Project excavations began in 1983 led by Mark Roberts and continued until 1996. A multidisciplinary research team was formed to evaluate not only the archaeology, but also geological processes and sedimentary contexts, establishing a chronostratigraphical framework including the palaeoclimate and palaeoenvironment (Roberts & Parfitt 1999). Nine hectares of the site were subsequently purchased in 2003 by English Heritage via the Aggregates Levy Sustainability fund, with the site now managed by UCL's Institute of Archaeology (Pope 2003). In the early stages of the project, from 1983-92, excavations of Quarries 1 and 2 took place ahead of commercial quarrying activities for gravel and sand; this phase included 2426 m^2 of excavation (Roberts 1999a) with the main areas of test pitting and excavation covering 1221 m^2 (Roberts 1999a). The main output of these excavations was a volume published in 1999 (Roberts & Parfitt 1999) with contributions throughout from the multidisciplinary team, as well as a series of papers focusing on the human remains (Trinkaus et al. 1999; Stringer et al. 1998; Hillson et al. 2010) and a thesis and publications pertaining to the lithic artefacts and behavioural implications (Pope 2002; Pope 2003; Pope & Roberts 2005). At the time, the excavation produced the oldest evidence of humans in the UK, and the human remains continue to represent the earliest dated human fossils in the British Isles.

Units 4a, 4b, and 4c contained the bulk of the in situ archaeological material and consist of the Slindon Silts deposits, which overlay the raised beaches and Slindon sand. These are covered by Unit 5a consisting of marsh deposits and representing the transition between the final phases of the interglacial MIS 13, and the early glaciation in MIS 12 (Roberts 1999b; Parfitt 1999b). The palaeolandscape has been interpreted as an intertidal saltmarsh with grasslands intersected by chalk cliffs similar to those on the southeast coast of England in the present day (Pope 2003). Dated biostratigraphically to around 500,000 BP (Parfitt 1999a; Parfitt 1999b), the period saw a cooling of temperatures which resulted in lowering sea levels, and at the site freshwater springs attracted animals that would have repeatedly drawn both hominins and carnivores to the area (Pope 2003). Large areas of this palaeolandscape apparently underwent rapid burial, preserving lithic artefacts alongside faunal remains that bear marks showing involvement with the faunal material by both hominins and carnivores (Pope & Roberts 2005; Roberts & Parfitt 1999).

In 1993 a hominin tibia was discovered during test pitting at Quarry 1/B (Q1/B), also called the 'Water Hole' locality, prompting two further seasons of excavation of this area (Roberts et al. 1994; Pope 2002). Two hominin incisors were subsequently found in there in 1995-96 (Hillson et al. 2010). The tibia and incisors have been provisionally assigned to *H. heidelbergensis* and represent either one or two individuals of a tall and robustly built, cold-adapted species, with the tibia from a relatively elderly individual (Roberts et al. 1994; Stringer et al. 1998; Trinkaus et al. 1999; Streeter et al. 2001; Hillson et al. 2010).

Excavations resulted in 20,899 lithic artifacts across the series of localities and include a large selection of primarily ovate Acheulian handaxes, in situ knapping scatters created during with the manufacture of handaxes, a small selection of cores, flakes from manufacture and resharpening of handaxes, flake tools, hammerstones, and an anvil (Pope 2002; Austin et al. 1999). Hammerstones recovered from Q1/B consist of cortical flint nodules weighing between 111g and 667 g (Fig. 5.2), with evidence of battering, incidental flake removals, and cracking (Austin et al. 1999). Large beach cobbles are also present (Austin et al. 1999), though it is unclear from the analysis whether these bear any evidence of use. In addition to the lithic artefacts, bone tools and antlers bearing traces of use also show complex technological behaviours (Pope 2002; Pope 2003; Pope & Roberts 2005).

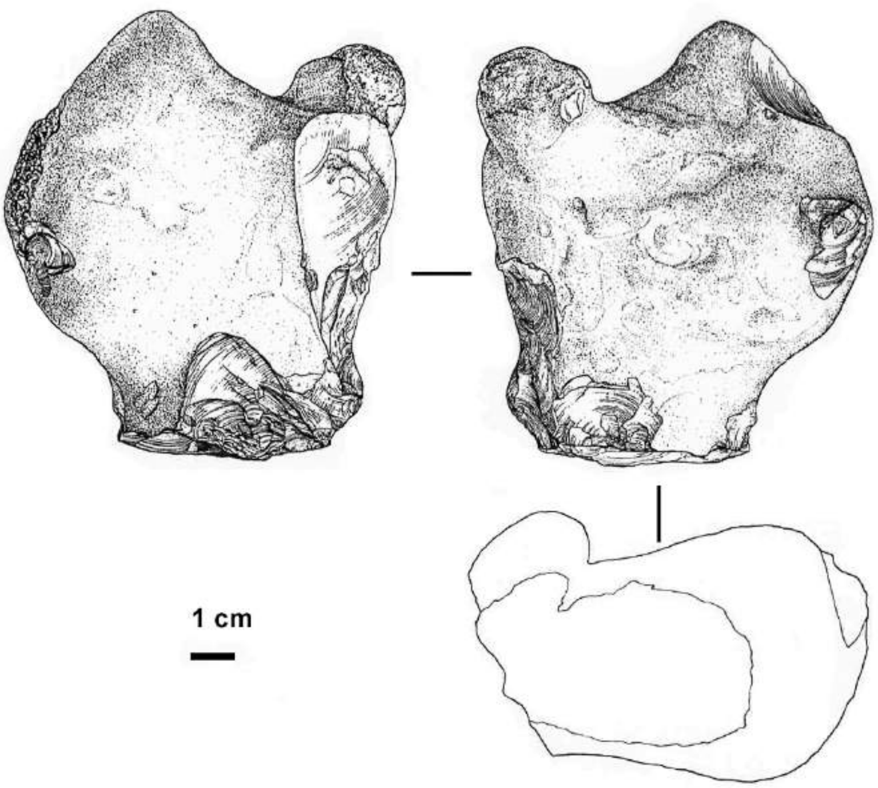


Figure 5.2. Cortical flint hammerstone from Q1/B with signs of battering and incidental flake removals in multiple places. (modified after Austin et al. 1999, Fig. 248, a)

Including both natural background fauna as well as those with signs of human modification, the mammals at the site represent 50 species, one of the largest and most diverse collections of the European Pleistocene (Parfitt 1999a). Herbivores range from megafauna including elephant and rhinocerous (*Stephanorhinus hundsheimensis*), as well as bovids, equids and a range of cervids of different size classes including giant deer (*Megaloceros* cf *verticornis*), red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*). Crucial to interpreting hominin activities at the site is the presence of the spotted hyaena (*Crocuta crocuta*) and lion (*Panthera leo*) (Parfitt 1999a) demonstrating that hominins were sharing this landscape with dangerous social carnivores.

Human modification of faunal remains includes cut, scrape, and chop marks as well as percussion damage consistent with use of hammerstones and anvils (Parfitt & Roberts 1999). These marks indicate various butchery activities including skinning, filleting, dismemberment, disarticulation, and breakage of bones (Parfitt & Roberts 1999). Elements showing bone breakage for access to marrow, fatty tissues and/or bone grease include long bones (femur, metapodial, radius, humerus, and tibia), mandibles, and scapulae for marrow (Parfitt & Roberts 1999). Species bearing evidence of hominin modification include Deninger's bear (*Ursus deningeri*), red deer (*Cervus elaphus*), giant deer (*Megaloceros* sp.), roe deer (*Capreolus capreolus*), horse (*Equus ferus*), rhinoceros (*Stephanorhinus hundsheimensis*), and bison (*Bison* sp.) (Parfitt & Roberts 1999; Bello et al. 2009). A limited amount of carnivore damage is also present on the humanly modified bones at Boxgrove, and where carnivore marks and cutmarks overlap, tooth marks are over the cutmarks indicating that the hominins had primary access to these carcasses (Parfitt & Roberts 1999).

Q1/B, where a Pleistocene freshwater spring was located, represents a palimpsest of hominin and faunal activity, including background fauna as well as human modification of rhinoceros, red deer and horse (Parfitt & Roberts 1999). In contrast to this, GTP17 (Unit 4b) is interpreted as a single episode, with the presence of highly fragmented bones of a small percentage of elements from a single butchered adult horse, estimated to have been between 1.5-1.7 m at the withers (Parfitt & Roberts 1999). The remains of the horse along with associated debitage scatters, spread over 150 m^2, underwent rapid burial and when excavated were in a primary context (Austin et al. 1999). Alongside the horse remains were a series of lithic scatters that refit to indicate the on-site knapping of handaxes for butchering the animal, which were then taken away (Roberts & Parfitt 1999; Pope 2003). The highly fragmented bones have cut marks from disarticulation, skinning and filleting, as well as marks indicating the use of hammerstones and anvils to access within-bone nutrients (Parfitt & Roberts 1999). Two fragments of the right scapula remain including part of the blade (Fig. 5.3) and part of the neck (Parfitt & Roberts 1999, Fig. 314). Key to interpreting the behaviour at GTP17 and over the wider site is the evidence of the comprehensive processing of the horse carcass, including the use of hammerstones and anvil to access within-bone nutrients such as marrow in the long bones, fatty deposits in the mandible, and bone grease in cancellous tissues, behaviours that are replicated at other localities at Boxgrove (Parfitt & Roberts 1999). The fact that horse marrow goes rancid fairly quickly supports the suggestion that this horse was either hunted or power scavenged from other predators (Outram & Rowley-Conwy 1998). Although representing a short period of time during which a group of hominins butchered a single horse carcass, it is made clear that the distinction cannot definitively be made between power scavenging and hunting (Roberts & Parfitt 1999); this is where the horse scapula fragment enters the discussion and why the cause of the curvilinear fracture requires a detailed analysis. Regardless of whether the fragment bears a lesion consistent with impact from a wooden spear, the case for either social hunting or power scavenging by a group of hominins at Boxgrove remains strong, including the frequency and location of cut marks, the small number of carnivore marks that always are subsequent to hominin butchery marks, direct association between the lithic artefact scatters and the horse carcass, and the fresh condition and minimal disturbance of the artefacts at GTP17 (Parfitt & Roberts 1999). The significance and uniqueness of the site lies at least in part in the combination of clear evidence for group cooperation and behaviourally complex *chaînes opératoires* in terms of both technology and processing of animal carcasses at an early date.

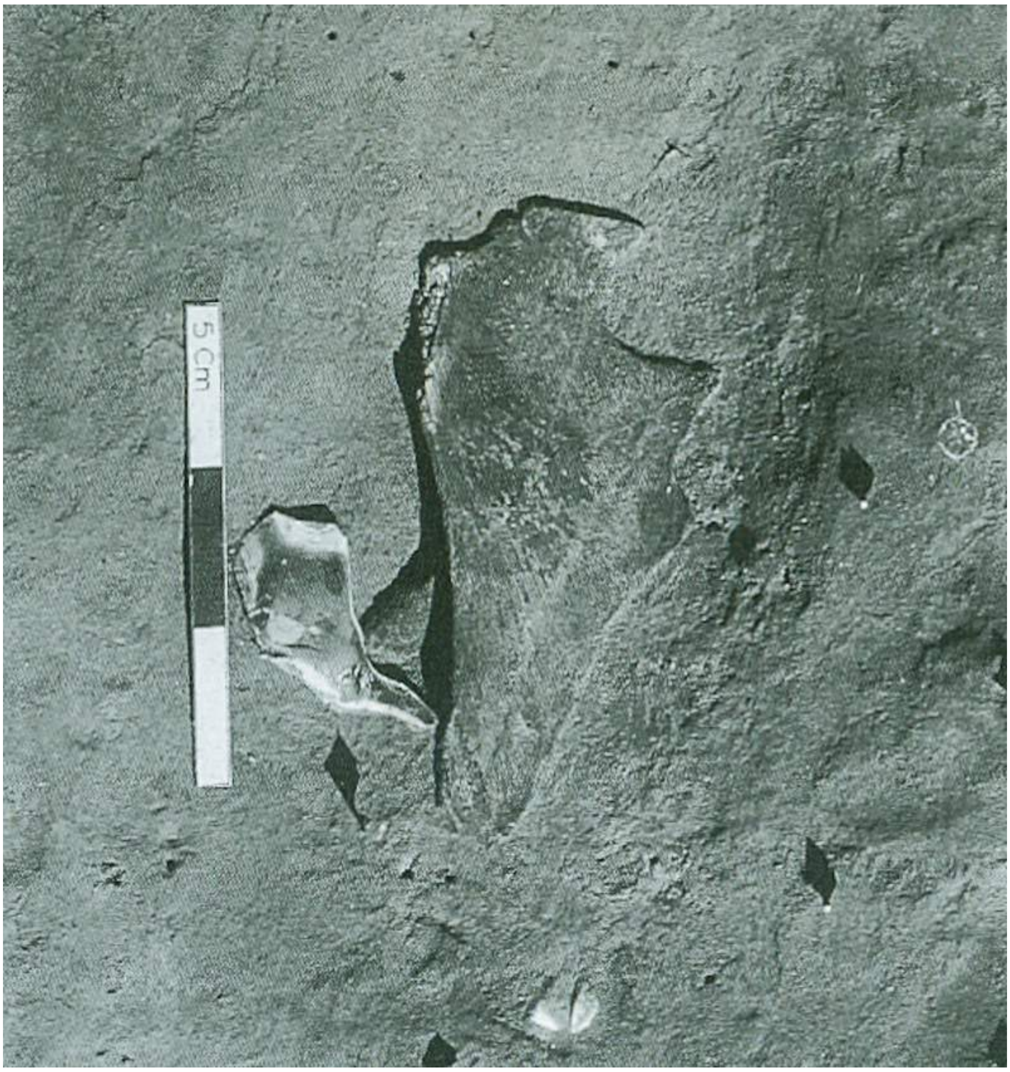


Figure 5.3. Photograph of the blade fragment in situ from the horse in GTP17 (Unit 4b). View is of the lateral side of the fragment (From Austin et al. 1999, Fig. 289, permission to reprint from S. Parfitt)

5.1.1.2 Swanscombe, Kent (UK)

Barnfield Pit, Swanscombe in Kent is one of the most important sites in the British Lower Palaeolithic, with a rich excavation history and an important sequence of MP sediments. Located five km east of Dartford, like Boxgrove the site was discovered as a result of quarrying activities. During the 19th century, chalk quarrying in the area exposed Pleistocene deposits consisting of gravel, sand, and loam sitting on top of the Thanet Sand and Chalk surface (Conway, McNabb & Ashton 1996a). These quarrying activities also exposed artefacts within the Pleistocene exposures and this began a long history of amateur collectors documenting the site, alongside systematic investigations of the geology and archaeology. Detailed accounts of the excavation history of the site can be found elsewhere (Conway, McNabb & Ashton 1996c; Schreve 2004). The earliest systematic investigations aimed to understand the geology and stratigraphy at the site, and were conducted by Smith and Dewey in 1912-13 (Conway 1996). The stratigraphic units proposed by Smith & Dewey were Upper Gravel, Upper Loam, Middle Gravel, Lower Loam, and Lower Gravel; a subdivision of the Middle Gravel into Lower Middle Gravel and Upper Middle Gravel was proposed in the notebooks but intriguingly was not in the publication (Conway 1996). These units have broadly continued to be followed in subsequent excavations and publications.

The significance of the site in early research phases related both to its comparisons with research on the continent, particularly in relation to the stratified lithics (Conway 1996), as well as to the discovery in 1935 of two hominin cranial fragments - an occipital and a left parietal bone - by Alvan T. Marston, a local dentist who visited the site in search of lithic artefacts (Conway 1996; Stringer & Hublin 1999). Barnfield Pit was gifted by the Associated Portland Cement Manufacturers in 1954 to the Nature Conservancy, and became the first geological Nature Reserve in Britain. John Wymer found a right parietal bone refitting with the hominin skull fragments discovered by Marston and subsequently excavated at the site from 1955-1960 (Conway 1996). During his time as lecturer in Palaeolithic Archaeology at UCL's Institute of Archaeology, John d'Arcy Waechter led further excavations at Swanscombe from 1968-72 with a particular interest in the Lower Gravel and Lower Loam (Fig. 5.4) (Conway, McNabb & Ashton 1996c). Excavation reports were published (Waechter & Conway 1968; Waechter et al. 1969) but full results of the excavation were published several decades after Waechter's death by a team including members of Waechter's excavations and specialists who undertook palynological, geological, avifaunal, mammalian, and lithic analyses (Conway, McNabb & Ashton 1996c). Many other excavations took place throughout the 20th century, with the results of some of these undocumented and unpublished (Conway 1996). The site today is called the Swanscombe Skull Site National Nature Reserve which is managed by the Swanscombe and Greenhithe Town Council, and is a Site of Special Scientific Interest with some areas of Pleistocene sediments intact (Fig. 5.4) (Schreve 2004).

The site was formed at the end of the Anglian glaciation of MIS 12 when the River Thames system cut through Thanet Sand and Chalk and was subsequently infilled with river gravel deposits, forming the Lower Gravel (Conway, McNabb & Ashton 1996c). The entire sequence of terrace deposits, which measure between 12 and 15 m are understood to have formed during the following interglacial MIS 11, making the site broadly contemporary with the earliest wooden spear, the Clacton spear point. Numerous lines of evidence underpin the dating of this site including aminostratigraphy, geomorphology, and the mammalian fauna (e.g. Bridgland 1994; Bridgland & Schreve 2004; Conway, McNabb & Ashton 1996c). Swanscombe was a key site in the formation of the idea that core and flake technologies preceded Acheulian technologies, but excavations at Boxgrove and High Lodge, with Acheulian handaxes securely dated earlier than MIS 11 called into doubt this paradigm, with the debate continuing (e.g. Ashton et al. 1994; Ashton & McNabb 1996b; Ashton 2015; Ashton et al. 2016). The cranial fragments probably represent a young female, with a mix of features suggesting that this may represent an early Neanderthal (Stringer & Hublin 1999; Dinnis & Stringer 2013).

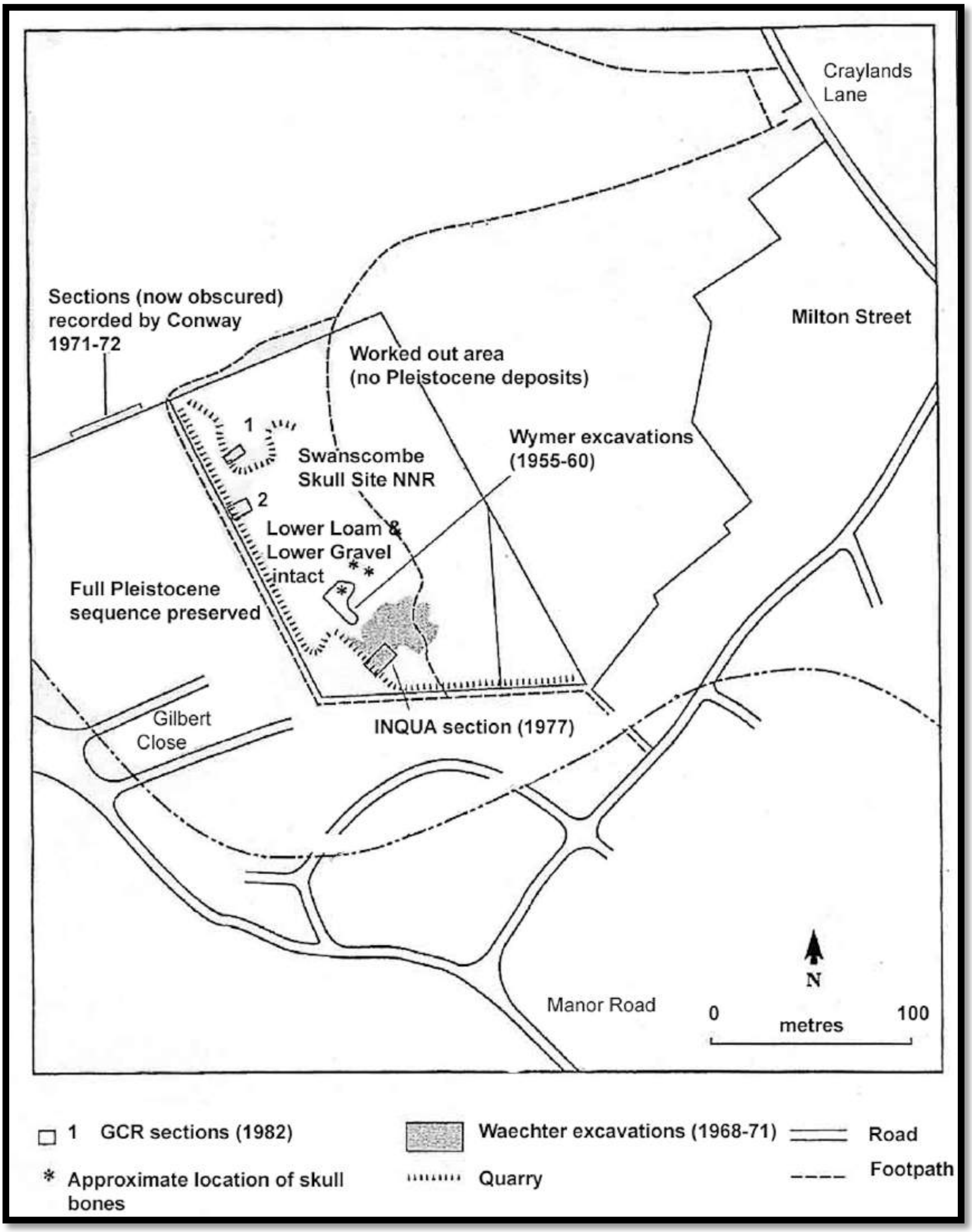


Figure 5.4. Map of the Swanscombe NNR, with locations of key excavations including the Waechter excavations, and approximate location of the skull fragments (Modified after Schreve 2004, Fig. 11)

The Lower Gravel, from which the cervid scapula originates, is between 0 and 2.9 m thick and consists of a sandy/gravel deposit containing shells, flint artefacts, and faunal remains (Conway 1996). Lower Gravel deposits were excavated in spits during Waechter's excavations, divided into Units 1-4. The context of the cervid scapula under analysis is Trench A3, Unit 3 which consisted of these Lower Gravel deposits. Trench A3 was 4.5 m deep with the spits not tied to heights below a datum point. The first two spits were 20 cm each, but below this the excavation of this trench followed a scheme of spits divided into four units (Ashton & McNabb 1996a). Units 3 and 4 of the Lower Gravel contained few mammalian bones, and were mostly cervid and bovid remains but also included rhinoceros (Schreve 1996). These lower two units probably represent the final part of the cold stage of MIS 12 or the earliest part of the MIS 11 interglacial, with a mix of closed forest and open habitats, leading to fully interglacial conditions by the upper two Units (Conway, McNabb & Ashton 1996b; Schreve 1996; Hubbard 1996; Schreve 2004). The largest percentage of faunal material from the Lower Gravel is either unweathered or lightly weathered, but cracking and pitting of the surfaces of bones is widespread (Smith 2010). There are high levels of fragmentation of bones, some with edge rounding, and little evidence of either hominin or carnivore modification, with the former mainly concentrated on cervid elements (Currant 1996; Smith 2010; Smith 2013). The rounding and battering of material, along with the cracking and pitting and selective destruction of elements together suggest that the material is derived and the deposits formed in high-energy fluvial accumulations (Currant 1996; Schreve 2004; Smith 2010). The lithic artefacts from the Lower Gravel in Waechter's excavations included flakes, cores, flake tools and chips, and - key for interpreting the Lower Gravels as representing an absence of Acheulian technology - one ovate biface (Ashton & McNabb 1996a). The condition of lithics in the Lower Gravel also supports the interpretation that the material is derived, with artefacts from Unit 3 being moderately to heavily rolled. This short review of Swanscombe contextualises the cervid scapula considered in this thesis.

5.1.2 The function and anatomy of ungulate scapulae

As the features of ungulate scapulae are discussed throughout the remainder of this thesis, they are described and illustrated here for reference purposes. Flat bones include the skull, scapula, pelvis and ribs, and the role of these bones is to protect the vital organs of the body including the brain, heart and lungs, thoracic and pelvic organs (Frandson et al. 2013). In ungulates, the scapula lies over the ribs and caudal vertebrae (Fig. 5.5), consisting of two plates of relatively thin cortical bone which are separated by varying amounts of cancellous bone, also called spongy or trabecular bone which contains marrow and grease (Figs. 5.6 - 5.8). The edges of the blade and surface of the spine of a scapula are covered in fibrous connective tissue (Frandson et al. 2013).

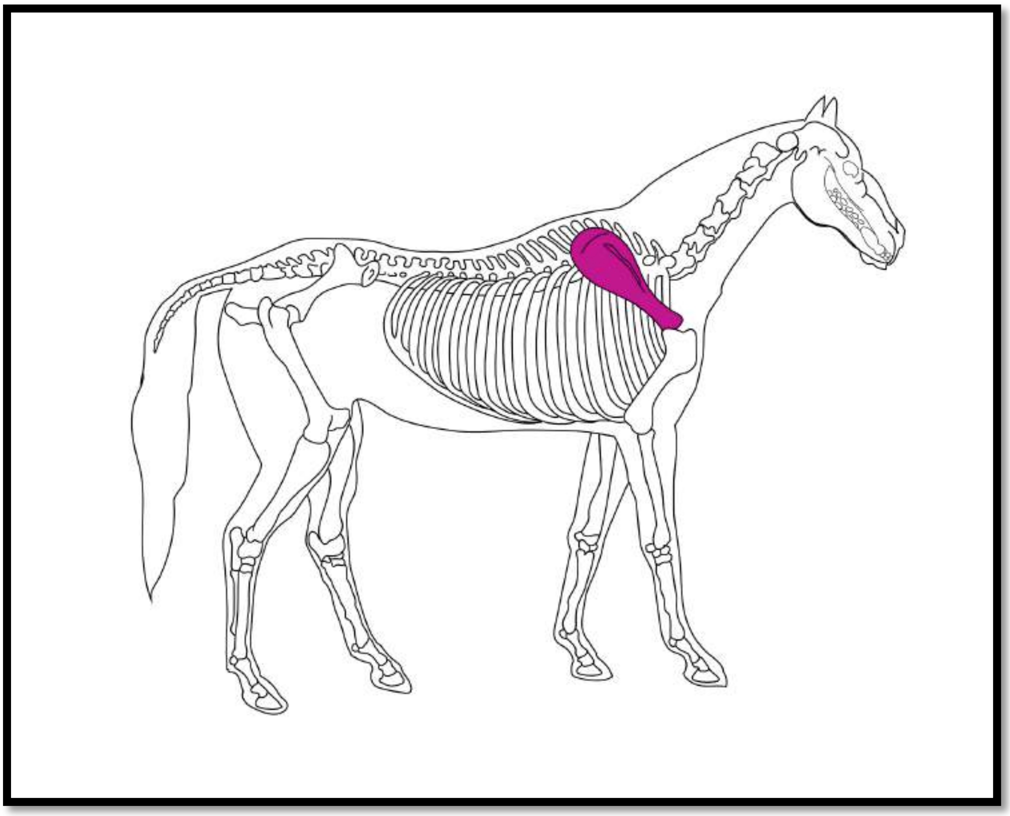


Figure 5.5. Location of right scapula on a horse

Figure 5.6. Cancellous bone exposed by cortical bone removal on a horse scapula blade. Photo is after cleaning by enzymatic maceration

Figure 5.7. Cross section of a horse scapula near the neck showing cancellous tissue with liquid marrow and grease

Figure 5.8. Exposed cancellous bone of horse scapula blade showing liquid marrow and grease

The scapula acts as a shield, and as it articulates at the glenoid cavity with the humerus, it shifts during locomotion. Together with the ribs the scapulae provide coverage for the vital organs and a major artery in the target zone most frequently exploited by human hunters (e.g. Guthrie 1984), and as such they frequently feature as elements bearing hunting lesions from later periods, particularly with punctures and/or perforations with or without embedded weapon tips (e.g. Noe-Nygaard 1974; Leduc 2012; Nikolskiy & Pitulko 2013; Gaudzinski-Windheuser 2016). However lesions to flat bones also frequently heal whether the cause looks to be intraspecific aggression (e.g. Guthrie & Koenigswald 1996; Van Kolfschoten, Buhrs, et al. 2015) or weapon impacts (e.g. Noe-Nygaard 1974; Leduc 2012). The lateral side of the scapula (Fig. 5.9) has a raised spine separating the blade into unequal parts, with an area of cartilage at the end of this blade. The medial side sits over the ribs and vertebrae and is relatively flat.

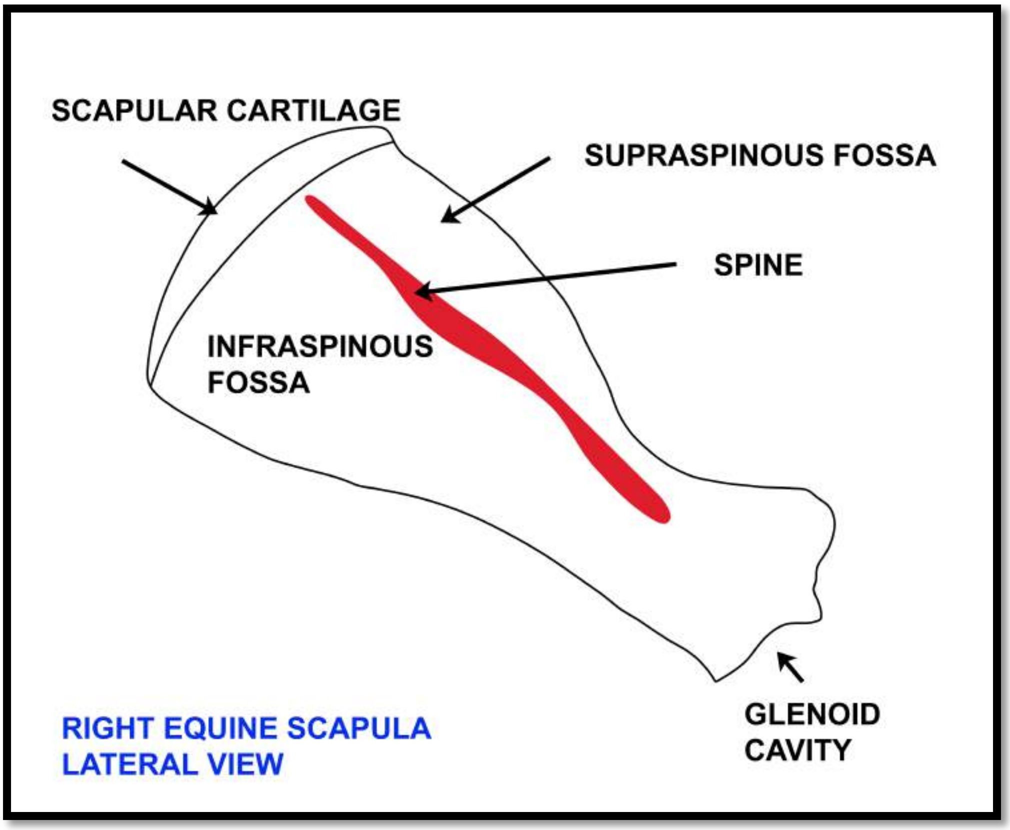


Figure 5.9. Schematic drawing of right horse scapula, in lateral view, with relevant features labeled

5.1.3 Interpreting potential Middle Pleistocene hunting lesions

The most relevant experimental work pertaining to interpreting hunting lesions produced by wooden spears is summarised here. In addition to the evidence of wooden spears from MIS 11 onwards, the MP also has numerous sites with faunal remains bearing impact damage from the use of hammerstones to open bones for accessing marrow and grease reserves (e.g. Stiner et al. 2009; Blasco et al. 2013; Smith 2013; Van Kolfschoten, Buhrs et al. 2015). Both Boxgrove and Swanscombe have produced such evidence, and therefore some relevant findings pertaining to this behaviour are also covered.

5.1.3.1 Experimentally produced hunting lesions and untipped wooden spears

The first experiment that was designed to evaluate the ability of wooden spears to perforate a large mammal scapula was undertaken by forensic scientist Bernard Knight and the Boxgrove Project team for the documentary *The Butchers of Boxgrove* (1996). This involved impacting two de-fleshed horse scapulae with the point of a wooden spear using an impact machine and the methods and results are unpublished but the two scapulae (labeled 'Knight Scapulae' in this thesis) were made available for analysis by the NHM and are presented in Chapter 8 (8.5). Limitations of this experiment include an unknown force of impact, and the use of de-fleshed bone, so although the footage demonstrates the ability of a wooden spear to perforate a horse scapula, it does not demonstrate the ability of a wooden spear to create such damage on an animal with hide and muscle tissue intact.

A subsequent experiment was conducted in which a female javelin thrower threw a 2 meter long wooden spear from a distance of 6 meters at a 15.5 kg lamb carcass, resulting in cracking, splintering, 'saw-toothed' fractures and complete fracturing of portions of the scapulae (Smith 2003). This experiment also replicated spear thrusting into a lamb carcass using untrained human participants, resulting not only in splintering, cracking and bone deformation, but also in perforations (Smith 2003). While it is the only such known experiment using wooden spears on an animal carcass there are limitations here as well. One is that a lamb carcass is a small-sized juvenile individual, falling into size class 1 whereas an adult horse would fall into size class 4 (Table 2.1). Hide, tissue and skeletal morphology of a lamb carcass differ significantly from that of a horse. Additionally, juvenile animals' bone mineral density differs from adults, and is thought to improve the ability of a projectile to puncture animal bones (Letourneux & Pétillon 2008). No measurements of the DoP of resulting lesions are provided, nor is there a discussion of how they relate to the spear morphometrics or impacts.

Another relevant experiment is that published by Parsons & Badenhorst (2004), who thrust and threw (from a distance of 3 to 4 m) lithic-tipped spears at a 180 kg wildebeest carcass, which falls into size class 3 and thus is more relevant to understanding damage on horse remains, but the experiment used lithic-tipped spears not untipped wooden spears. Interestingly, like Smith (2003) their results demonstrated that thrusting but not throwing actions resulted in scapulae perforations. Letourneux & Pétillon (2008) conducted an experiment involving osseous tipped weapons, fired using a spear-thrower and bow/arrow at a juvenile cow and an adult fallow deer. Problems with using these results to interpret the Boxgrove scapula involve the mechanical differences of complex weapons in relation to hand-delivered weapons, as well as the age and size classes of the animal targets. However, they did make some interesting observations that shapes of perforations and punctures on faunal remains may fit the cross-section of weapons, and that embedding of lithic points into faunal material was a relatively rare occurrence (Letourneux & Pétillon 2008).

Finally, Smith et al. (2007) conducted experiments looking at the morphology of impact wounds created by lithic-tipped arrows. Impact velocities of spear-thrower and bow/arrow technologies, particularly in conjunction with lithic-tipped weaponry are unlikely to be directly comparable with damage from hand-delivered wooden spears. However, some interesting observations on morphology of hunting lesions were made. Like gunshot wounds, perforations in their experiments tended to show internal beveling, with larger 'internal' than 'external' breakage of cortical bone, similar to patterns observed by Noe-Nygaard on prehistoric hunting lesions (1974) (discussed further in sections 5.2.2.1, 5.3.2.3, 5.3.2.4). Also of interest was the observation that all of the perforations resulted from the larger arrows tested whereas the smaller weapons tended to only produce punctures (see Table 5.1 for definitions) (Smith et al. 2007). The quantification regarding bevelling is relevant to the assessment of the Boxgrove and

Swanscombe artefacts in question as this characteristic was a feature pointed out by the forensic scientist Bernard Knight in the aforementioned Boxgrove documentary (1996) in favour of evidence of weapon impact. The experimental research outlined above cannot be directly applied to interpreting the lethality of wooden spears on large mammals, or the analysis of possible hunting lesions they create, necessitating further experimental research, which is presented in Chapter 8.

5.1.3.2 Hominin assemblage modification: hammerstone impacts for marrow and grease extraction

To identify and assess hunting lesions in the archaeological record it is necessary to consider other possible causes of damage, whether related to human activities or taphonomic factors. Before criteria for identifying lesions can be considered 'diagnostic', a range of processes must be considered and compared. MP hominins, including those at both Boxgrove and Swanscombe used hammerstones to break open the bones of prey animals in order to consume marrow and grease reserves contained within both cancellous bone and medullary cavities (Parfitt & Roberts 1999; G. Smith 2010). 'Cold' marrow processing was practiced by humans prior to the Upper Palaeolithic to access marrow and grease reserves in animal bone (Stiner 2005), and Assaf (2017) has recently proposed that 'spheroids' found in association with equid remains at Qesem Cave (Israel) dated to 420-200 BP, were used as hammerstones to access bone marrow. Although most typically it is long bones and mandibles that are the focus of marrow extraction, Stiner (Stiner 2005) provides a Middle Palaeolithic example of the exploitation of scapulae for marrow and grease: all medium and large ungulate scapulae recovered from the Mousterian Layer E at Hayonim Cave were opened for marrow and grease exploitation. Numerous ethnographic studies describe the practice of marrow extraction, particularly from long bones (e.g. Hiatt 1968; Binford 1981; O'Connell et al. 1988; Oliver 1993; Abe 2005). Hadza hunters break not only long bones with hammerstones and anvils, but also axial elements, including zebra ribs at kill sites for marrow (Oliver 1993). For prey of size classes II and greater, the Hadza used hammerstones and anvils for 93% of breakage of axial and limb bones (Oliver 1993). What is particularly relevant to evaluating zooarchaeological assemblages during periods from MP sites without good evidence of the use of fire, the Hadza consumed uncooked cancellous bone, accessed by striking the bone with a hammerstone on an anvil, a process that left marks on the cortical bone including 'pits, dents, and scratches', and then using a knife to cut out cancellous tissue for sucking and chewing (Oliver 1993). Examples exist of pulverising cancellous bone for bone grease rendering but these processes involve heating the resulting bone fragments and mush to extract grease (e.g. Abe 2005; Costamagno 2013).

Marrow has a high fat content, and is high in caloric yield. For humans with a high protein/low carbohydrate diet, which would particularly be the case in cooler temperate periods such as at Boxgrove, the fat in marrow could provide an essential component of the diet (Outram 2001). Additionally, increased processing of animals, especially marrow, is known to coincide with resource stress, not only in order to maximise the return from the animal but also because if the animal itself is lean or in a state of starvation, the bones continue to hold a significant amount of fat as they are the last source that the body metabolises (Outram 2001 and references therein; Stiner 2005).

Horses have very low quantities of marrow compared with other ungulates although quantities vary by individual (Outram & Rowley-Conwy 1998). Horse marrow is liquid in consistency, and contains a high amount of essential polyunsaturated fats, which are very healthy compared with the saturated fats found in most animal marrow (Outram & Rowley-Conwy 1998), and ethnographic examples suggest that humans will consume marrow from relatively low-yield animals such as equids due to taste preferences as well as nutritional concerns. All of these factors support the possibility that MP hominins were accessing grease and marrow from ungulate scapulae, and particularly for horses with low long-bone marrow yields and nutritious marrow in liquid form, using a simple and readily available technology.

5.2 Materials and Methods

5.2.1 Materials

5.2.1.1 Boxgrove scapula and scans

One of the two fragments of the right scapula from the butchered horse at Boxgrove GTP17 (Unit 4b) is the object of the analysis here (Fig. 5.10). The fragment is part of the infraspinous fossa of a right scapula. The siding of the fragment is on the basis of the curvature of bone on the medial side, which is a feature of the edge of the infraspinous fossa on a horse which is not mirrored on the edge of the supraspinous fossa. In addition, features indicating muscle attachments place the scapula fragment to the right side (Simon Parfitt, pers. comm.). Clarification is necessary as the scapula has been referenced as being a left scapula fragment (Gaudzinski-Windheuser 2016), and the siding has implications for the results and discussion that follow regarding a possible spear impact and bevelling. The original artefact (Figs. 5.10 - 5.13), a CT scan and 3D print and the in situ photograph of the fragment together comprise the materials for studying the this fragment. At the time of excavation the fragment was discovered with the lateral side facing upwards (Fig. 5.3). In an extremely fragile state, the bone was damaged during lifting of the artefact, with a small removal of the initial edge of the curvilinear fracture. For this reason the original excavation photograph is key for a quantitative analysis. It also facilitates a visual reconstruction of the approximate location of the damage in relation to a modern horse scapula. Due to its friable nature, a CT scan was taken of the bone in 2014 by the Natural History Museum, and was generously made available for analysis in this thesis. A video of the scan is viewable on the accompanying CD (Video 5.1). A 3D print in plaster, a material suitable for complex shapes without support structures, was subsequently made at UCL's Bartlett DMC. Both the scan and print have proved of great value not only for further analysis of the damage but also as a means of sharing the object with colleagues and members of the public. Access to the original artefact was provided by the NHM.

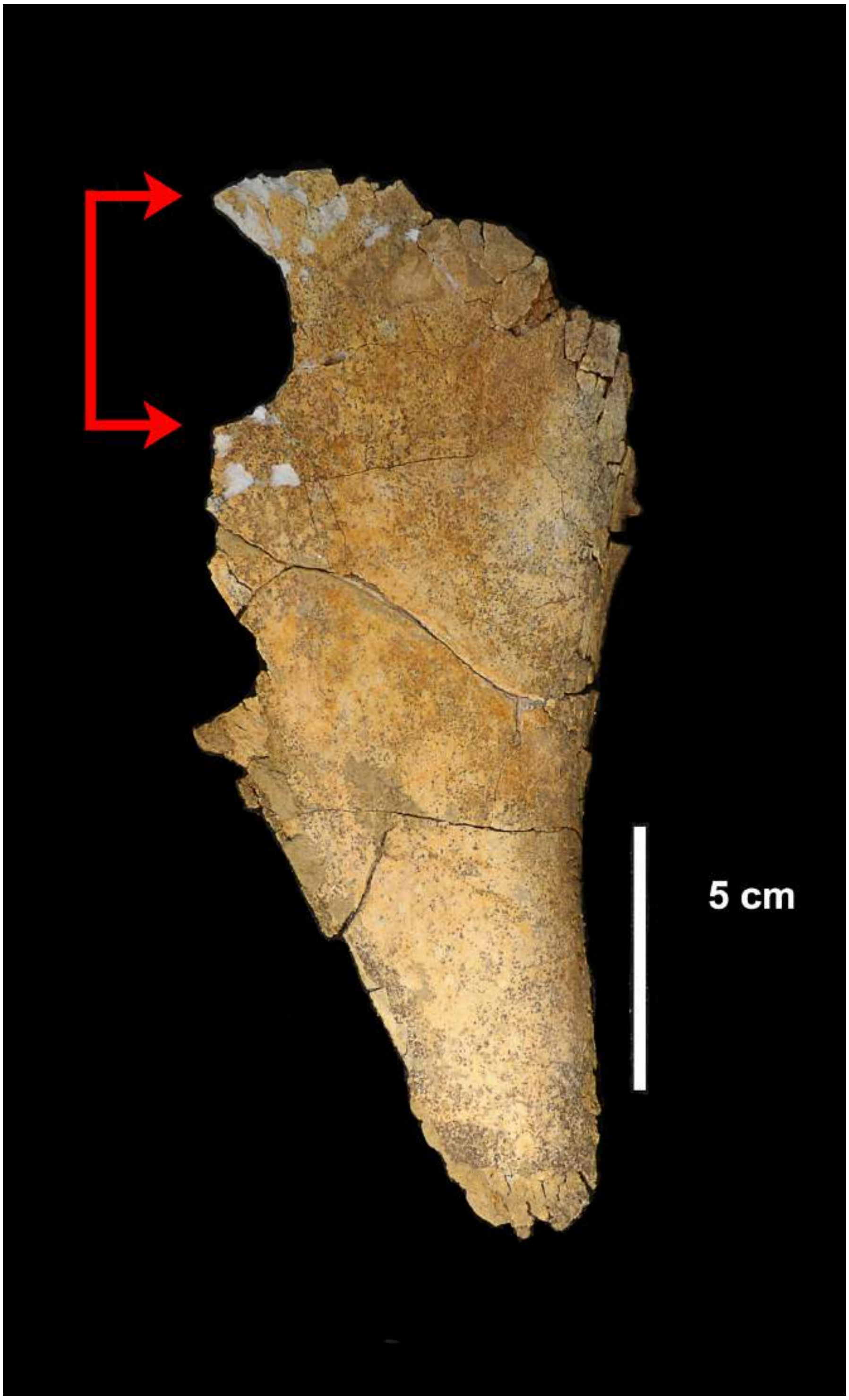


Figure 5.10. Boxgrove scapula fragment. Medial View. Bracket indicates the curvilinear fracture

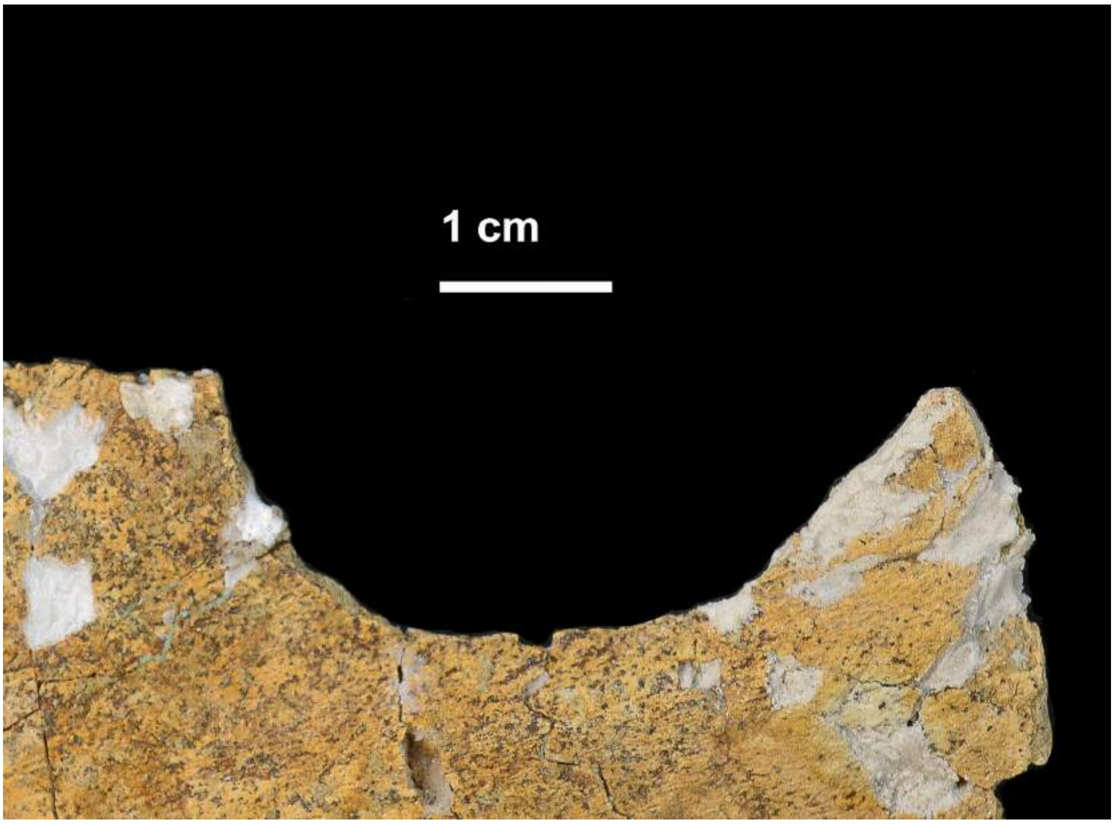


Figure 5.11. Close-up of the medial side of the curvilinear fracture

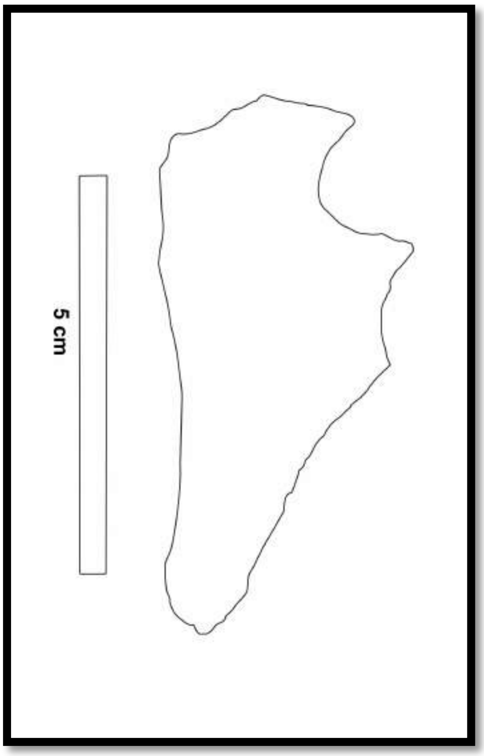


Figure 5.12. Outline of the in situ photograph, lateral side. (Drawing by A. Milks after Austin et al. 1999, Fig. 289)

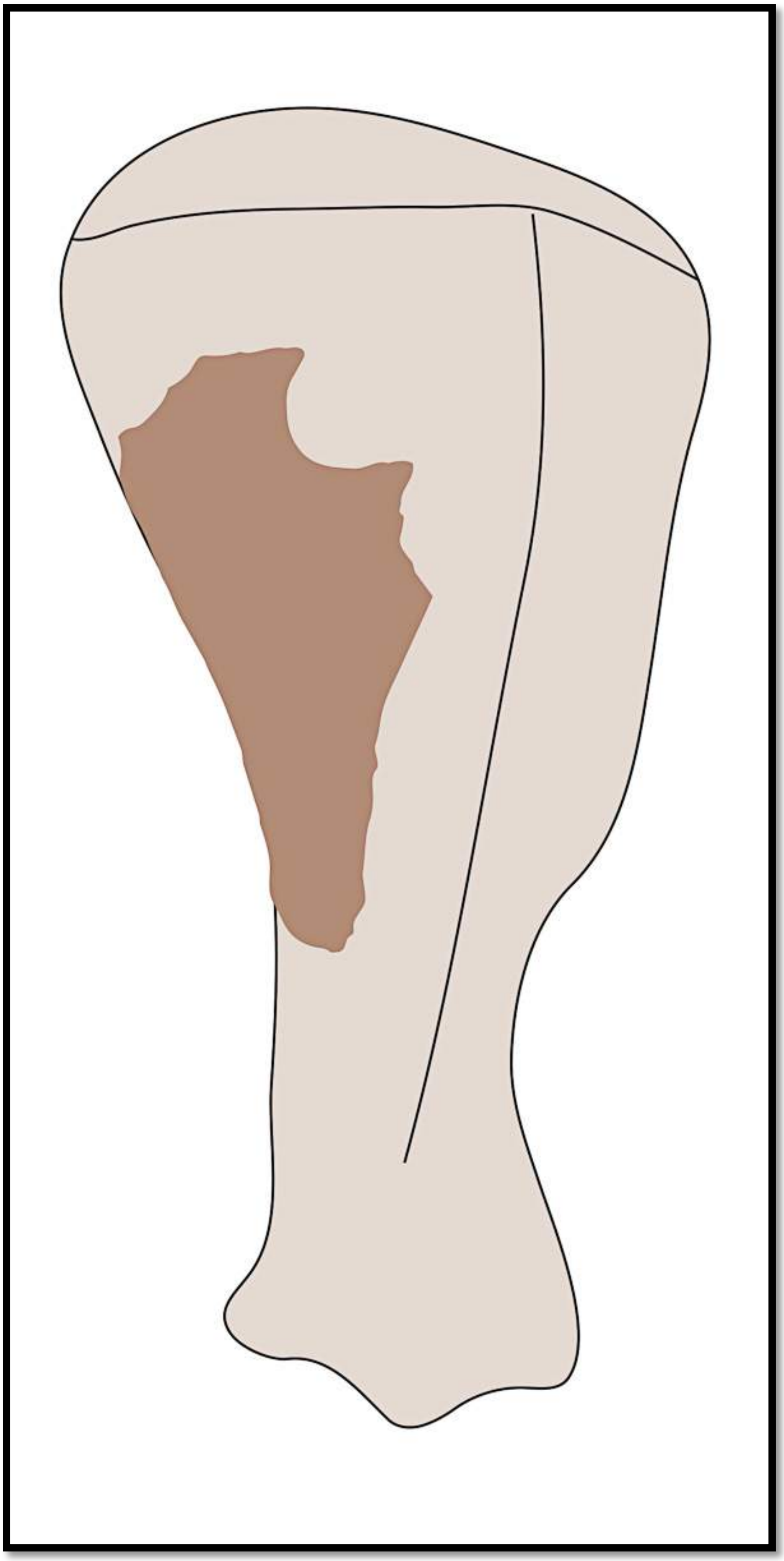


Figure 5.13. Lateral view of a horse scapula blade with the outline of the in situ outline superimposed to show approximate location of the fracture. The scapula outline is traced over a modern horse scapula

5.2.1.2 Swanscombe scapula

The Swanscombe scapula (SC 71 A3 60-80) is from the collection of faunal material from the Waechter excavation season in 1971, Trench A3 from the Lower Gravel Unit 3. It consists of the glenoid, neck and part of the blade of a fallow deer (*Dama dama clactoniana*) and was suggested by Smith (2010) as possibly having a hunting lesion similar to that on the Boxgrove scapula (Figs. 5.14-5.16). In addition, 34 cervid scapulae from the Lower Gravel at Swanscombe A.T. Marston Collection (1938) were examined for similar fractures and evidence of microscopic percussion marks. Access to the artefact was granted by the NHM, where the mammalian collections are held, and access to the British Museum Swanscombe archive was granted by the British Museum.

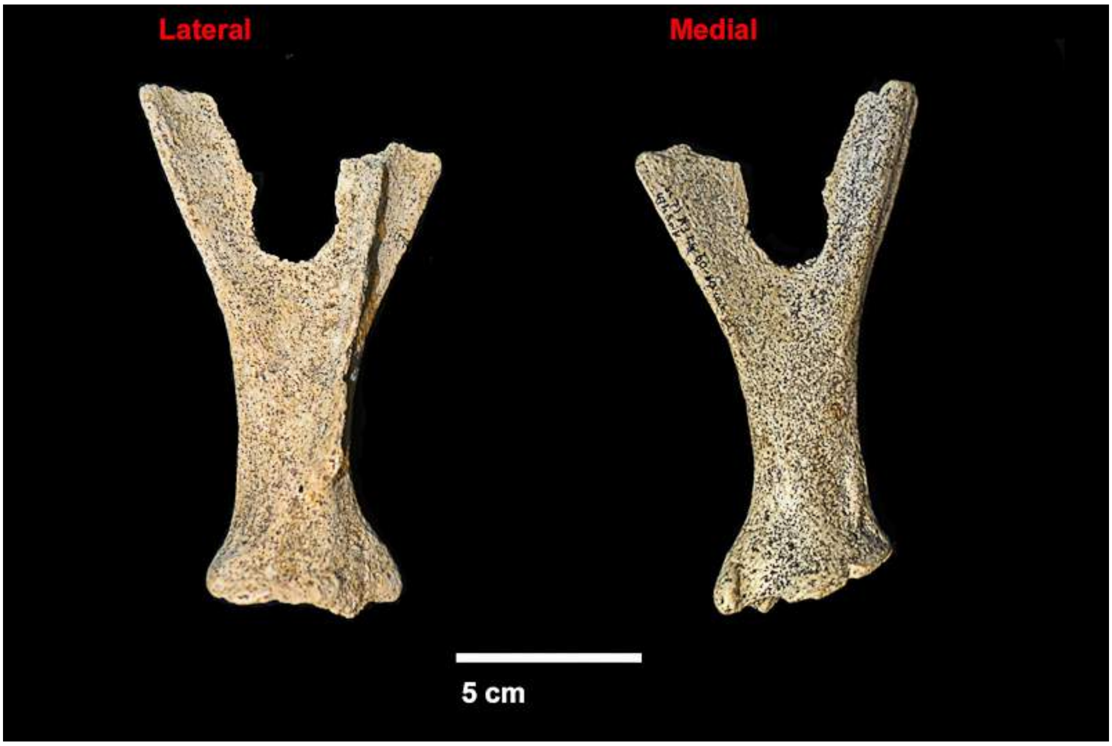


Figure 5.14. Lateral and medial views of the cervid scapula from Swanscombe Lower Gravels, bearing a curvilinear fracture suggested to potentially represent a hunting lesion

Figure 5.15. Close up of Swanscombe damage, lateral side

Figure 5.16. Close up of Swanscombe damage, medial side

5.2.2 Methods

The methods described in this section were also used for the comparative analysis bringing together the archaeological and experimental data presented in Chapter 8 (section 8.5). Microscopic analysis on the Boxgrove and Swanscombe scapulae used a zoom microscope at 50x magnification. Photographs were taken using a Nikon D3100 Digital SLR camera. Image editing and preparation used Adobe Photoshop® and Adobe Illustrator®. The reconstruction in Fig. 5.25 was in order to visualise what the dimensions and shape of the damage may have been if the perforation was completely enclosed, as it would have been if the result of impact from a wooden spear. This was executed by tracing the outline of the damage (Fig. 5.25, pink area), copying and pasting this shape and rotating it to mirror the fracture (Fig. 5.25, yellow area). This is only intended as a heuristic visualisation, and is not intended to propose that this was the original size and/or shape of the damage.

5.2.2.1 Descriptive analysis

A descriptive analysis for damage to bone was developed to integrate methodologies on patterns of bone damage, including percussion impact damage, projectile impact damage and blunt force trauma. This descriptive method facilitates the comparison in Chapter 8 which brings together data from the Boxgrove and Swanscombe scapulae with those from original experimental research in this thesis, and published and unpublished datasets pertaining to experimental and archaeological examples of hunting lesions and hammerstone damage.

O'Driscoll and Thompson (2014) developed a descriptive terminology to describe hunting lesions and break down the terms into five main categories. The method aimed to develop a framework to distinguish between hunting lesions and butchery damage, but the latter addressed only cut marks from lithic tools, and not impact damage from percussion. Because humans are known to use hammerstones to access marrow in large ungulates after hunting them with weapons and de-fleshing with sharp edged tools (e.g. Binford 1978; Binford 1981; Oliver 1989), a system to compare marks from multiple human activities is necessary. Therefore, O'Driscoll et al.'s (2014) system is modified and expanded in this thesis to encompass further traits and avoid overlaps in terminology. Traits are broken down into primary (Table 5.1) and secondary (Table 5.2) damage categories that are relevant to this research and have been modified using terminology from other studies (Binford 1981; Bunn 1981; Villa, Bouville, et al. 1986; Villa, Courtin, et al. 1986; Quatrehomme & Yaşar Işcan 1998; Outram 2002; Hart 2005; Letourneux & Pétillon 2008; Churchill et al. 2009; Spatola 2015).

Crushing is a term that is used as both a primary as well as secondary damage characteristic. This is because crushing can be used to characterise an entire impacted area, when the bone is not punctured or perforated, in which case this accurately describes the primary fracture.
The term 'notch' is sometimes used in describing hunting lesions particularly to long bones and ribs (e.g. G. Smith 2003; Letourneux & Pétillon 2008; Pétillon et al. 2011) but this term is also used to describe damage from hammerstone percussion (e.g. Capaldo & Blumenschine 1994; Pickering & Egeland 2006) and therefore is not used here in relation to potential archaeological or experimental hunting lesions. Instead the term 'curvilinear fracture' is used in this thesis to describe a fractured edge of a flat bone that is curved in plan view. This is different from 'spiral' (also known as 'helical') fractures, which typically occur as a result of impacts to fresh long bones (e.g. Capaldo & Blumenschine 1994; Outram 2001) but can also occur on weathered, and to a certain extent frozen and heated bone (Shipman 1981; Morlan 1984; Outram 2001). Causes of spiral fractures include hammerstone loading for marrow breakage (e.g. Pickering & Egeland 2006), weapon impact (G. Smith 2003), traps (Oliver 1989) and trampling (Myers et al. 1980; Shipman 1981). Crushing can also occur around the margins of punctures and perforations, and in these cases is a secondary damage characteristic. 'Percussion mark' refers to marks from hammerstone percussion activities, and is generally used in the literature to indicate microscopic marks on bone from percussion activities aimed at marrow and/or grease

extraction (e.g. Blumenschine & Selvaggio 1988). Galàn et al (2009) expand upon previous studies on percussion marks, and define three types of microscopic percussion marks (Table 5.3). The percentage of these microscopic percussion marks to long bones that have been experimentally broken using hammerstones varies by taxa, hammerstone type and type of mark, and never reaches 100% (Galàn et al. 2009).

Internal bevelling, referred to in prehistoric hunting lesion studies (e.g. M. Smith et al. 2007; Letourneux & Pétillon 2008; Leduc 2012), is a fracture characteristic in which the area of the external surface of the fracture is smaller than the internal surface (Fig. 5.17), and is a typical feature of a ballistic entrance wound (Quatrehomme & Yaşar Işcan 1998). In rare cases external bevelling, with the opposite pattern, can also occur with entrance wounds (Peterson 1991) but internal bevelling is more common and typically indicates direction of impact. Although typically associated with projectile weapon impacts, bevelling can also occur as a result of blunt force trauma (Delannoy et al. 2012; Spatola 2015) and sharp force trauma (Delannoy et al. 2013). Throughout the research on hunting lesions, methodological questions regarding measuring internal and external damage to damage were encountered, as frequently large quantities of cortical bone are removed, most often internally, which could also be classified as 'flaking'. For the purposes of this study, the edge of cortical bone on either side was used to define the damage margin. The descriptive terms adapted for the purposes of the comparisons of multiple types of damage are presented in Tables 5.1-5.3.

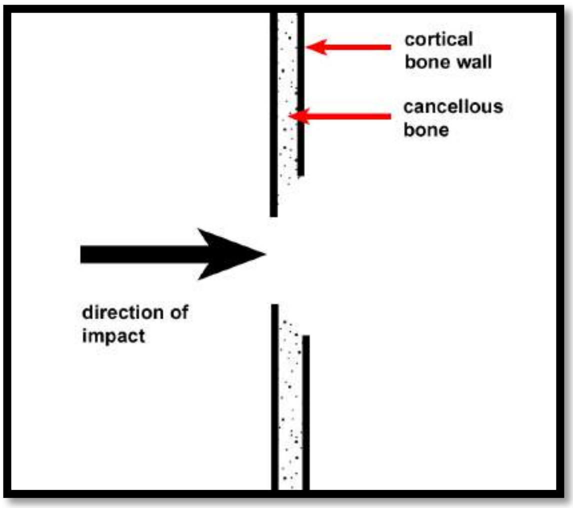


Figure 5.17. Schematic drawing of internal bevelling to a bone

Table 5.1 Primary damage characteristics

Term	Description
Crushing	small pieces of cortical bone displaced inwardly, depressed area without loss of cortical tissue
Puncture	impact through one surface bone wall but not all the way through entire bone, no exit wound
Perforation	object has passed all the way through the bone structure; Perforating trauma has an entrance wound and (often larger) exit wound through the cortical bone; can be a variety of shapes including circular, oval, ovoid, vesica piscis, and irregular Perforations can also result in breaking away of sections of bone, leaving sections of the original perforation, which are designated here as fractures (e.g. see curvilinear fracture below)
Fracture	a break in bone • Spiral fracture/helical fracture: a fracture which spirals around the diaphysis, typical of fractures to fresh long bones. Often have an impact point, and may have microflakes still attached (see secondary characteristics in Table 5.2) • straight fracture: can be longitudinal, diagonal or transverse*, typical of un-fresh bones • curvilinear fracture: a margin which does not create a fully or nearly-fully closed shape but is semi-circular/semi-elliptical in morphology, appears typical of fractures to flat bones
Cracking	cracks/splits of bone, without completely breaking
Drag	cut-like marks, striations
Embedded fragments	fragments from the impacting object remaining embedded in the bone

Table 5.2 Secondary damage characteristics

Term	Description
Crushing	small pieces of cortical bone displaced inwardly, depressed area without loss of cortical tissue 'Microflakes' - small flakes (<1 cm) which have not completely detached from the bone, and are normally associated with impact sites. †
Hinging	partial detachment and outward displacement of chips of cortical bone
Cracking	cracking or splitting of bone emanating from primary damage, can include radiating fractures
Feathering	lifting up of bone without removal ✠
Flaking	complete removal of flakes or areas of cortical bone
Bevelling	internal beveling: area of entrance is smaller than exit external bevelling: area of exit is smaller than entrance
Fracture Angle	obtuse/acute, characteristic of fresh fractures; right angles characteristic of un-fresh fractures, particularly applies to long bone fractures
Fracture edge	helical, transverse, longitudinal, diagonal, stepped/columnar *, sharp, jagged

† Microflakes, also called chips, (Binford 1981) have been considered to be diagnostic of hammerstone impact (Binford 1981; Villa, Bouville, et al. 1986; Villa, Courtin, et al. 1986; Villa & Mahieu 1991) but are also known to occur from natural processes (Oliver 1989). This term has been used loosely, and therefore is quantitatively defined here as flakes measuring less than 1 cm. ✠ Feathering differs from hinging. It results from impact from projectiles on long bones and ribs (see O'Driscoll & Thompson 2014 for images) * Relevant to long bone fractures

Table 5.3. Definitions of microscopic percussion marks (After Galàn et al. 2009)

Type	Characteristics	Potential causes
Isolated striation fields	Microstriations without any associated pits or scores	Direct hammerstone impacts Contact with anvil in hammerstone percussion Trampling
Pits with micro-striations	Occur within and/or emanate from the depression; some pits can look more like scores, scores usually associated with microstriations	Primarily direct hammerstone impacts
Isolated pits	Pits without associated microstriations	Direct hammerstone impacts, most commonly with non-modified hammerstones

5.2.2.2 Quantitative analysis

Length and thickness measurements for damage to the Boxgrove and Swanscombe scapulae, as well as experimentally damaged scapulae (Chapter 8) that were analysed directly from the objects were taken using calipers. Length was defined as the longest measurement parallel to the long axis of each fracture. Breadth measurements were not taken due to the varied nature of fracture types, including both curvilinear fractures (semi-circular) and fully closed perforations, which would have made a comparison of this measurement problematic. The thickness measurements reflect the thickness of bone lateromedially at the point of fracture. Where scaled photographs were analysed for length measurements, for example from publications as well as for the in situ photograph of the Boxgrove scapula, the measurement tool in Adobe Photoshop® CS6 was utilised, setting a custom measurement scale to match the scale in the image.

For area values, calculations were taken from photographs using the software SketchAndCalc™ (Dobbs, 2011) which is capable of calculating areas and perimeters of complex shapes to high accuracy. Both medial and lateral areas were calculated to quantify bevelling. The area calculated for hunting lesions consists of negative space. When damage consists of curvilinear fracture edges, a line was drawn to enclose this space between the fracture edges (Fig. 5.18). For fully closed perforations, area and perimeter were calculated for the entire space (Fig. 5.19). The perimeter was digitally drawn around the rim of cortical bone, and areas with crushing were not included. If cortical bone had been removed exposing cancellous bone, the rim of cortical bone was followed.

Damage of perforations to the lateral sides of scapulae were measured for area and for length of the longest axis of the perforation, unless only the medial view was available in which case this side was used in order to increase the sample size. Bevelling ratios were calculated when areas of both lateral and medial sides of damage could be taken. It is important to clarify that the area calculated for bevelling for the Boxgrove fracture relates to the present state of the artefact, not the in situ photograph, as the medial side of the object in its original state was not photographed at the time of excavation making such a calculation impossible. The lateral area calculated and used elsewhere to make comparisons with other lesions was made from the in situ photograph, and therefore does not match that used to calculate bevelling.

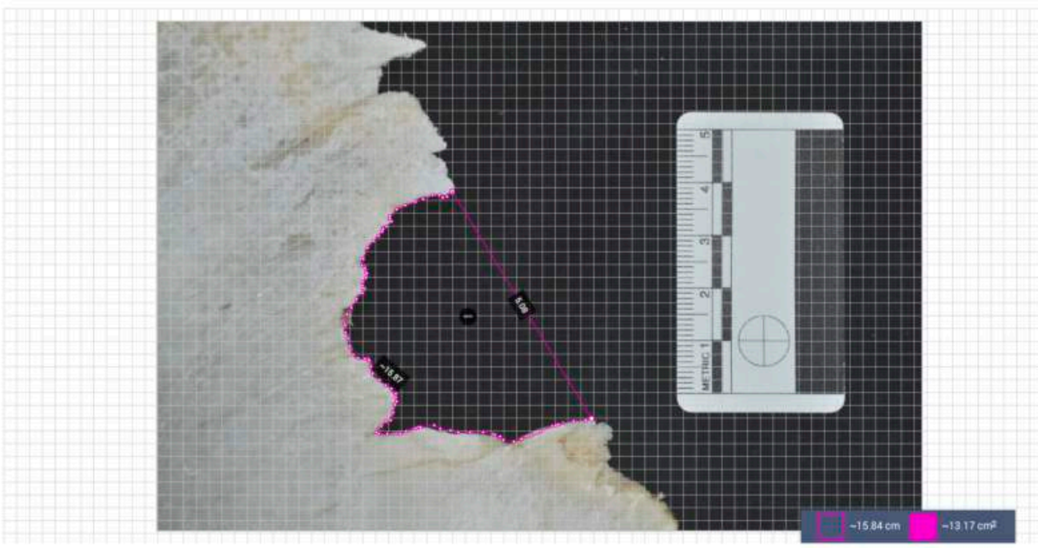


Figure 5.18. Example of method used to calculate area and perimeter of curvilinear fractures

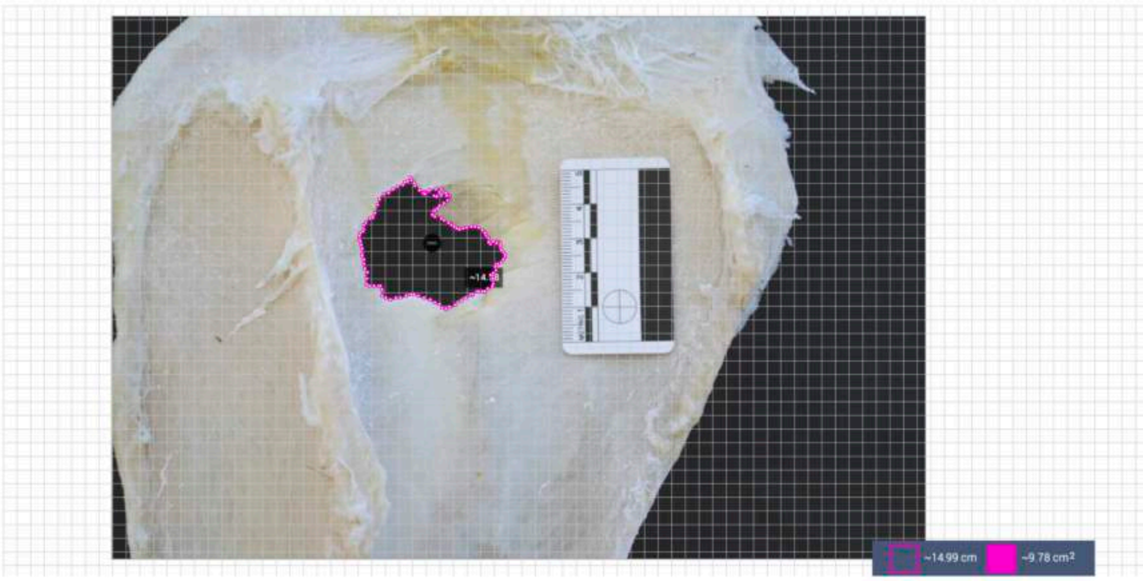


Figure 5.19. Example of method used to calculate area and perimeter of perforations

5.3 Results

5.3.1 Descriptive analysis

5.3.1.1 Descriptive analysis of Boxgrove scapula fragment

The Boxgrove scapula fragment has a curvilinear fracture on the infraspinous fossa with a relatively sharp margin which could have resulted from a dynamic impact. The Boxgrove fracture does not show any clear secondary damage characteristics (Table 5.4), with taphonomic processes potentially obscuring these. Cut marks to the medial side illustrated elsewhere (Parfitt & Roberts 1999, Fig. 314) represent de-fleshing of the scapula. These cut marks do not overlap the curvilinear fracture and therefore a sequence of damage cannot be implied from the cut marks (contra Ash & Robinson 2010). No microscopic percussion marks were seen that would be evidence of hammerstone impact. The lateral side of the fragment is less well preserved than the medial side due to post-depositional processes (Simon Parfitt, pers. comm.).

Table 5.4. Damage characteristics of the Boxgrove and Swanscombe scapulae

Scapula	Primary Damage	Secondary Damage	Shape	Fracture Rim Characteristics	Microscopic Damage
Boxgrove	**Lateral and medial**: curvilinear fracture. Possibly resulting from a perforation	None visible	Curvilinear fracture	**Lateral and Medial**: sharp	None
Swanscombe	**Lateral and medial**: curvilinear fracture. Possibly resulting from a perforation	**Lateral and medial:** Flaking	Curvilinear fracture	**Lateral and Medial**: both jagged and sharp	None - heavily pitted surface

Figure 5.20 is a composite image of the 3D print over a modern horse scapula on a lightbox, which shows that the perforation is in a relatively thin area. The perforation occurs around scan site 3 for BMD (Table 3.2 and Fig. 3.4 of this thesis; Lam et al. 1999) which has a slightly denser value in equids than scan site 5 at the end of the blade, but is less dense than the other three scan sites. Whether caused by a hunting lesion, a hammerstone impact or some other factor, the fracture is in a relatively thin area prone to damage.

Figure 5.20. Horse scapula blade with print of Boxgrove scapula fragment superimposed to show approximate location of the fracture in relation to blade thickness

5.3.1.2 Descriptive analysis of Swanscombe scapula

The curvilinear fracture on the Swanscombe scapula is a semi-circular perforation on the infraspinous fossa, and is located on one of the denser areas of cervid scapulae (Table 3.1). The remaining section of the blade extending from the fracture mimics a typical v-shaped fracture pattern often seen on naturally-broken mammalian scapulae. The surface of the bone is heavily pitted and scratched, most likely as a result of deposition in a high-energy fluvial environment. The poor condition of the surface makes it impossible to assess the scapula for either microscopic percussion marks or cut marks, making evidence of hominin modification of the scapula uncertain. The fracture edge is somewhat jagged in areas and sharp in others, with flaking evident on both the lateral and medial sides (Figs. 5.21 and 5.22). None of the additional cervid scapulae examined (n = 34) had clear evidence of percussion damage. Cervid scapulae examined from the Lower Gravel do show evidence of cut marks, which confirms hominin involvement with cervids in this context at Swanscombe (Figs. 5.23 and 5.24). The archival search did not produce any additional photographic or written information such as in situ photographs or desriptions of the artefact in excavation notebooks.

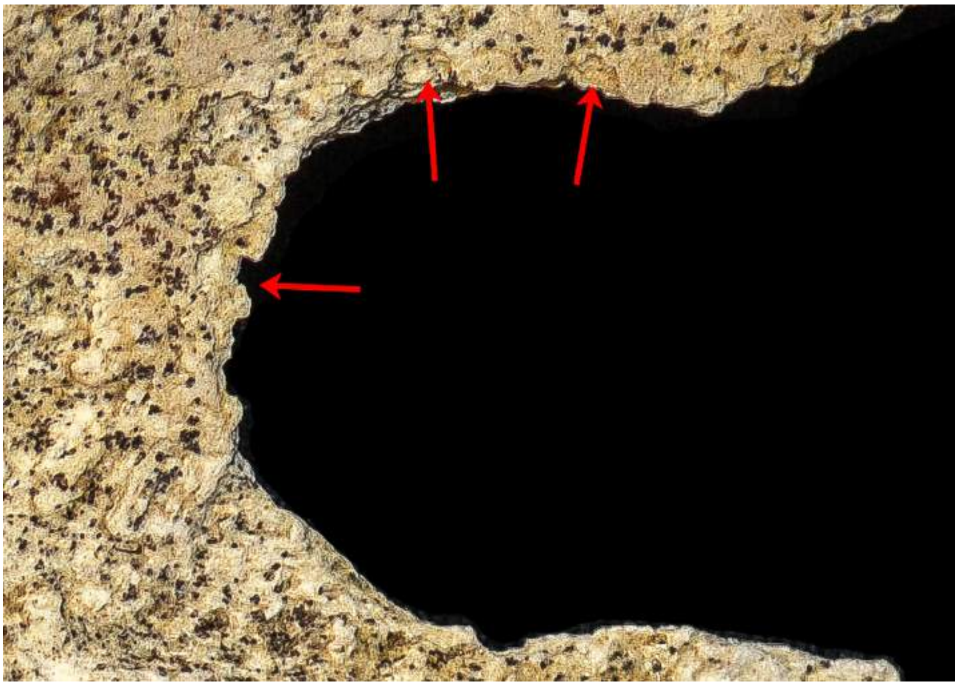


Figure 5.21. Flaking on lateral margin of the Swanscombe scapula

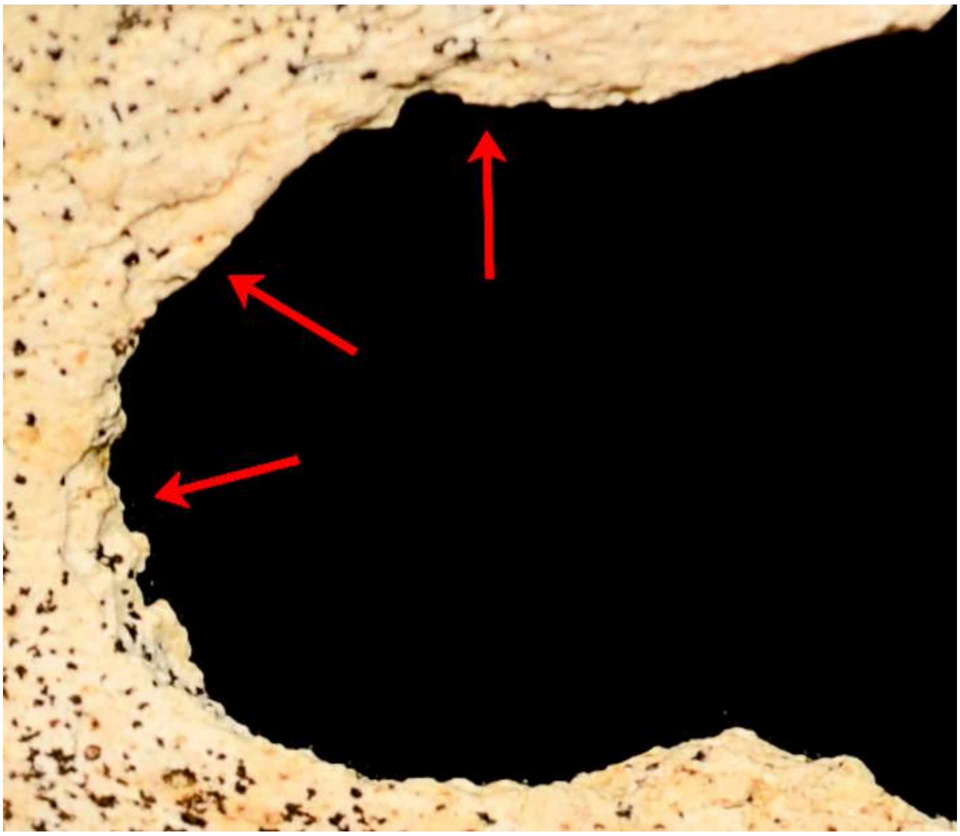


Figure 5.22. Flaking on medial margin of the Swanscombe scapula

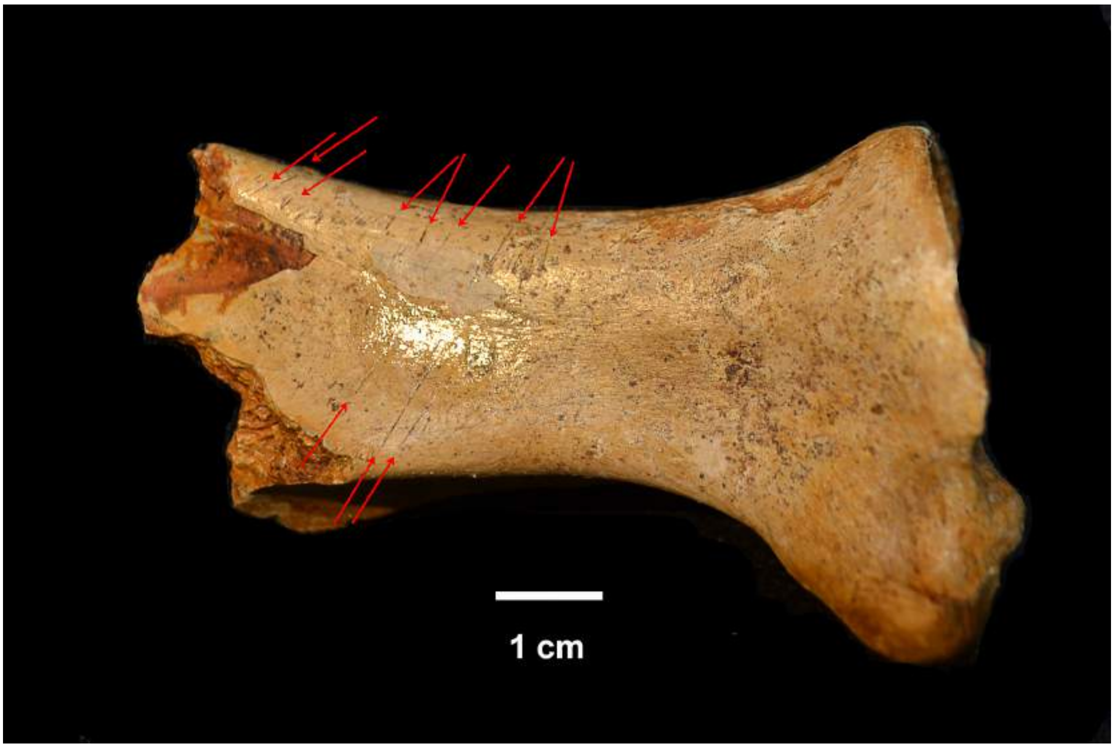


Figure 5.23. Cervid scapulae from A.T. Marsten collection at the NHM. Red arrows point to cut marks

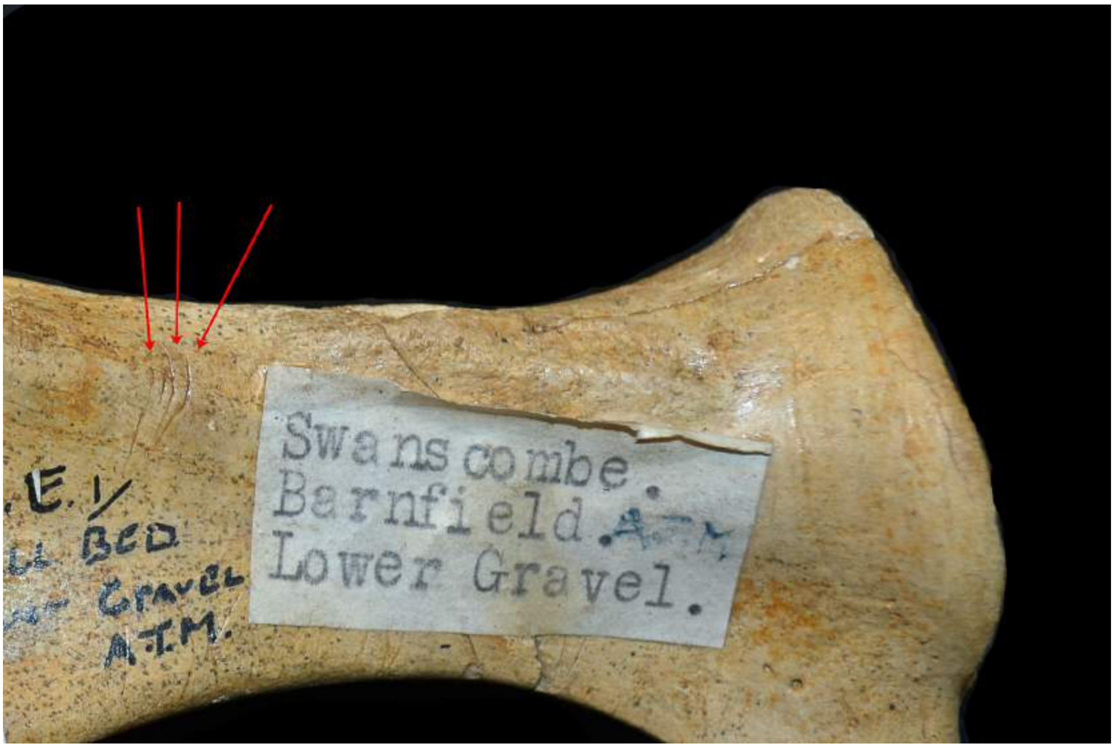


Figure 5.24. Cervid scapulae from A.T. Marsten collection at the NHM. Red arrows point to cut marks

5.3.2 Quantitative Analysis

5.3.2.1 Dimensions of Boxgrove damage

The maximum length of the Boxgrove fracture as measured from the in situ photograph is 48 mm, with the maximum length located between the two fracture edges. The distance perpendicular to this measurement is 23 mm, which suggests that if the original fracture had been an enclosed perforation, it would have been roughly circular though with some straighter edges in areas, as can be seen in Fig. 5.25. The thickness of the bone at the fracture measures from two mm to four mm.

5.3.2.2 Dimensions of Swanscombe damage

The maximum length of the Swanscombe fracture is 22 mm. As the shape of the fracture is nearly circular, the overall diameter can be estimated at ca. 22 mm. The thickness of the damage ranges from one to three mm, and like the Boxgrove damage is in a thin area of the blade.

5.3.2.3 Bevelling of Boxgrove scapula

The Boxgrove scapula displays a very small amount of external bevelling (Table 5.5), with a ratio of 1.03 to 1 lateromedially. Three cross-sections of the curvilinear fracture have been taken from the CT scan to visualise the edge (Figs 5.26 and 5.27). Video 5.2 (on accompanying CD) provides a further visualisation of the three cross-sections. These illustrate the small amount of external bevelling present on the curvilinear damage. As described in 5.2.2.1, internal bevelling most typically results from dynamic impact. If the curvilinear fracture on the Boxgrove scapula resulted from an impact, the most likely scenario is that this impact occurred from the medial side. This makes the possibility of impact from a weapon less likely, as spearing through a horse scapula from the inside would be difficult to achieve given the location of the fracture on the blade and the anatomy of a horse.

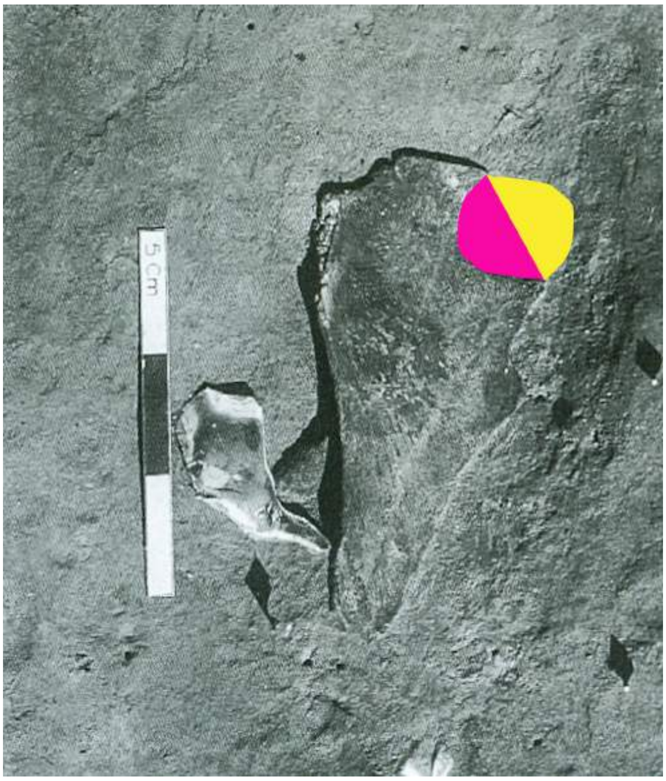


Figure 5.25. Reconstruction of possible area of damage on Boxgrove scapula had the perforation been a complete hole (modified after Austin et al. 1999, Fig. 289)

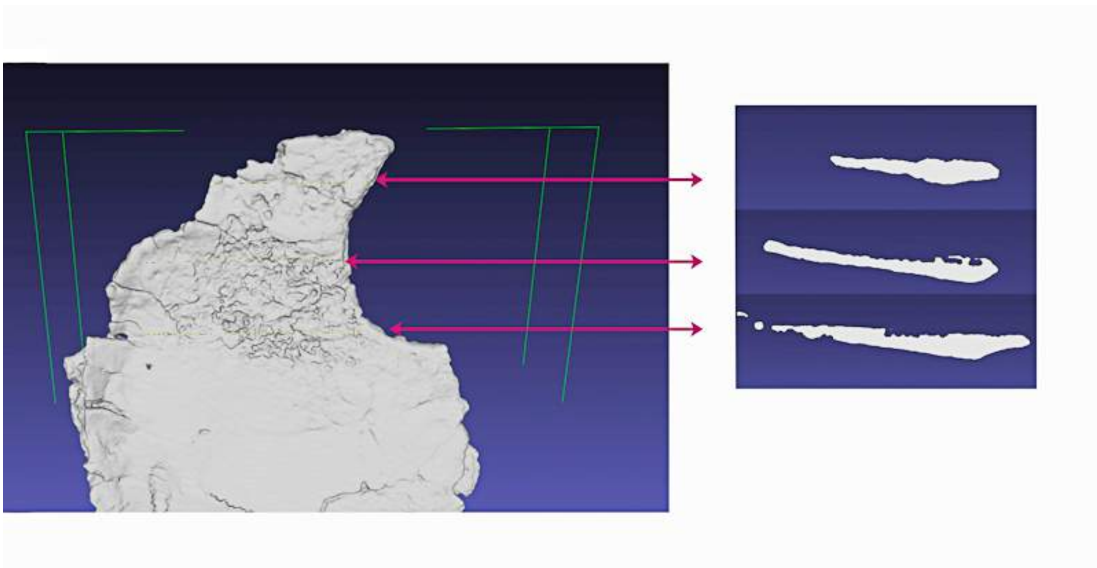


Figure 5.26. Cross-sections of CT scan at three points along the curvilinear fracture, with arrows indicating their location on the scan. The plan view is of the lateral side

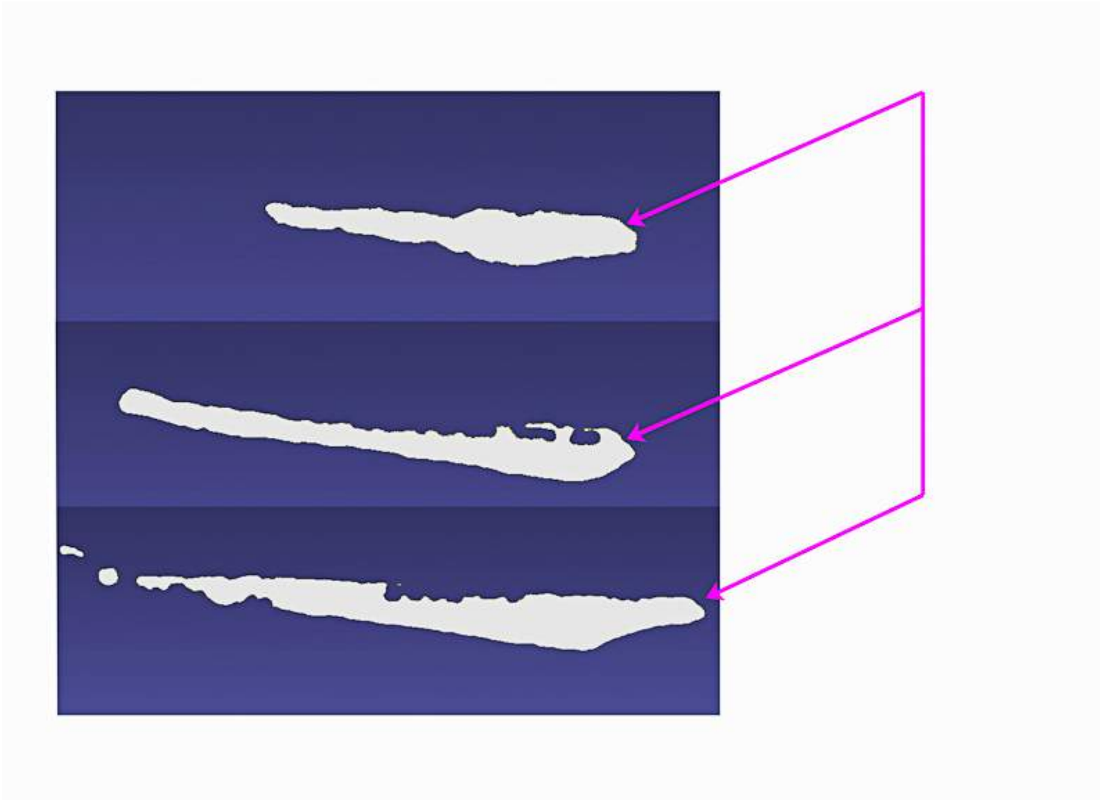


Figure 5.27. Close-up of the three cross-sections of the Boxgrove curvilinear fracture. The arrows point to the slight bevelled edge. The direction of bevelling is external, i.e. the lateral edge is larger than the medial edge

5.3.2.4 Bevelling of Swanscombe scapula

The Swanscombe scapula also has a very small amount of bevelling (Table 5.5), with a ratio of 1 to 1.1, but the direction of bevelling is internal, consistent with an impact from the lateral side. Overall, the ratios of bevelling on the two MP scapula examples are very small, and will be further compared with ratios from experimental and published archaeological scapula hunting lesions in Chapter 8 (section 8.5).

Table 5.5. Bevelling directions and ratios calculated for Boxgrove and Swanscombe

Scapula	Estimated Area (lateral, mm^2)	Estimated Area (medial, mm^2)	Bevelling	Bevelling Ratio (lateral to medial)
Boxgrove *	49.9, (present state)	48.3, (present state)	External	1.03 : 1
Swanscombe	3.56	3.93	Internal	1 : 1.1

*** Note that the areas presented for Boxgrove bevelling differ from the areas calculated for overall size comparisons as both sides were needed for the calculation**

5.4 Discussion

5.4.1 Assessing the Boxgrove scapula

The location of the damage on the blade of the Boxgrove horse scapula suggests that a perforation from impact of some kind is possible. Because it only is a fragment it is possible that the scapula, like the remainder of the horse, was impacted with hammerstones after de-fleshing to access marrow and grease reserves; although there are no microscopic percussion marks, experimentally these are only visible between 25% and 45% of the time when made by unmodified hammerstones, depending upon the type of mark and taxa (Galàn et al. 2009), and additionally it is as yet unclear what role post-depositional factors play in obscuring these marks. Only a small fragment of the neck of the scapula remains and the left scapula is missing entirely, which may indicate that hominins had undertaken nearly complete fragmentation of the horse bones for the purposes of consuming within-bone nutrients. Carnivore involvement with the carcass, which likely took place after hominin involvement, may have removed from GTP17 the majority of the remainder of the bones after hominins had butchered it. A combination of these two factors would explain the highly fragmentary state of the horse bones. Hominins were also fragmenting scapulae with hammerstones at Boxgrove elsewhere at the site, with *Cervus elaphus* scapulae from Q1/B bearing impact damage, particularly focused on breaking open the neck and glenoid cavity (Simon Parfitt, pers. comm.; pers. obs.). If the damage is hypothetically reconstructed as a circular perforation, it would have had a diameter of roughly 48-50 mm. Assuming observations that the shape and size of hunting lesions match those of weapon tips are correct (Letourneux & Pétillon 2008; Noe-Nygaard 1974), and the Boxgrove damage represented impact from a wooden spear, the weapon would have had a very large diameter at the point of penetration. As presented in Chapter 4, the Clacton spear has the largest diameter of the sample of archaeological spears directly studied, measuring 38 mm at the widest section of the distal point. Therefore the size of the Boxgrove damage is well in excess of the archaeological spears studied. Proposals on the basis of size, shape, and bevelling that the damage to the scapula fragment from Boxgrove represents a hunting lesion from a wooden spear are therefore tenuous.

5.4.2 Assessing the Swanscombe scapula

Regarding the cervid scapula from Swanscombe, the location of the curvilinear fracture on the blade is consistent with the general location of hunting lesions on scapulae (Fig. 3.3) and bevelling indicates a possible impact from the lateral side which would also be consistent with a spear impact. The location of the fracture on the blade would make a hammerstone impact difficult to execute, and due to the pitted surface, other signs of human modification cannot be recognised. The diameter of the fracture of ~22 mm is a better match for wooden spears than that from Boxgrove. At Swanscombe the Lower Gravel cervid scapulae with cut marks studied had both the glenoid and neck areas intact, as does the scapula with the fracture. These areas have the largest areas of spongy bone, though in small cervids these reserves would be small. Together this evidence suggests that hominins were not hammering small cervid scapulae in this context for marrow and/or grease, making an explanation that hammerstone impact caused the Swanscombe fracture unlikely. However, interpretations of hominin behaviours at Swanscombe must be made with caution due to the poor resolution at the site (G. Smith 2013). The high-energy fluvial environment, particularly in the Lower Gravel brings up the possibility of natural damage occurring, possibly due to impact from stones during movement in the river system. In addition, the material from Waechter's excavations display troweling damage (Schreve 1996), and Trench A3 was excavated in deep spits which means that possible excavation damage of this bone also cannot be ruled out. Neither quantitative nor qualitative approaches to these artefacts can yet be used to draw definitive conclusions regarding the cause of curvilinear fractures on the Boxgrove and Swanscombe scapulae. Experimental approaches are necessary for comparative purposes, not only to investigate potential alternative causes to the use of wooden spears, but also the damage that hand-delivered wooden spears are likely to make to these bones. These two artefacts will be re-assessed in light of the experimental work regarding hammerstone use (8.2) and spear use (8.4). Section 8.5 will draw together these results with further pertinent published and unpublished data to make a final assessment of these potential hunting lesions.

Chapter 6. The ethnographic record: revising characterisations of the use and morphometrics of hand-delivered wooden spears

> *You will not wonder at our anxiety to avoid a rencontre with them and their formidable spears; a weapon they wield with deadly effect. We had seen six or seven kept as prisoners in Hobarton….They threw the spear for our amusement. This is merely a slender stick, nine or ten feet long, sharpened at the heaviest end; they poise it for a few seconds in the hand, till it almost spins, by which means the spear flies with great velocity to the distance of sixty yards, and with unerring aim.*
>
> - Mrs. Prinsep's letters, in Roth 1890, p.71

The aim of this chapter is to provide a revision of the ethnographic record in relation to the use of hand-delivered wooden spears, which facilitates the evaluation of previous claims regarding both Middle Pleistocene (MP) wooden spears as well as hand-delivered spears in general. The first half of this chapter (6.1-6.4) provides a detailed synthesis of a selective review of the recent use of wooden spears based on ethnographic and ethnohistoric literature. Relevant data were wide-ranging, and included those on use, performance, environments, prey, design and manufacture. Interpreting the context of wooden spears is problematic because most groups recorded in the literature used them alongside composite and/or complex weaponry (Ellis 1997). Although there are only a few examples, those groups who only used hand-delivered wooden spears may tell us the most about the effectiveness of thrusting and hand-thrown wooden spears; for that reason particular attention will be paid to these accounts. General theoretical and methodological problems pertaining to the use and abuse of ethnographic data was covered in Chapter 3, and such issues form part of a critical approach to the literature, for example in the caution paid to attributing function to ethnographic spears, and in evaluating accounts of use.

Previous reviews of the ethnographic literature have led to characterisations of wooden spears that require a critical evaluation based on larger and more representative datasets. Such generalised characterisations of the spears and by extension Early Pleistocene, Middle Pliestoecene and early Late Pleistocene hominin hunting include:

1. Early spears (whether wooden or tipped) would have been heavy and difficult to throw, are thrown at very low velocities, and have little kinetic energy at impact (e.g. Berger & Trinkaus 1995; Boëda et al. 1999; Shea & Sisk 2010a)
2. Effective distances (accuracy) of hand-thrown spears are generally limited to 5-10 m, and they are inaccurate weapons (e.g. Churchill 1993; Shea & Sisk 2010a)
3. Hand-delivered spears are generally aimed at larger prey, are less effective on smaller game, are primarily associated with disadvantage hunting, and their use is correlated

with or dependent upon landscape features (e.g. Churchill 1993; Lieberman et al. 2007; White et al. 2016; Rodríguez-Hidalgo et al. 2017)

4. Together the above points propose that hand-delivered weapons are inferior to complex weaponry on the basis of comparisons of effective distance, energy at impact, ease of use/accuracy, and the ability to capture a wide range of prey in a wide range of environmental settings. This is particularly suggested for colder regions such as northern Europe during the Pleistocene (Churchill 1993), with an emphasis on a reliance by hominins on landscape features to disadvantage prey.

These characterisations, several of which have been formed on the basis of faunal assemblages indicating the hunting of large mammals rather than of the performance of the spears themselves, will be addressed in turn at the close of the literature review. The second half of the chapter (6.5-6.8) provides a detailed analysis of morphometrics of a large sample of wooden spears from museum collections, with the aims of evaluating previous claims relating morphometrics to function, evaluating the quality of previously collected data, and contextualising the morphometric data of archaeological wooden spears presented in Chapter 4.

6.1 Literature Review of ethnography and wooden spears

6.1.1 Introduction to the literature review

Ethnographic and ethnohistoric accounts and morphometric data of ethnographic wooden spears in museum collections (Oakley et al. 1977; Churchill 1993; Ellis 1997) have played a significant - if sometimes indirect - role in interpretations of the design, function, and effectiveness of spear use during the Pleistocene. Because previous reviews of ethnographic data have impacted on perceptions of the effectiveness of early spears and have in turn influenced interpretations of hominin dispersals and origins of projectile technologies during the Pleistocene (Shea 2006; Shea & Sisk 2010a), it is particularly important to evaluate whether such reviews have been selective or representative in the presentation of said data. Due to time constraints within the context of a multi-disciplinary approach to the topic in the thesis, the review is not intended to be comprehensive but rather an augmented and more representative account of these weapons in recent contexts that can be extended based on the future utility of such data.

6.1.2 Limitations of previous approaches: false equivalencies and selectivity

The best-known examples of recent hunter-gatherers using wooden spears are the Aboriginal Tasmanians (Fig. 6.1), and the Tiwi who inhabited Melville and Bathurst Islands, which are part of the Northern Territory of Australia. Both used hand-thrown wooden spears in terrestrial and marine animal hunting, as well as interpersonal and collective violence. Unlike most other groups using wooden spears, the Tiwi and Tasmanians lacked both composite spears and complex projectiles, and as a result their technology was labeled 'simple' (e.g. Hiatt 1968; Oswalt 1976; McGrew 1987). Intriguingly, spear use in these two societies do not feature in interpretations of Pleistocene wooden spears (Movius 1950; Oakley et al. 1977; Thieme & Veil 1985; Thieme 1997; Schoch et al. 2015); whether this reflects a lack of awareness of the use of such spears by these groups, or a reticence to make such an analogy is unclear. As discussed in Chapter 3, problems with the use of these data are numerous, and one such issue relates to characterisations of technologies as 'simple' or 'complex'. For example, during the 19th and early 20th centuries Aboriginal Tasmanians were often interpreted by academics as intellectually inferior on the basis of a false equivalence: that simple technologies reflect simple intellects. An example is Fritz Noetling, a German geologist and palaeontologist, who in his analysis of Tasmanian spears (1911, p.64) wrote:

> A **modern mind** cannot understand how it was possible that such a suitable material as the siliceous rocks from which the implements were manufactured, was not also used for weapons. To us it seems unintelligible, why the Aborigines did not fix a suitable flake to a piece of wood, thus **producing a weapon far superior to the primitive wooden spear.** Yet this was apparently an invention the Tasmanian Aborigine never made. **His mind was just as unable to conceive the idea** of providing the wooden spear with a stone head, as it was to chip the tero-na-watta on both faces…

Much more recently Rhys Jones wrote (1977, p.203):

> Like a blow above the heart it took a long time to take effect, but slowly but surely **there was a simplification ... a squeezing of intellectuality**. The world's longest isolation, **the world's simplest technology** ... Even if Abel Tasman had not sailed the winds of the Roaring Forties in 1642, were they in fact doomed—doomed to a **slow strangulation of the mind?**

or perhaps more subtly (McGrew 1987, p.247):

> Tools used to get food are compared between wild chimpanzees in western Tanzania and aboriginal Tasmanians at the time of European contact...results show surprising similarity in the number of items in the tool kit, raw materials used, proportion of tools made versus those used unchanged, extent of complexity, type of prey, etc. Key contrasts also emerge: only human tools have more than one type of component and are made using other tools. Overall, however, the gap between the most technically diverse nonhuman tool kit and the simplest human material culture seems narrow.

Interpretations of the Tasmanians as somehow intellectually and evolutionarily inferior, or at best technologically similar to primates, show both early and persistent abuses of ethnography that continue to reverberate in relation to both Australian archaeology and Aboriginal rights (Ryan 2012, p.xix; Taylor 2014). Thankfully such interpretations of recent hunter-gatherer groups have largely fallen by the wayside and have been dealt with both theoretically and scientifically (Read 2006; Allen & Akerman 2015) and certainly do not feature in recent analyses of early weaponry. In spite of the problematic connections between technological and cognitive complexity, it is still helpful to evaluate the performance of these weapons in relation to Late Pleistocene technological innovations, and therefore evaluate whether increasingly complex weaponry conferred advantages. There are productive questions that do not explicitly rely upon theoretically bridging cognitive capacities (or ‘behavioural modernity’) with material culture; we can and should be able to evaluate the adaptive advantages of different weapon systems in order to evaluate ‘behavioural variability’ through time and space (Shea & Sisk 2010a; Shea 2011).

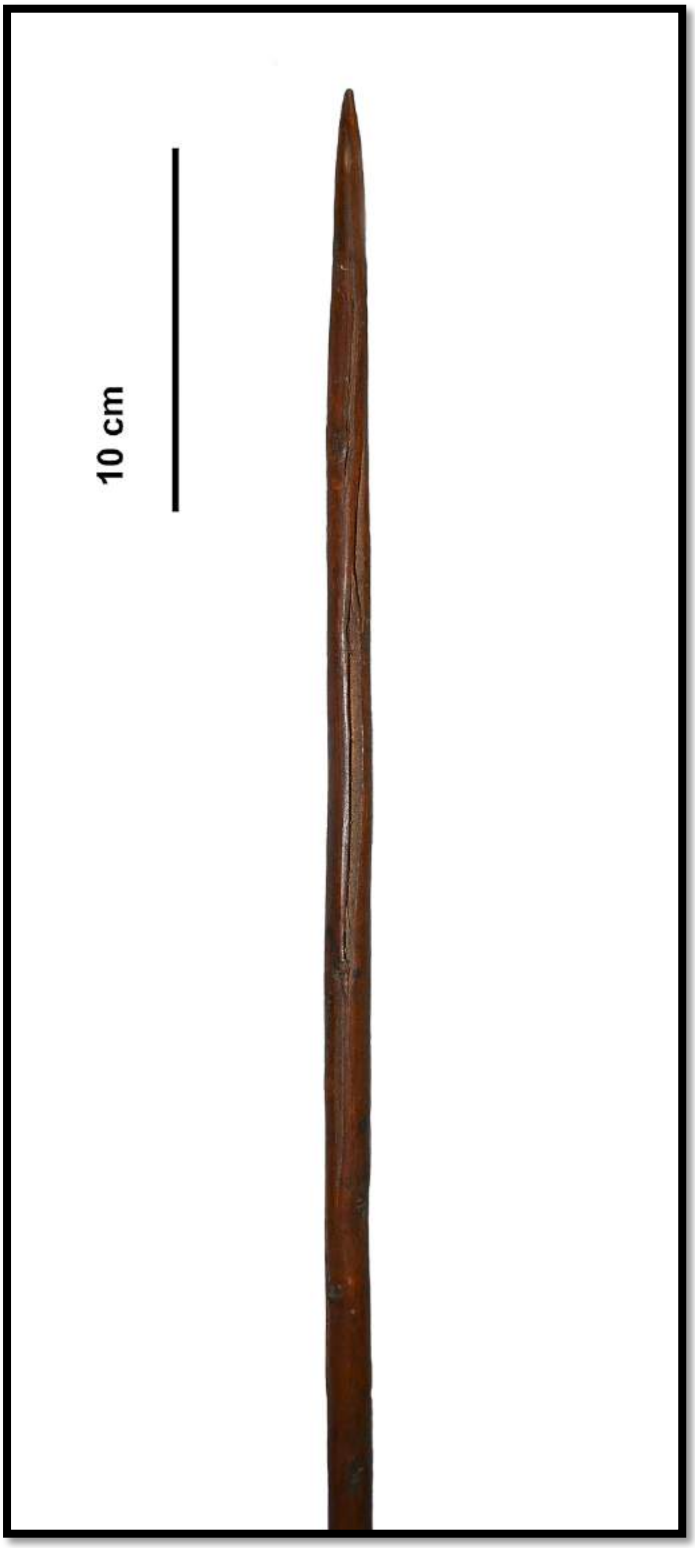


Figure 6.1 The distal tip of one of the few remaining Tasmanian throwing spears left (Photo A Milks)

Churchill's (1993) assessment of weaponry based on ethnography equivalence is influential at least in English-speaking academic circles and in particular in relation to the effective distance of hand-thrown spears (Kennedy 2004; Shea 2006; Lieberman et al. 2007; Shea & Sisk 2010a; Wilkins et al. 2014a; Iovita et al. 2016; Sano et al. 2016; Gaudzinski-Windheuser 2016; Wilkins & Schoville 2016). However, the review dismisses the performance of the Tasmanian hand-thrown spears thus (emphasis added, p.19):

> 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). **Hand spears among most groups are short-range weapons…**

Leaving aside for the moment additional data on throwing distances (detailed in section 6.3.4) that do not appear to be part of Churchill's (1993) calculations, the resulting estimate treated one of only a handful of groups known to have relied exclusively upon hand-delivered weapons for hunting as an outlier - the group who arguably would have been the most skilled in using such weapons. It is worth restating that the effective distance for hand-thrown spears estimated in that paper is frequently cited in the literature and has underpinned linear weaponry models that are part of reductionist narratives aiming to explain the increasing variability visible in the Late Pleistocene archaeological record. Although the oft-cited effective distance of 5-10 m has been contested elsewhere (Villa & Soriano 2010), the treatment of the ethnographic record in this instance is problematic because of the selectivity of data by researchers. It is therefore important to systematically summarise and critically analyse a larger body of accounts regarding spear use in these societies, including the use of multiple sources on the same groups, to create a synthesis enabling a more robust assessment. It does not require a statistical approach to evaluate the ethnographic record in this way, as there are too many confounding variables, the data are already inherently compromised, and such an approach masks variability and nuance, and prohibits an evaluation that encompasses those most skilled in the use of hand-thrown spears. Therefore the approach in this thesis is to bring together accounts including those that illustrate the upper limits of performance, particularly of hand-thrown spears, in order to re-evaluate previous estimates.

6.2 Materials and methods: Dataset for ethnographic literature review

The materials for the ethnographic literature review included text-based sources located through indexes and bibliographies in the existing literature on both hand-delivered spears and wooden spears, and were extended accordingly. Electronic databases were searched for text-based, image and video content, with inclusion/exclusion criteria set to eliminate data on composite and complex weaponry. Electronic databases searched included the Smithsonian National Museum of Natural History (Collections Search Center and SIRIS), Anthropological Index Online (The British Museum), Ethnographic Video Online (Alexander Street), British Library Images Online, eHRAF World Cultures, JSTOR and Proquest Social Science Database. Keyword searches included 'spear', 'spears', 'wooden spear' and 'wooden spears' and in the case of eHRAF the search focused on 'hunter-gatherers' as subsistence type. If searches returned results on composite and/or complex weaponry, the results were not included. Research focused on English-based texts, and included results on any geographical location and published in any period.

Results of the literature and database searches are combined with a thematic approach, looking at global distribution, function, prey and environments, 'effectiveness' of the weapons, wood selection, manufacturing techniques, and approaches to skill training. For the global distribution presented locations are approximate areas for a given group's region. Locations were excluded from the distribution map if their known function was only related to fishing, but were included when a function of either terrestrial hunting, violence, or both were evident. Examples from the ethnographic museum-based research presented in the second half of this chapter were also included in this distribution map provided provenance was clear.

6.3 Main findings of the literature review

This section presents the main findings of the review, integrating them with a critical appraisal of the outcomes, as well as of previous assessments of the use of wooden spears on the basis of the ethnographic and ethnohistoric data.

6.3.1 Global distribution and function of wooden spears

Hand-delivered wooden spears amongst recent societies were in use in North, Central and South America, Oceania, Australia, Southeast Asia, and Africa (Table 6.1 and Fig. 6.2). The majority of records of use relate to Oceania, Australia, and North and South America, and when functioning as hunting weapons are focused in Oceania, Australia, and South America with only a few examples in North America and Africa. Oakley et al. (1977) include wooden spears from locations in Zaire, South Africa and Malawi in their sample studied from the British Museum collections, but as these collections were unavailable for study, the objects could not be identified in the online collections database, and the provenance in terms of indigenous group they are associated with is not clear from the publication, they are not included in the study sample. However, based on this, further locations in Africa are expected. Wooden spears used for subsistence, including as hand-thrown and thrusting spears were evident in much of Australia including the mainland, Tasmania, Melville and Bathurst Islands. Figs 6.3 and 6.4 show different aspects of spear use in Australia, demonstrating that the use of hand-delivered wooden spears was widespread on the continent, including alongside and in absence of spearthrowers.

Table 6.1. Data on groups using untipped wooden spears. Locations are approximate. Species of prey, when reported or only one possibility of endemic species exists are provided and when not reported or unknown, genus is listed

Indigenous group	Approximate location	Delivery: TH/HT/NR	H/F/W	Target	Source
Mainland Aboriginal Australians (multiple groups)	Mainland Australia *	TH and HT	H F V	crocodile (*Crocodylus* spp.), kangaroo (*Macropus* spp.), emu (*Dromaius novaehollandiae)*	Hardman 1889; Spencer 1914; Davidson 1934; Gould 1970
Aboriginal Tasmanians (multiple groups)	Tasmania, Australia	HT	H V	Forester Kangaroo (*Macropus giganteus tasmaniensis*); wombat (*Vombatis ursinus tasmaniensis*); pademelon (*Thylogale billardierii)*; possibly bandicoot (*Isoodon obesulus, Perameles gunnii*) though perhaps with waddy; humans	Robinson 1966; Lloyd 1862; Roth 1890; Hiatt 1968
Tiwi	Melville and Bathurst Islands, Australia	HT	H F V	wallaby (*Macropus agilis*) fish, ?crocodile (*Crocodylus porosus*); humans	Spencer 1914; Hart & Pilling 1960; Goodale 1971
Admiralty Islanders (?)	Admiralty Islands, Papua New Guinea	HT	H V	wild pig (*Sus scrofa*)	Moseley 1877
Dani (Ndani, Dugum Dani)	Western New Guinea	TH and HT	V	humans	Heider 1970; Heider 1974
Massim	Trobriand Islands, Papua New Guinea	?	V	humans	Malinowski 1920
?	Solomon Islands	?	?	?	National Anthropological Archives, Smithsonian Institution, Photo Lot 97 DOE Oceania: Solomon Island: General 05254600 (4th spear from left in photograph)
Samoan Natives (Tagata Māo'i)	American Samoa	?	F V	Marine species, humans	Smithsonian CSR, . Accession Number 66A00050, USNM number E3454-0, E3455-0
Māori	New Zealand	TH	V	humans	Smith 1893; Tregear 1904, pp.308-19; Green & Svinth 2010, p.276
Marquesans	Marquesas Islands, French Polynesia	?	V	humans	National Anthropological Archives, Smithsonian Institution,Photo Lot 97 DOE Oceania: French Polynesia: Gen/Misc 04974200; National Museum Australia Database, "Oz 1287, Oz 1288"
Chuuk (Truk)	Truk Islands, Micronesia	TH and HT	V	humans	Bollig 1927; LeBar 1964
Marshall Islanders	Marshall Islands	TH and HT	V	humans	Erdland & Neuse 1914
Kaska	Northeastern British Columbia, southeastern Yukon, Canada	?	H	Bear (*Ursus arctos/Ursus americanus*, species not reported), beaver (*Castor canadensis*)	Honigmann 1954

Otoe	Missouri, USA	?	?	?	Smithsonian department of Anthropology collections database, record EZZ422-0
Tula	Arkansas, USA	?	V	humans	Swanton 1946
Cherokee	Southeastern USA	TH	H	deer (*Cervus* spp.)	Goodwin 1977
Mattole	Cape Mendocino, CA, USA	TH, maybe HT?	H F	?	Driver 1939
Sinkyone	South Fork Eel River, CA, USA	TH maybe HT?	V	humans	Driver 1939
Tlingit	Pacific Northwest, USA	?	?	?	Emmons & De Laguna 1991
Chumash	Morro Bay to Malibu, CA, USA	HT	?	?	Greenwood 1978
Shoshone	Nevada, Eastern Utah, Southern Idaho, USA	TH	V	humans	Steward 1941
Mohave	Mohave Desert, USA	?	V	humans	Stewart 1947
Yuma	Fort Yuma Indian Reservation, USA	TH	V	humans	Forde 1931; Drucker 1937
Pima, Maricopa	Gila River Indian Reservation, Pinal County, AZ, USA	?	V	humans	Spier 1933; Drucker 1941
Apache (Western, Eastern)	San Carlos, AZ, USA	TH	V	humans	Buskirk 1986; Goodwin & Basso 1971; Opler 1941
Desert Diegueño	Escondido, CA, USA; Ensenada, Mexico	TH	V	humans	Gifford 1931; Drucker 1937
Yavapa (Northern)	San Francisco Peaks, AZ, USA; Northwestern Mexico	?	V	humans	Drucker 1941
Cocopa	Sonora, Mexico	TH	?	?	Gifford 1933; Drucker 1941
?	Nicaragua	?	?	?	Smithsonian department of Anthropology collections database, record E165446-0
Guayaki, Ynarö group	Paraguay	?	H	White-lipped peccary, *(Tayassu pecari*), jaguar (*Panthera onca*); capybara (*Hydrochoerus hydrochaeris)*	Clastres 1972
Ticuna	Brazil, Peru, Columbia	TH and HT	H	White-lipped peccary, *(Tayassu pecari*); jaguar (*Panthera onca*)	Nimuendajú 1952
Wichí (Mataco)	Bolivia, Argentina	TH and HT	H	tapir (*Tapirus terrestris*); Chacoan peccary (*Catagonus wagneri*); jaguar (*Panthera onca*)	Alvarsson 1988; Pelleschi & Lafone Quevedo 1896
Bubis (Edeeya)	Bioko, Equatorial Guinea	?	H	Not reported which species; hunted Ogilby's Duiker (*Cephalophus ogilbyi*), Red River Hog (*Potamochoerus porcus*), forest buffalo (*Syncerus*	Jerdan 1848; Thomson 1850; Kingsley et al. 1897

				caffer nanus) porcupine (Atherurus africanus), forest buffalo (*Syncerus caffer nanus*), primates, snake (species unknown), also used slings for hunting	
Bari (Kuku)	South Sudan/North Uganda	?	?	The literature reports the use of metal tipped hand-thrown spears amongst the Bari; short untipped wooden spears are also found in the Australian Museum collection and forms part of the sample studied, but function is unclear	See Baker 1874 in Cundy 1989; Yunis 1924

TH= Thrust; HT=Hand Thrown; ? = Not Recorded or unclear in the sources consulted; H = Hunting, F = Fishing, V = Violence (collective and interpersonal). * See maps of Australia, Figs. 6.3 and 6.4.

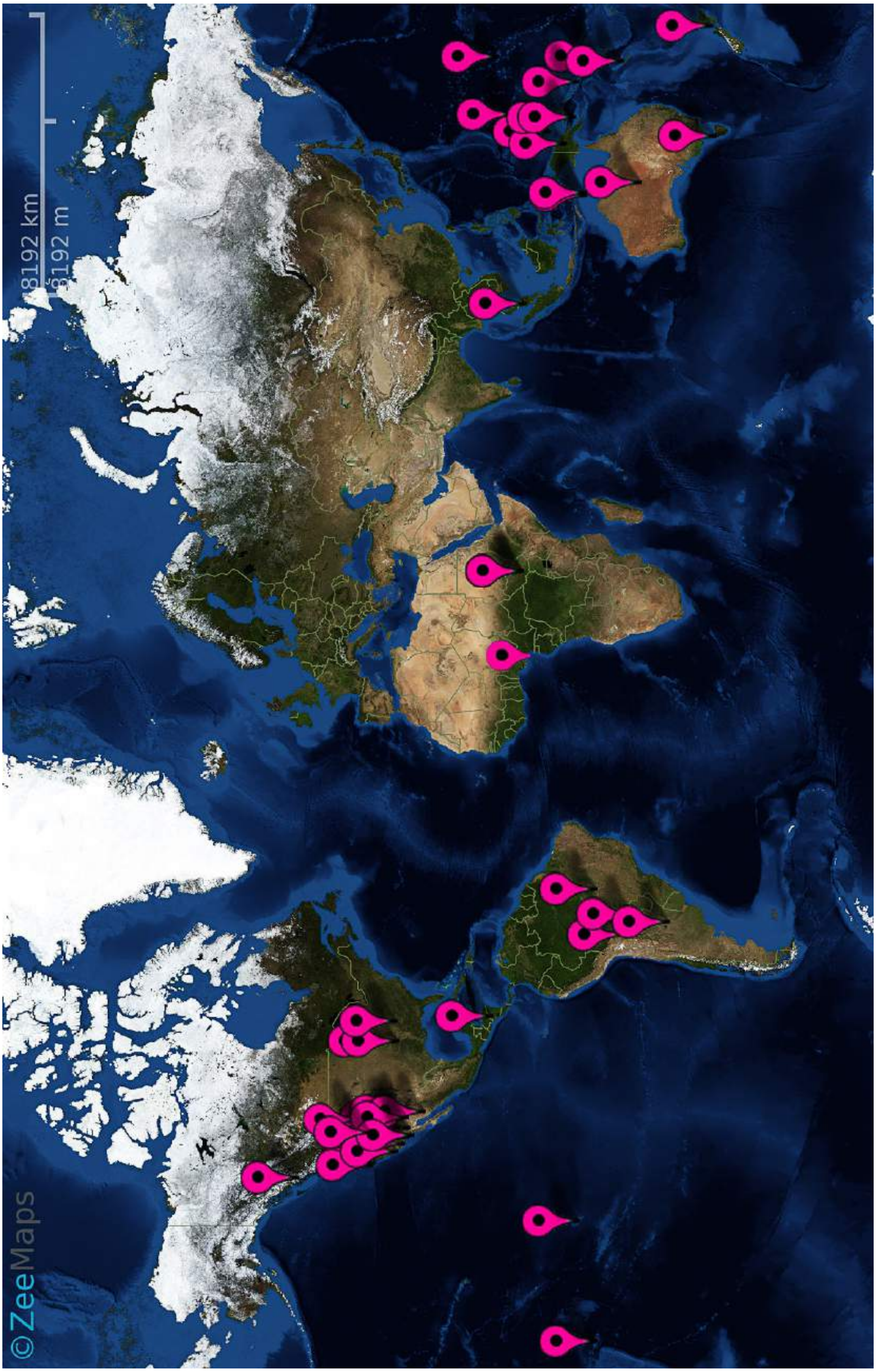


Figure 6.2. Global distribtution of hand-delivered wooden spears. Locations are approximate and/or centralised locations for each group

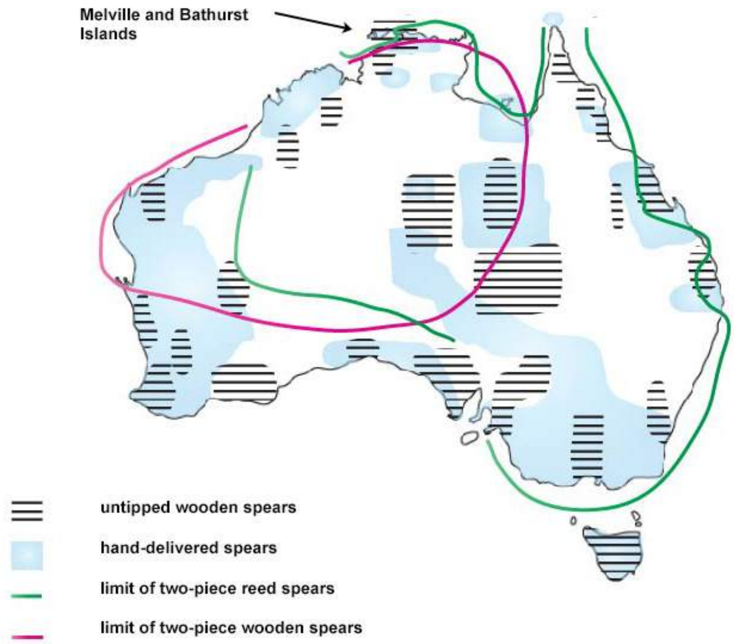


Figure 6.3. Distribution of spear types in Australia (redrawn by author after Davidson 1934, Figs. 1 and 2)

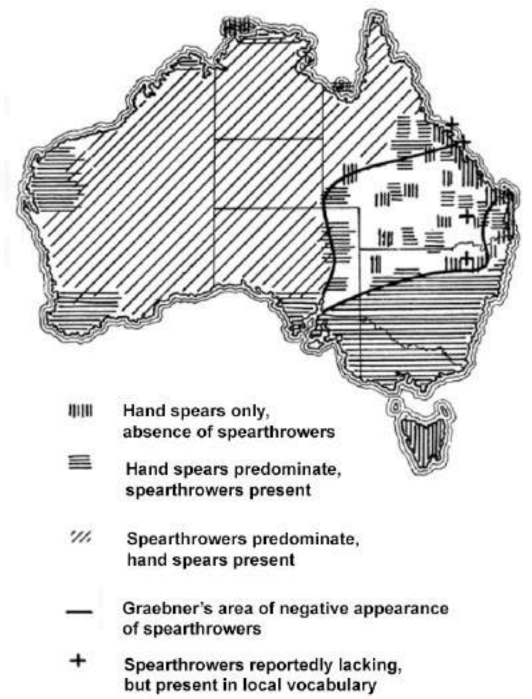


Figure 6.4. Distribution of hand spears and spearthrowers in Australia, modified after Davidson 1936, Fig. 2

6.3.2 Thrusting and hand-throwing of wooden spears for use in hunting and violence

The sources for the following summaries are found in Table 6.1 unless otherwise provided. Figure 6.3 is a juxtaposition of maps on the distribution of different spear types and delivery systems in mainland Australia, Tasmania and Melville and Bathurst Islands. This map, based on Davidson (1934) shows that in addition to the islands, parts of mainland Australian Aboriginals may have used hand-delivered wooden spears with an absence of spearthrower use. Comparing this distribution map with Fig. 6.4 (from Davidson 1936) showing distributions of spearthrowers and hand-thrown spears, it is possible that some small areas along the east coast may also have only used hand-delivered wooden spears, with no spearthrowers or composite weapons present, but this is somewhat unclear. The Tiwi spears were large and heavy weapons, which the Tiwi were capable of throwing large distances, and they also made and used heavy barbed spears for hand-throwing (Spencer 1914). Although no examples of the plain, unbarbed Tiwi spears were available for direct study in museum collections, one was seen on display in the South Australian Museum (Adelaide), confirming their existence. The lack of such spears in collections probably reflects collection bias towards more ornate forms. The Tasmanians also only threw their spears by hand, with no mention of use as thrusting weapons (Davidson 1934), and their design differed greatly from those of the Tiwi spears (Spencer 1914; Noetling 1911). In many cases the same spears could have been used in both delivery methods, particularly in dangerous situations, first throwing spears and reserving one for thrusting, making them multifunctional weapons (Tregear 1904; Krieger 1926; Clastres 1972). There are also groups that used different designs for different delivery methods. For example, the Ticuna poisoned the tips of their hand-thrown wooden spears and had different designs for thrusting (called a dë) than for throwing (called a va:ma'gu) (Nimuendajú 1952). Regardless of delivery method, wooden spears were almost always used alongside complex weaponry of some kind, with the Tasmanians, Tiwi and possibly small regions of the eastern coast of Australia being the clearest exceptions to this pattern.

Examples of use as hunting weapons include the mainland Australian Aboriginal populations, who also used the weapons against humans. There is also mention of the use of wooden spears for hunting by the Admiralty Islanders, the Kaska in Canada, the Cherokee in the southeastern United States, Mattole in western United States, the Bubi in Africa and the Guayaki, Ticuna, and Wichí in South America (references in Table 6.1). Both delivery methods were employed for hunting, though this is frequently not reported. Section 6.3.3 provides further details on prey and environments with wooden spears used in hunting.

Wooden spears frequently featured as weapons for collective or interpersonal violence, either alongside use as hunting or fishing spears, or exclusively for violent encounters. In general as weapons for violence, delivery included both thrusting and hand-throwing. Groups which appear to have used wooden spears for violence but not for hunting are particularly focused in Oceania and North America (references in Table 6.1). Amongst North American indigenous groups, wooden spears were used for violence alongside complex projectiles, and Gifford (1931, p.30) reports that amongst the Kamia ‘Only two warriors, very brave and fleet of foot’ carried these spears, which also served as standards, emphasising the importance of bow/arrows in collective violence. The Māori from New Zealand used spears as thrusting weapons (Fig. 6.6) and occasionally hand-thrown weapons in conflict, which were lethal as such (Tregear 1904). The Tiwi certainly used their heavy hand-thrown wooden spears in collective violence against settlers, including plain and barbed wooden spear designs which were capable of penetrating through human torsos, vertebrae, arms and legs (Morris 1964; Goodale 1971, p.9). Spear throwing was used in interpersonal violence amongst the Tiwi, typically in socially mediated retribution with the aim of injury rather than death, and it was considered just as skillful to dodge thrown spears as to throw them (Hart & Pilling 1960, p.81-2). The Tiwi are generally reported as using wooden spears - both plain and barbed - as hand-thrown weapons, but one example of collective violence against a settler suggests they may have used them as thrusting spears as well (Morris 1964, p.8). There are numerous accounts of Tasmanian spears used in violent encounters and their lethality to humans is demonstrated through reports of penetration through a settler’s pelvis and torso as well as through a boot and into the foot (Roth 1890, p.71). These accounts are useful because they demonstrate the ability of wooden spears to lethally wound humans, who have a body mass fitting into size class 2 (Table 2.1). Figure 6.5 is a poster that was aimed at Aboriginal Tasmanians, demonstrating that the settlers were well aware of and concerned by the lethality of these light throwing spears.

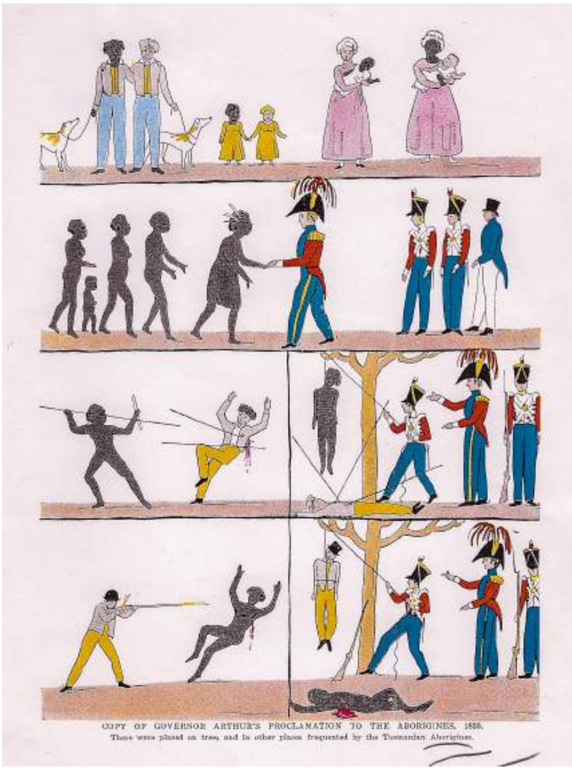


Figure 6.5. Governor Davey's [sic] Proclamation to the Aborigines, 1816 [sic]. (Public Domain)

Various ethnographic and martial arts sources demonstrate that there is a wide variety of foot positions, attacking postures, hand holds and thrusting techniques involved in spear thrusting in combat situations illustrating the diversity of this delivery method, which would also be useful in hunting scenarios given differences in prey size and postures during hunting (e.g. McLaglen 1916, pp.14-43; Mandelbaum 1940, p.215; Lessa & Velez-I 1978; Hallander 1981; Lowry 1983; Ripley 1999, pp.13-15; Evans 2002, p.51; Kortlandt 2002; Knutsen & P. Knutsen 2004 Fig. 51; Matthew 2012, plate 5). Illustrations and accounts of spear throwing generally show this to be one-handed, with the hand located near the centre of the spear (Fig. 6.7) (Roth 1890, p.71). Spinning or possibly vibration of hand-thrown spears is also proposed as having been a technique for hand-thrown spears though this is unclear and only based on a single source (Roth 1890, p.71).

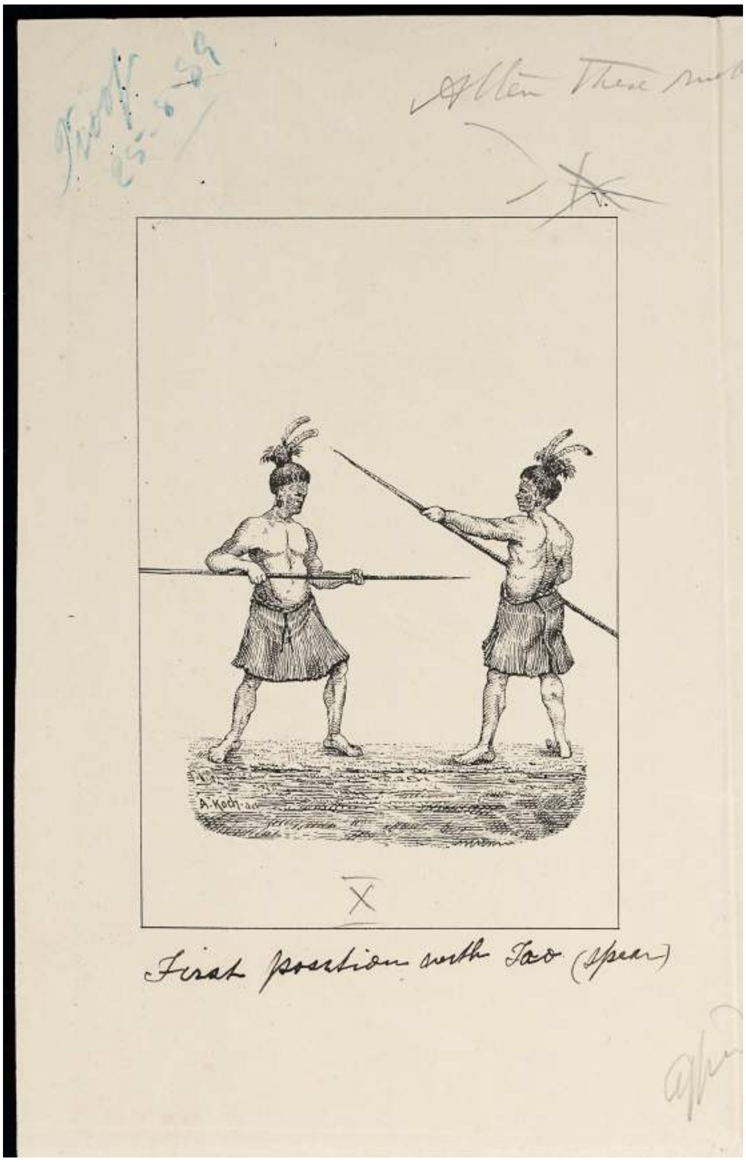


Figure 6.6. Koch, Augustus, 1834-1901 : First position with tau (spear). ([Wellington, 1891] Various artists :[Proofs and related pictorial material for illustrations to J White's Ancient history of the Maori (Wellington, 1891)] 1832, [1880s?] 1890. Ref: B-110-010-1. Alexander Turnbull Library, Wellington, New Zealand. http://natlib.govt.nz/records/23184543. Permission to reprint granted by the Alexander Turnbull Library)

Figure 6.7. 'Timmy, a Tasmanian Aboriginal, throwing a spear' by Benjamin Duterrau (1768-1851). (Public Domain)

6.3.3 Environments and prey

Comparing Fig. 6.8, a global map of climate classifications, with the map of the distribution of wooden spears (Fig. 6.2), it is clear that climates of the regions covered by the recent use of wooden spears include tropical, arid, temperate and cold regions, though no examples of use in polar climates were found. Environments include those of both tropical and cool temperate rainforests, deserts and desert fringes, woodlands, shrub lands and savannah, covering a wide range of both open and closed habitats including lowlands and higher elevations in mountainous regions (Fig. 6.2, Table 6.1). The use of wooden spears specifically for terrestrial hunting (Table 6.1) includes regions with tropical savannahs, monsoonal and tropical rainforests, temperate forests, grasslands and rainforests, hot arid deserts, and cold mountainous regions with warm summers.

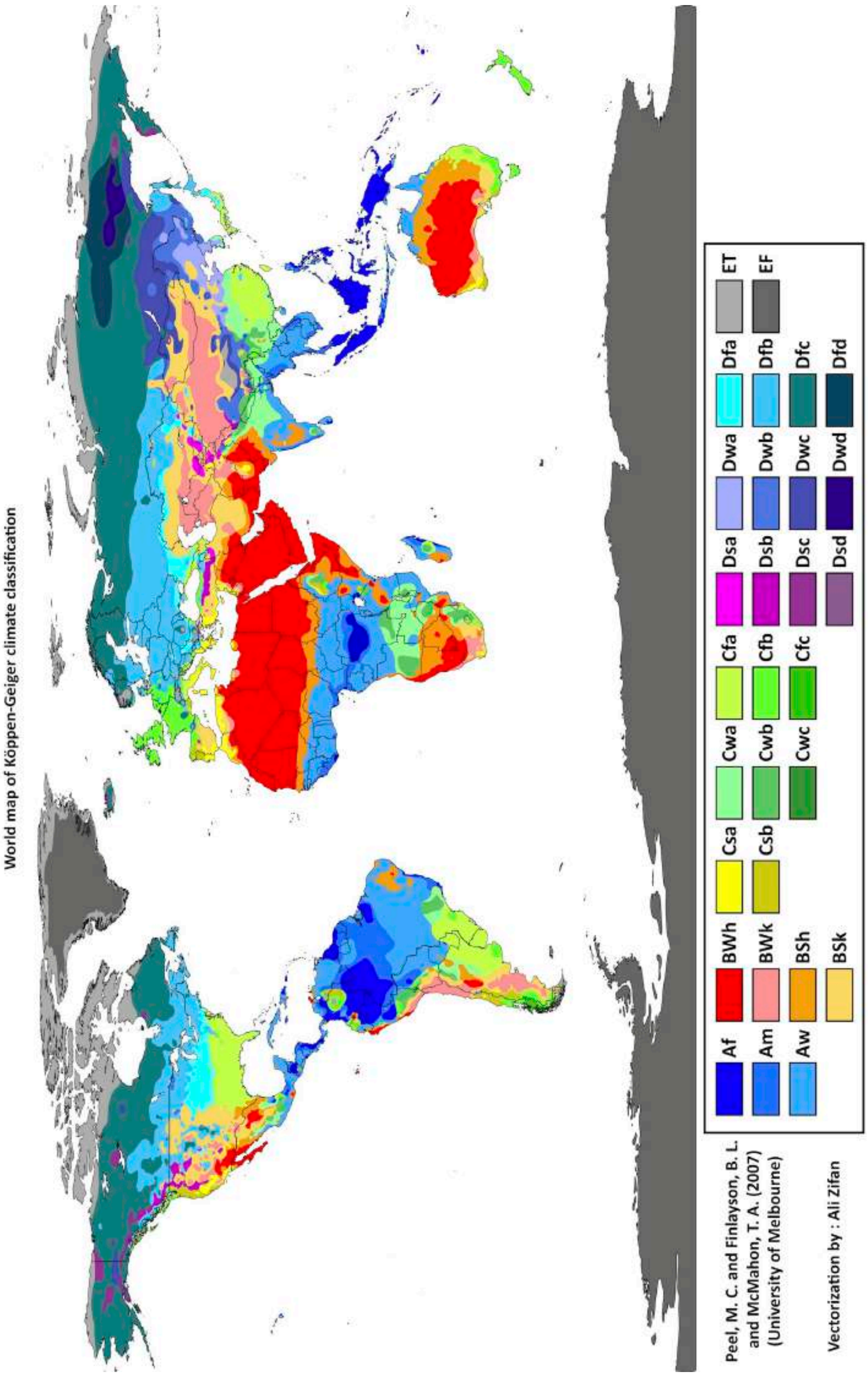


Figure 6.8. "Updated world map of the Köppen-Geiger climate classification" (Peel, M. C., Finlayson, B. L., and McMahon, T. A. (University of Melbourne), Enhanced, modified, and vectorized by Ali Zifan. - Hydrology and Earth System Sciences. Image free to use, from Wikimedia Commons, license CC BY-SA 4.0. Legend: A-Tropical, B-Arid, C-Temperate, D-Cold, E-Polar. For a detailed explanation of the legend, see https://hal.archives-ouvertes.fr/hal-00305098/document)

Figure 6.9. An example of a size 2 prey hunted with wooden spears is the Forester (eastern grey) kangaroo (Photo by A. Milks)

Terrestrial prey hunted with wooden spears include kangaroo (Fig. 6.9), emu, wombat (Fig. 6.10), wallaby, bandicoot, wild pig, deer, forest buffalo (Fig. 6.11), capybara, tapir, peccary, jaguar and possibly saltwater crocodile (Table 6.1). The size range of these prey ranges from the smallest animals in size class 1 through to large animals in size class 4 with the majority falling into size classes 1 and 2 (Table 6.2). Overall, prey includes both herding flight animals, solitary animals, and large and extremely dangerous animals. Although Churchill (1993, p.16) suggests that 'all spears historically whether stone-tipped or not, and with only the odd exception, were used on "larger game" or in warfare', in fact the analysis here shows that while wooden spears were indeed used on larger game, there are also multiple examples of their use on small game (Tables 6.1 and 6.2). The fact that hand-delivered wooden spears were used to target small and fast-moving prey as long-distance weapons by recent hunter-gatherers is problematic for hypotheses that complex projectiles should be seen as niche-broadening technologies (Sisk & Shea 2009; Shea & Sisk 2010a). Two of the largest prey in the list carry some uncertainty pertaining to being hunted with wooden spears: saltwater crocodile were hunted by the Tiwi but by the time any record was made of this, it was done using metal-tipped spears and so whether wooden spears were used prior to this remains unclear (Goodale 1971). The Kaska, inhabiting northwestern Canada, reportedly hunted bear using wooden spears (Honigman 1954), though it is unclear in the source consulted whether this was the American black bear (*Ursus americanus*) or the North American brown bear (*Ursus arctos*), with both inhabiting the region traditionally occupied by the Kaska and falling in different size classes (Table 6.2). The largest animals clearly hunted with wooden spears were the tapir, a size class 3 animal that inhabits forests and rainforests in South America, and the forest buffalo (Fig. 6.11) which inhabits equatorial Africa and was hunted on the island of Bioko (Tables 6.1 and 6.2). Several of the prey targeted with wooden spears are fast-moving, including the forester kangaroo and emu who can reach speeds of 71 km/h and 50 km/h respectively (Penny 2002; Grzimek 1972). In addition to these examples of wooden spear use, it is worth adding that although the spears used by the Tyua (San group) were composite weapons, spears were their primary hunting weapon and in comparison with other groups in the region who favoured bow/arrows for hunting, they captured a much larger range of prey with spears than groups using bow/arrows (Hitchcock & Bleed 1997). The large range of prey size and behaviours shows that hand-delivered wooden spears are not limited to either small or large game procurement and are capable of killing a variety of animals of different size classes and with differing behaviours and habitats, and as well as the terrestrial animals including mammals and birds, prey also includes marine resources. Again, this result rejects hypotheses that later developments in weaponry signal niche-broadening technologies.

Figure 6.10. A juvenile wombat, a species endemic to Australia and Tasmania, and which were hunted using wooden spears and waddies. Wombats are aggressive to predators and can be dangerous to humans (Photo by A. Milks)

Figure 6.11. Forest Buffalo (*Syncerus caffer nanus*), one of the prey hunted by the Bubi in Bioko with hand-delivered wooden spears. (By H. Zell - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=11416969)

Table 6.2. Prey hunted by untipped wooden spear according to the ethnographic and ethnohistoric literature, broken down by size class (After Bunn 1982)

Size Class	Mass	Prey	Estimated mass (kg)
1	<23 kg (<50 lbs)	*Thylogale billardierii,* tasmanian pademelon	6[f]
		Macropus rufogriseus, red-necked wallaby	17[f]
		Vombatus ursinus, common wombat	23[h]
		Castor canadensis, beaver	11-26[o]
		Cephalopus ogilbyi, Ogilby's duiker	20[q]
2	23-113 kg (50-250 lbs)	*Vombatus ursinus,* common wombat	23[h]
		Macropus giganteus tasmaniensis, forester (eastern grey) kangaroo	male=25-50[e] female=27-30[e]
		Dromaius novaehollandiae, emu	up to 55 kg[g]
		Tayassu pecari, white-lipped peccary	25-40 kg[b]
		Catagonus wagneri, Chacoan peccary	29.5-40 kg[c]
		Panthera onca, jaguar	male=95[d] female=78[d]
		Hydrochoerus hydrochaeris, capybara	35-91[k]
		Ursus americanus, american black bear	male = 86[m] female = 58[m]
		Sus scrofa, wild pig/boar	91[p]
		Potamochaoerus porcus, red river hog	68[q]
3	113-340 kg (250-750 lbs)	*Tapirus terrestris,* tapir	150-200[a]
		? *Ursus arctos,* grizzly bear	male=389[n] female=207[n]
		Syncerus caffer nanus, forest buffalo	285[q]
4	340-907 kg (750-2000 lbs)	? *Crocodylus* sp., crocodyle	up to ~1000[r]

? indicates uncertainty whether this species was hunted at all, which species was targeted, and/or whether they were hunted using wooden spears or another weapon. Mass estimates are as means if single figure, or range if hyphenated. Sources: a. Padilla & Dowler 1994 b. Mayer & Wetzel 1987 c. Mayer & Wetzel 1986 d. Seymour 1989 e. Poole 1982 f. Le Mar & McArthur 2005 g. Grzimek 1972 h. Damuth 1987 k. Mones & Ojasti 1986 m. Larivière 2001 n. Pasitschniak-Arts 1993 o. Jenkins & Busher 1979 p. Boitani & Bartoli 1983 q. Fa & Purvis 1997 r. Grigg et al. 1998

Connected to the diversity of prey and environments is an evaluation of hunting strategies associated with hand-delivered wooden spears. The literature shows that strategies included approach hunting, disadvantage hunting, ambush hunting, and pursuit hunting (Roth 1890, pp. 15, 98; Hart & Pilling 1960, pp.41-42; Robinson 1966, pp.566, 618, 623). Both solitary hunting (Hart & Pilling 1960) as well as large group social hunting involving men, women and children for game drives were part of the strategies, and the taking of single animals as well as practicing multiple predation are noted (Roth 1890, p.98). Several spears were often carried by an individual, either all intended for throwing, or either to throw some and retain one for thrusting (Krieger 1926, p.51). The Tasmanians carried multiple spears each in their hands, even dragging additional spears along the ground using their feet, and could throw two spears at once, one with each hand (Kelly 1921, p.165; Robinson 1966, p.292).

6.3.4 Effectiveness of wooden spears

Although Churchill (1993) concludes that hand-thrown spears have an effective distance of ca. 5-10 m, a figure which as has been discussed is frequently used for the distance of hand-thrown spears, a revisiting of multiple sources shows this is understated (see also Villa & Soriano 2010). The Tasmanians are reported to have thrown accurately at 37 m (Lloyd 1862, p.45) and 55 m (Roth 1890, p.71), with distance throws of 60-70 m (Robinson 1966, p.873). The Tiwi according to one source could throw accurately up to 55 m (Morris 1964, p.6), even if they tended to prefer approach hunting as a strategy (Goodale 1971). Spencer (1914, pp.364-65) conducted a distance throwing competition of nine Tiwi men using a 3.2 m long spear weighing 1814 g, with distances ranging from 31.8 m to 43.7 m, and a mean of 36.6 m (Fig. 6.12).

Figure 6.12. 'Natives throwing spears on Melville Island'. From Spencer 1914, p. 365. Public Domain

On mainland Australia, there are reports of hand-thrown distances of 64-73 m (Lloyd 1862, p.45) with accuracy around 36-46 m (Giles 1889, p. 10, cited in Cundy 1989). There are shorter distances recorded as well, including accuracy distances of 9-14 m amongst the Adelaide tribe (Eyre 1845, p.306; Tindale 1925, p.94) but Cundy (1989) points out that examples such as the Dieri and Wongkonguru who reportedly accurately threw up to 18 m were groups who rarely hand-threw spears. Outside Australia, examples include the Baris in South Sudan, who threw accurately up to 27 m with distance throws of ca. 46 m (Baker 1874 p.135 cited in Cundy 1989 p.12) and the Mae Enga in Papua New Guinea who achieved accurate throws of up to 30 m and maximum distances of 50 m (Keeley 1996, p.51). The oft-cited accurate distance of 5-10 m is also questioned elsewhere (Villa & Lenoir 2009) as Roman soldiers threw javelins between 15-30 m using heavy spears, weighing between two and four kilograms. Together these distances cited suggest that although groups may have often approached prey *when possible* to a close distance, hand-thrown spears certainly look according to the literature to have been accurate to much larger distances than 5-10 m. Perhaps the lower figures used in calculating the mean throwing distances by Churchill (1993) are a reflection of the fact that most groups using hand-thrown spears had technologies in place which may have made accuracy at greater distances easier, and which required less skill and training to fire from a distance (also see Cundy 1989, p.17). Naturally, the shorter the distance, the easier the aim, but this does not mean that hand-thrown spears are by design limited to being close-distance weapons. Although data from the ethnographic literature should always be treated with caution, on the whole the picture painted of accuracy of hand-thrown spears is that in the hands of skilled users and regular throwers they were accurate to distances significantly greater than 5-10 m, and a conservative estimate based on the ethnographic literature discussed above would place effective distance of hand-thrown spears by highly experienced throwers more in the region of 20-40 m. This means that spear thrusting and hand-throwing are not to be understood as the same strategies and should not be lumped together for analytical purposes. Accuracy of wooden spears as hand-thrown spears is experimentally tested in a human performance trial presented in Chapter 7.

Training and skill are not frequently mentioned in the ethnographic literature, but a few instances of casual training, formal training, and game playing are mentioned in relation to weapon use. Amongst the Tasmanians, Davies (1846, p.412) suggested that practicing spear throwing made up virtually the entire education of children. Although this is likely to be an exaggeration, we can see from this statement that spear practice began early and often for Tasmanian children. Similarly, Tiwi boys began learning spear making and throwing from a very young age, with the youngest learning from older boys, and these learning in turn from young men (Hart & Pilling 1960, p.49). Although not related to spear throwing, male children also began training for warfare amongst the Yuma, which included target shooting with arrows (Forde 1931, p.173). The Cree, who hunted caribou with composite spears had a game which simulated spear hunting called the Cup-and-Pin game (Tap-han) (Skinner 1911, p.36) and young Apache warriors who used composite spears in warfare frequently practiced their spear skills, including a game called mushka which improved their strength and aim (Bourke 1890, p.56). Although most of these examples relate to composite and/or complex weaponry, it can be assumed that such practice and the skills gained were a large part of daily life of youth in societies relying on prehistoric weaponry for survival. For groups who only used hand-delivered weapons, their skill at using them reflects better on the performance of hand-delivered weaponry than the skills of those groups who had other technologies in place, and infrequently threw spears.

6.3.5 Manufacturing and curation

Initial cutting of wood, bark removal, and shaping of spears was typically executed with lithic tools, but in some instances was also done using shells and teeth (e.g. Deacon & Wedgwood 1934, p.215; Gould 1969, p.98). There are several mentions of materials used for smoothing and polishing spears, including the use of tree trunks, sandstone, limestone, pumice, river weed, and sea sponges (Best 1924, p.245; Deacon & Wedgwood 1934, p.215; LeBar 1964, p.263), and the use of handfuls of small chips of debitage was noted in the polishing of wooden arrows (MacCalman & Grobbelaar 1965) a technique that would also be applicable to wooden spear manufacture. Fire was used in the making of wooden spears, including use of fire for shaping and hardening the distal end, as well as for straightening the shaft, for which teeth were also used (Fig. 6.13). These practices were noted for indigenous groups in North America, Oceania, Australia and Africa (Basedow 1913, p.302; Best 1924, p.245; Forde 1931, p.170; Opler 1941, p.391; Swanton 1946, p.583; Robinson 1966, p.532; Hiatt 1968; Gould 1969, p.99; Heider 1970; Heider 1974; Greenwood 1978, p.522; Goodale 1971, p.158).

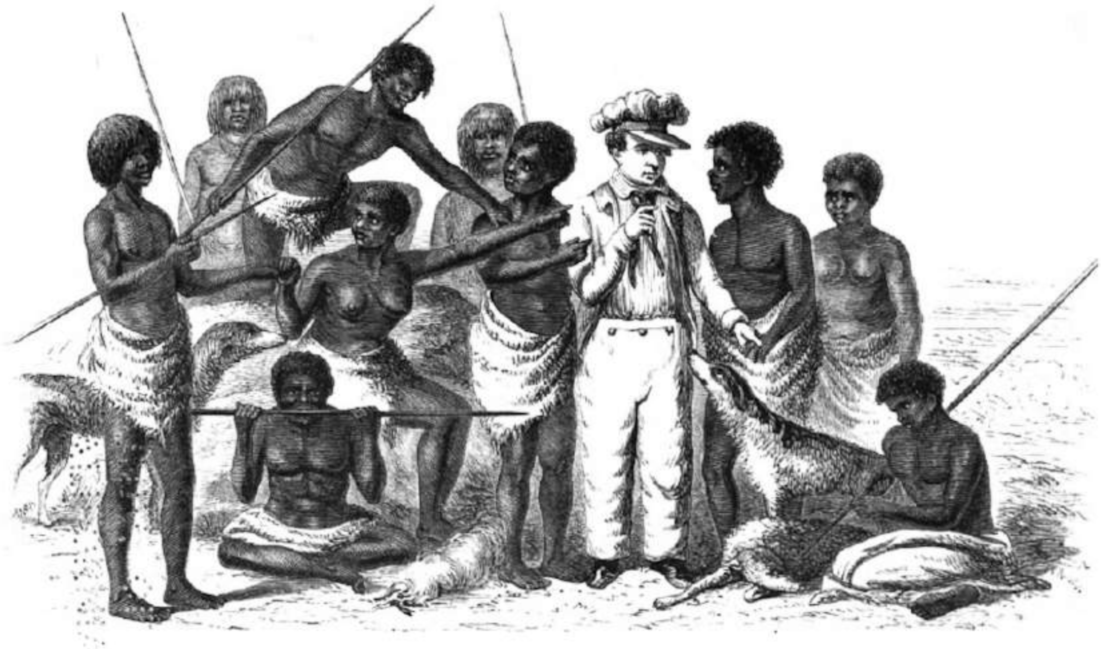


Figure 6.13. 'Last of the Tasmanians', woodcut 5 - Mr. Robinson on his conciliatory mission (artist Benjamin Duterrau (1768-1851), Public Domain)

Where mentioned, wood selected for the manufacture of wooden spears are species with high densities (densities from Zanne et al. 2009). Examples include the use of mesquite and ash (*Prosopis* spp., *Fraxinus* spp.) by the Yuma, Apache, Kamia and Mohave in North America (Bourke 1890, p.56; Forde 1931; Gifford 1931; Stewart 1947; Buskirk 1986), coconut palm (*Cocus nucifera*) in Oceania (Bollig 1927; LeBar 1964), desert oak (*Casuarina dacaisneana*) by Aboriginal groups in central Australia (Spencer & Gillen 1899), tea tree (*Leptospermum scopanium*) by Tasmanian Aboriginal groups (Roth 1890; Hiatt 1968) and both tea tree (also called manuka) and akeake (*Dodonaea viscosa*) for wooden spears used by the Māori in New Zealand (Smith 1893; Tregear 1904). When no species is mentioned, there are still notes that hard woods were selected, for example by the Guayaki in South America whose spears were used for hunting large and dangerous prey and predators (Clastres 1972) and for spears from New Guinea (Davidson 1936). The quality of wood can be affected by many factors, including seasonality (Gould 1969). People are noted to have travelled distances of up to 50 km and to specific known locations including islands in order to aquire the right species and quality of wood for spear making (Robinson 1966, p.618; Hayden 1979). The ethnographic data on wood selection demonstrates awareness of the raw material properties of wood including selection for hard woods, which would have been more difficult to manufacture. These represent a considerable investment of time and energy in the manufacturing of spears including (Gould 1970; Hayden 1979, p.75):

- the choice of durability of raw material over ease of manufacture
- a willingness to travel distances of up to 50 km to gather the appropriate raw material, which takes more time than manufacturing of spears themselves
- possibly the use of fire to create new growth for suitable wood for spears

The selection of wood with high density for spears conforms with species of wood selected for prehistoric wooden spears.

Ethnographic accounts of macrofractures of spears are few. Ellis (1997) mentions a few examples of selection of wood or bone spears over stone, particularly for spear thrusting due to the breakage of stone tips. Another example is from Gould (1969, p.10), who cites faulty wood as a cause for breakage in spear throwing, and mentions that spear shafts dry out and become brittle with Western Desert Australian Aborigines replacing these approximately every three weeks (Gould 1980, p.128). Although this may in fact relate to stone-tipped spears it is still relevant that in arid environments dry wood may be a greater issue regarding the use-life of these weapons.

6.4 Summary and critical appraisal of findings from literature review

Previous reviews of the ethnographic literature have led to the characterisations of wooden spears mentioned at the start of this chapter. These characterisations are addressed here in turn on the basis of the data presented thus far.

1. Heavy spears are difficult to throw, and rapidly lose kinetic energy in flight (e.g. Shea & Sisk 2010a).

The review above has demonstrated that both light and heavy spears are known to have functioned effectively as hand-thrown spears for the purposes of both hunting and violence. The clearest examples are the spears thrown by hand by the indigenous Tasmanian and Tiwi. Their spears are very different from one another in length and especially mass, and yet both groups, according to the literature, were able to throw at significant distances. There are no mentions in the literature of their kinetic energy, but by looking at distances thrown, it seems unlikely that this would be less than bow/arrows. Partly because data on impact velocity, kinetic energy and force of hand-delivered spears has understandably not been reported in the ethnographic literature, it must be tested experimentally to begin to establish these performance parameters, which is addressed through two human performance trials in Chapter 7.

2. Effective distances of hand-thrown spears are generally limited to ca. 5-10 m and are generally inaccurate weapons (e.g. Churchill 1993).

The review has demonstrated that a number of sources indicate that hand-thrown spears were capable of significantly larger distances than 5-10 m. This review, based on multiple sources, demonstrates that a conservative estimate would indicate accuracy was possible between ca. 20-40 m, with maximum distances even greater. The latter measurement is useful when considering a throwing strategy that would involve social group hunting throwing a volley of spears either at a single animal or a herd of animals from a distance, and therefore would require less precision. The review has demonstrated that ethnographically, multiple spears were often carried for this purpose, perhaps retaining a spear for use as a thrusting and/or defence weapon. The present review rejects this statement regarding the effective distances of hand-thrown spears.

3. Hand-delivered weaponry is generally aimed at larger prey, are less effective on smaller game, are primarily associated with disadvantage hunting, and correlate with the use of landscape features (e.g. Churchill 1993).

Although this review did not make a detailed analysis of prey targeted with hand-delivered weaponry, this suggestion is based on conflating spear thrusting with hand-thrown use and it must be clarified that Churchill (1993) makes clear that hand-delivered spears were used on a wide range of prey sizes, but just with a trend towards larger prey. Overall, hand-delivered wooden spears were found in this review to be used to target prey ranging from size classes 1 through 4, and includes animals with predator responses ranging from flight to aggressive display and attack. It is probable that Churchill's (1993) review was correct in determining that overall hand-delivered spears are generally used on larger prey, particularly when complex projectiles are also an option. However, when focusing on wooden spears, a range of smaller prey were hunted, alongside large and dangerous prey. Examples of the use of a range of hunting strategies were covered, showing variability in human group sizes, how animals were approached and whether natural features were used or not. A limited number of sources regarding spear throwing show that hand-delivered wooden spears were with a wide range of hunting strategies including disadvantage, ambush, pursuit and approach hunting, and multiple predation. This review therefore rejects this statement in part, as it shows that hand-delivered wooden spears were employed to hunt a range of prey sizes and types, using a variety of strategies, and were neither limited to small nor larger animals.

4. Hand-delivered weapons are inferior to complex weaponry on the basis of effective distance, energy at impact, ease of use/accuracy, and the ability to capture a wide range of prey in a wide range of environmental settings and for cold regions during the Pleistocene, the reliance on terrain to disadvantage prey.

The review has demonstrated that hand-thrown spears are capable of significant and safe distances from prey, and are able to capture a wide range of prey in a wide range of environmental settings, rejecting the suggestion that hand-delivered spears were inferior to more complex weapon systems on the basis of these attributes. However, it is recognised that there is a fine distinction to be made between the upper limits of a weapon system and typical use. Although complex projectiles may facilitate approach hunting for example, this does not indicate that humans using only simple technologies were *unable* to practice such strategies using hand-delivered spears, and thus this is not a limitation of the latter but rather potentially a facilitator by the former. In terms of ease of use, there are some indications on the basis of this review that spear throwing may be difficult to master, and involve significant time investment to learn to throw for distance and accuracy, potentially indicating a further advantage of mechanically-projected weapons. Thrusting spears on the other hand are undoubtedly close-range weapons, and are described as being associated with bravery at least in warfare, underpinning that it this delivery method carries more danger, perhaps supporting claims that this delivery method is inferior. However, it was clearly both a viable and important tactic in hunting including by groups that had access to complex projectiles (Hitchcock & Bleed 1997), and it has been suggested that a distinct advantage of untipped wooden spears over stone in spear thrusting is that stone spears break more easily than wood and put the user in immediate danger if they are left without a viable weapon (Ellis 1997, p.60). It is probable that complex and composite weaponry holds advantages over hand-delivered wooden spears, with experimentation providing the most fruitful avenue for exploring such advantages (e.g. Salem & Churchill 2016).

Overall the review demonstrates that several of the characterisations regarding hand-delivered wooden spears are not supported by a detailed and focused review. Perhaps part of previous characterisations which have shaped our understanding of MP human hunting comes out of research aims looking to identify macroscale chronogeographic patterns in human behaviours. Particularly in human evolution where evidence can be scarce, such broad generalisations can aid in evaluating the success or otherwise of a particular species of *Homo*. However, such an approach risks masking variability in technologies and behaviours that are seen when looking in finer detail at other lines of evidence from the Pleistocene. Extending such data on the use of hand-delivered spears back to periods where a multiplicity of hunting technologies may or may not have been absent presents problems, not only by potentially comparing ‘apples and oranges’ in terms of physiology and cognition, but even by equating simplicity of technology with cognition in the first instance.

6.5 Museum-based study of ethnographic wooden spears

6.5.1 Introduction to the morphometric study of ethnographic wooden spears

A museum-based study of ethnographic spears was necessary in order to evaluate previous morphometric data (Noetling 1911; Oakley et al. 1977) and the integrity of conclusions drawn from them, as well as to provide a larger dataset, particularly aiming to gather distal tip morphometrics. This is significant not only to provide a potential comparative dataset for archaeological examples, particularly now with the discoveries from Schöningen, but also because morphometrics of thrusting and throwing spears are often used in discussions pertaining to human evolution including changes in physiological capacities, the ability to kill from a distance, change through time in weapon design and what these signal about hominin behaviours and cognition.

6.5.2 Previous published morphometric data of ethnographic wooden spears

Oakley et al. (1977) synthesised data on a selection of ethnographic spears in museum collections but there are a number of methodological problems, which will be addressed here in some detail. The analysis included a selection of eight spears designated as ‘thrusting spears’ and 28 spears designated as ‘throwing spears’. Mass data are provided for the entire sample of throwing spears, and for seven of the eight spears designated as ‘thrusting spears’. Similarly lengths and diameter measurements are provided for much, but not all of the sample studied. However, it is unclear how the distinction was made between ‘thrusting’ and ‘throwing’ spears, and with some of the same examples included in the sample studied for this thesis, it must be highlighted that assigning delivery method in some of these cases is questionable. If criteria used to evaluate delivery of archaeological were also first used to assign delivery method to ethnographic examples, the argument is clearly circular. There were also differences in mass calculations for duplicated examples, with one example (MAEC 6377 1901 in Oakley et al 1977) reported as weighing 460 g less than the mass measured in the present study. In addition, composite examples are part of Oakley et al.’s (1977) sample, as is a ‘children’s spear’. Descriptive statistics of some of the key measurements calculated on the basis of the raw data provided in the original study are presented in Tables 6.3 and 6.4, separating out the spears by function as Oakley et al. (1977) did.

A key feature that Oakley et al. (1977) used to evaluate the function of the Clacton spear point related to tip morphology, a feature which has been more or less absent in assessments of the archaeological examples from Germany (Thieme & Veil 1985; Thieme 1997; Schoch et al. 2015). As the morphometrics of the front of a spear are key for penetration, understanding the

Table 6.3. Descriptive statistics based on data from Oakley et al. 1977, for collection of spears designated as 'thrusting spears'

Measurement	Min	Max	Mean	SD	n =
Length (mm)	1845	2716	2170	307.6	8
Mass (g)	283	1358	772	386.4	7
Max DIA (mm)	20	31	27	3.6	8
PoB (%)	53	82	60	12.0	6
DIA at 100	9.5	17	13	3.1	6
DIA at 200	12	25	19	4.6	7
DIA at 300	17	21	19	1.6	4

PoB expressed as % distance from distal end of spear

Table 6.4. Descriptive statistics based on data from Oakley et al. 1977, for collection of spears designated as 'throwing spears'

Measurement	Min	Max	Mean	SD	n =
Length (mm)	1587	2614	2161	284.3	28
Mass (g)	113	566	258	110.0	28
Max DIA (mm)	7	23	15	3.5	28
PoB (%)	36	66	46	6.4	28
DIA at 100	4	11	7.4	2.0	13
DIA at 200	6	17	10.7	3.3	20
DIA at 300	7	16	NA	NA	2

design of the point is highly significant, and thus this omission is intriguing. Oakley et al. (1977) determined that on the basis of point measurements the Clacton spear point most resembled the distal tip morphometrics of ethnographic thrusting spears, and as such, this has played a key role in assigning this function to this oldest spear. Summaries of a selection of measurements at the distal end from Oakley et al's (1977) paper are presented in Tables 6.3 and 6.4, to be compared with similar measurement data in Chapter 4 and section 6.7 of this chapter. Finally it is not always clear in the data table which of the thrusting and throwing spears are double pointed, and which have a flat proximal end, complicating conclusions about overall morphology.

Oakley et al's (1977) generalisations of delivery methods on the basis of the morphometric analysis are that overall

- thrusting spears tend to be slightly longer than throwing spears (both range and mean)
- thrusting spears tend to have larger maximum diameters than throwing spears
- thrusting spears tend to be heavier than throwing spears
- throwing spears tend to have double-pointed designs
- thrusting spears can be either double-pointed or can be flat at the proximal end
- both thrusting and throwing spears have tapering distal points, but throwing spears tend to be finer morphometrically than thrusting spears

Nevertheless, as the only existing published morphometric data from a diverse collection of ethnographic hand-delivered wooden spears, Oakley et al.'s (1977) morphometric data are referenced and even directly used for calculations in relation to hand-delivered Pleistocene spears (e.g. Churchill 2002; Shea 2006; Maki 2013; Churchill 2014; Rios-Garaizar 2016).

Some additional morphometric data exist in the literature that are helpful to consider. Spencer (1914 p. 364) reports that a spear he chose for its average size thrown in a throwing competition he held amongst the Tiwi weighed >1800 g and was 3200 mm in length, although he does not specify whether this is a plain wooden spear or a barbed example. This mass is in excess of all but the one outlier of spears presented earlier in this chapter. Spencer (1914, p. 359-60) describes another example from the Tiwi, of a wooden throwing spear measuring 2600 mm. These measurements exceed the lengths and mass provided in Oakley et al.'s (1977) data on wooden spears, regardless of the delivery method they assigned to examples.

Wooden thrusting spears intended for warfare used by the Cocopa and Mohave in North America were reported as measuring between 900 and 1500 mm in length (Gifford 1931; Stewart 1947) and the Guayaki wooden spears for killing boar, jaguar, and capybara measured ~1800 mm long (Clastres 1972). In terms of general design, the Kalahari San reported that longer spears were better for throwing (Hitchcock & Bleed 1997).

Noetling (1911) summarised a selection of morphometric data on the Tasmanian throwing spears, but there have been some concerns over his data and data analysis. As the last known remaining spears in museum collections, including those studied by Noetling, formed part of the morphometric analysis presented later in this chapter, his original data are not included in this section. Palter (1977) measured Australian Aboriginal hand-thrown spears (n = 33) to compare with spear-thrower spears. Although the data are not presented in raw form, and the selection criteria do not clearly rule out thrusting use, Palter does provide some useful summaries. The determination as hand-thrown spears involved the lack of an indentation at the end for use with a spearthrower, but Australian Aboriginals used spears for thrusting as well (Davidson 1934). Additionally, Palter included composite spears in the analysis. Nevertheless for purposes of comparing length, mass and point of balance (PoB) for spear thrusting vs. throwing, these data are summarised here. The mean mass of hand-thrown spears was 740 g. PoB is not reported directly for hand-thrown spears, but the range appears to be approximately 43% to 56% of total length from the distal point, keeping in mind that this may also include thrusting spears in the sample studied. The range of masses is ca. 100 g - 1350 g (Palter 1977, Fig.3).

It is demonstrated here that previous claims regarding morphometrics of wooden spears have problems with the data both in terms of inclusion/exclusion criteria, conflicts with morphometric data collected for this thesis on the same objects, and unclear methods for assigning function to spears in ethnographic museum collections, which usually lack detailed provenance and use data and thus these data must be referred to with caution. In light of these methodological shortcomings and the impact the resulting data have had on interpretations of Pleistocene weaponry, it was deemed necessary to collect data on wooden spears from museum collections with clear and robust methods and inclusion/exclusion criteria, married with an honest approach regarding the lack of clear taxonomies and provenance data in old museum collections.

6.6 Materials and methods

6.6.1 Limitations of ethnographic spear dataset

There are clear limitations of using data from objects from ethnographic collections, and some of the most obvious are outlined here. The collections of ethnographic spears do not represent 'natural' or representative collections. This is because it is often unclear who manufactured them, what the purpose for manufacture was (e.g. ceremonial, for trading with collectors, or for use), whether they were manufactured by the group they were collected from, and whether the collector was biased in selecting objects (e.g. Allen 2011). In particular, spears such as plain wooden spears were in all probability under-collected in favour of elaborately-designed (e.g. barbs, composite, and/or unusual materials) and/or decorated objects. Their under-representation in collections cannot only be interpreted as their rarity as utilised weapons, but rather we must acknowledge the preference for unusual and ornate objects, particularly amongst 19th century collectors. Spears from the Melville & Bathurst Islands provide a good example: whilst it is known that the Tiwi made and used wooden spears, the collections in the Australian Museum and the South Australian Museum are almost entirely made up of ornately carved and painted barbed spears (pers. obs). In searching the shelves and database for examples of these spears in the Australian Museum and South Australian Museum, only one example was discovered (South Australian Museum) which was on display and unavailable for study. The Tasmanian Aboriginal spears represent a sample of spears manufactured by Aboriginals in the Flinders colony for Dr. Joseph Milligan and therefore as they were made for a collector it is unclear whether they were made in the same way as though intended for use. However, a further distal 1490 mm of a broken spear recovered from the body of a colonist in the 19th century was donated to the museum in 1963 and the distal measurements available and tip morphology fit very well with the sample made for Dr. Milligan, suggesting that the spears in the Milligan collection, two of which are now held in the Australian museum and were also studied were made close to functional examples. Often 19th and early 20th century collectors and museums were unsystematic in noting precise provenance, and therefore the connection with a particular group can be tenuous, making assigning delivery method problematic. It is for this reason that 76% of the spears studied for this thesis (n = 58) do not have a delivery method assigned, for it was only when provenance was detailed and relatively secure, and clear data regarding one delivery method in absence of another for a given society could be gleaned from the literature, that an assignment was made. These limitations are taken into account when presenting the results of this study.

6.6.2 Materials: collections and selection criteria

A sample of 58 suitable examples of untipped wooden spears were studied in museum collections, primarily originating from Oceania, making this the largest sample ever studied. Museum collections were targeted both on the basis of balancing the suitability and breadth of collections with time and cost for travel and curatorial availability of spears. Collections at the British Museum and the Pitt Rivers Museum (University of Oxford) were not available for study due to the recent move of ethnographic collections and the large nature of the spear collections. Spear collections studied include those from the Horniman Museum, the Museum of Archaeology and Anthropology (University of Cambridge), Australian Museum (Sydney, Australia), South Australian Museum (Adelaide, Australia) and the Tasmanian Museum and Art Gallergy (Hobart, Australia). The South Australian Museum contains the largest and most comprehensive Australian Aboriginal ethnographic material in world, providing a particularly excellent sample for studying wooden spears. In each of these collections, database searches for suitable spears were conducted in advance in collaboration with museum staff, producing an initial list of suitable material. In each case, apart from the Tasmanian Museum and Art Gallery which only held the sample of Tasmanian Aboriginal spears, the spear collections were also investigated in person to select additional suitable examples, as not all databases are comprehensive or detailed enough to make selections electronically. The latter approach proved particularly fruitful.

Spears were selected on the basis of being single-piece wooden spears. No spears with evidence for use with a spearthrower in the form of an indentation or hole at the proximal end were included. Spears needed to be complete or nearly complete with only very small amounts of damage that would be unlikely to affect measurements. If minor damage was present this was noted. Barbed and composite weapons were excluded, as were one-piece wooden spears with distal morphologies that were wide and blade-like, though some examples with slightly flattened or triangular points were included as long as they remained roughly conical in shape. The spears did not have to be double-pointed, and the proximal morphology was noted in the study. Spears with small amount of decoration such as carving, painting/liming, or binding were included as long as the decoration did not clearly interfere with the spear being functional. In some cases it was known that amongst certain groups such as the Tiwi that decorated spears were ceremonial and these were excluded, as were those with decorative features at the distal end that would interfere with penetration and which therefore suggest a ceremonial function. These criteria are more stringent than those applied elsewhere (e.g. Oakley et al. 1977) and provide a robust dataset to evaluate morphometrics. Function as hand-thrown vs. thrust was only assigned if the literature provides a clear indication that wooden spears by a group were only used in throwing but not thrusting or vice versa. It was not possible due to the unavailability of certain collections, as well as time and financial constraints to extend the study to include examples from Africa, North America and South America that are known to have been in use, but such a study would help in fleshing out the sample and testing conclusions made below.

6.6.3 Methods: measurement and analysis of the ethnographic spears

Measurements were taken in the same way that was described in Chapter 4. In addition, mass measurements were taken in g using scales provided by the museums. Point of Balance (PoB) was taken by holding the shaft and locating the balance point manually, then calculating this distance in relation to the length of the spear, which is expressed as a percentage of the total length from the tip. For example, a spear which would have its PoB located a third of the way from the distal tip would be expressed as 33%. ‘Location of maximum diameter’ was used to calculate how this relates to overall length using the same method. On the basis of their uniformity of design, it was not always entirely clear which side of double-pointed untipped wooden spears was the distal end and which the proximal. While most cases were clear, in the few cases where it was unclear, a qualitative judgment was made on the basis the morphology of the pointed ends - i.e. the sharper, pointier end was defined as ‘distal’ and the blunter end was defined as proximal. As described in the materials selected, a few examples had distal morphologies that were not completely conical in shape (n = 3) and therefore these examples are excluded from the statistical analysis of distal point metrics. Photographs were taken of distal ends, and in some cases proximal ends of spears in order to document shape. Select manufacturing and possible use traces were also recorded with digital photographs and with the Dino-Lite. Statistics were calculated with SPSS 24 and Excel.

6.7 Results of the morphometric study

6.7.1 morphometrics

Table 6.5 presents descriptive statistics of overall spear measurements. Wooden spears had a large range of lengths, with the maximum length exceeding that in Oakley et al’s (1977) study by >1500 mm. The maximum diameters ranged from 13 mm to 32 mm. The location of the maximum diameter had a mean of 35% from the distal point, whereas the PoB had a mean of 47%. These results suggest that maximum diameter is on average closer to the tip than the PoB. Interestingly there is a higher coefficient of variation (CV) for maximum diameter than for PoB, suggesting both that factors other than maximum diameter influence PoB even for an untipped wooden spear, but also that PoB is a key factor in spear design. Like length, mass measurements had a wide range from very light spears to very heavy ones, with a very high CV. The mean (701.2 g) is similar to those of experimental replicas of Schöningen spear II presented later in this thesis (Chapters 7 and 8). These results indicate that mass is not a particularly limiting design factor for wooden spears, with a wide range possible for functional weapons, rejecting hypotheses that heavy spears make ineffective weapons.

The length histogram demonstrates a bimodal distribution, which may indicate a separation of two groups by delivery systems (Fig. 6.14, top). Length by delivery systems were also graphed (Fig. 6.14, bottom). Although the majority of the spears could not have a delivery method assigned with confidence, broadly speaking hand-thrown spears were longer than thrusting spears (contra Oakley et al. 1977). The longest spears in the sample are those from Tasmania, which were throwing weapons.

Table 6.5 Descriptive statistics for measurements taken from sample of ethnographic wooden spears from museum collections

Measurement	Min	Max	Mean	SD	CV (%)	N
Length (mm)	1375	4385	2804	568.7	20	58
Max DIA (mm)	13	32	21	4.6	22	58
Loc. Max DIA (%)	4	66	35	16.5	47	58
Mass (g)	150	2246	701	411.5	59	58
PoB (%)	34	56	47	5.5	12	58

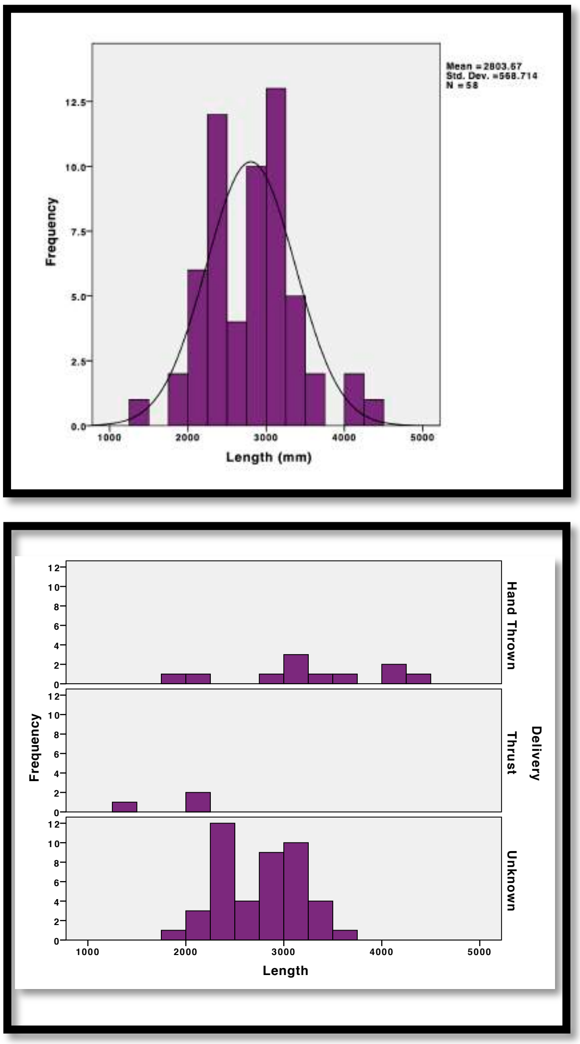
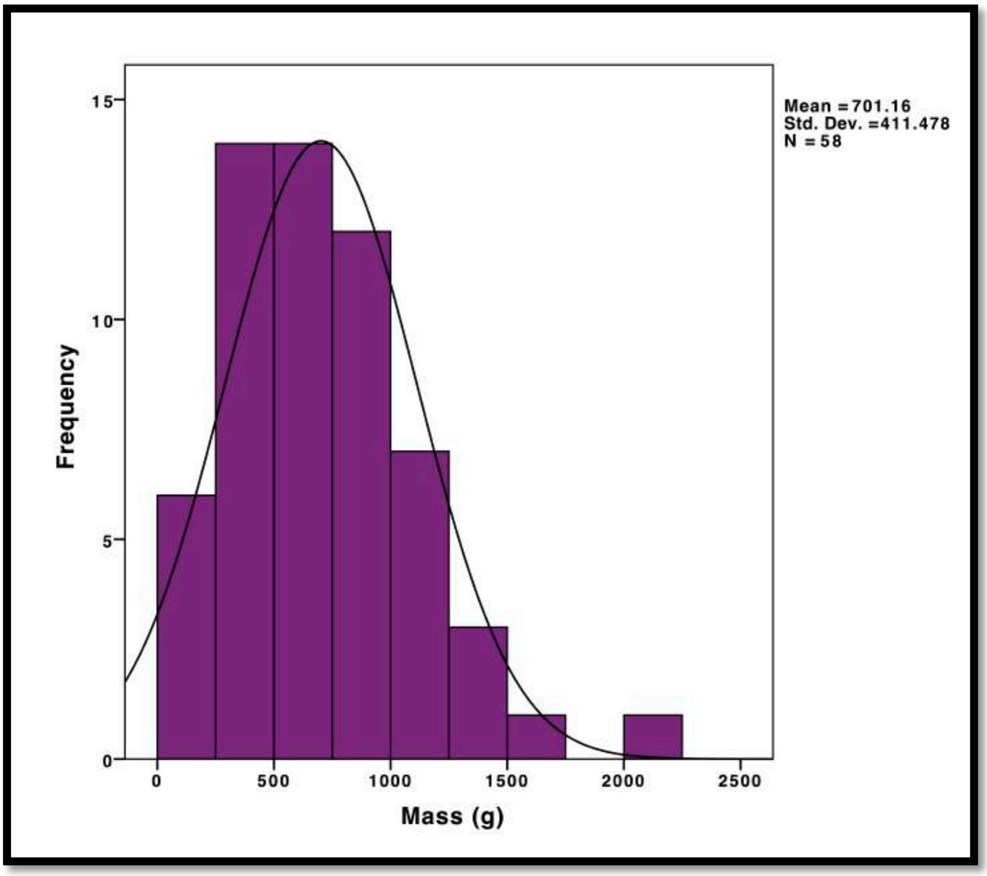


Figure 6.14. Top: histogram of length. Bottom: histogram of length broken down by delivery method



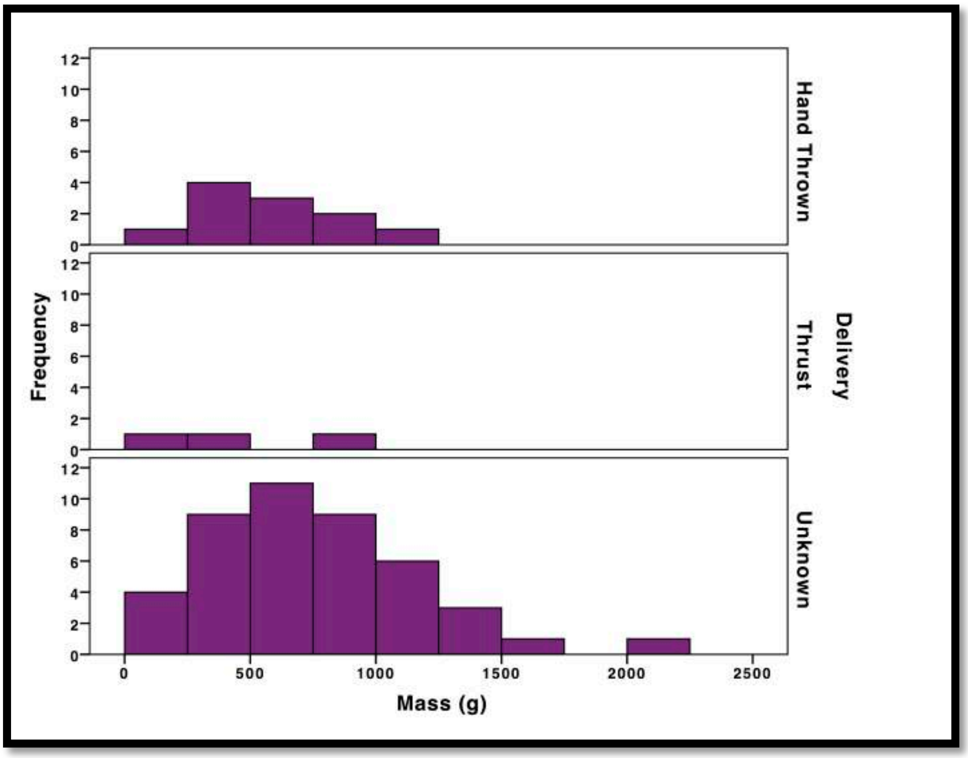
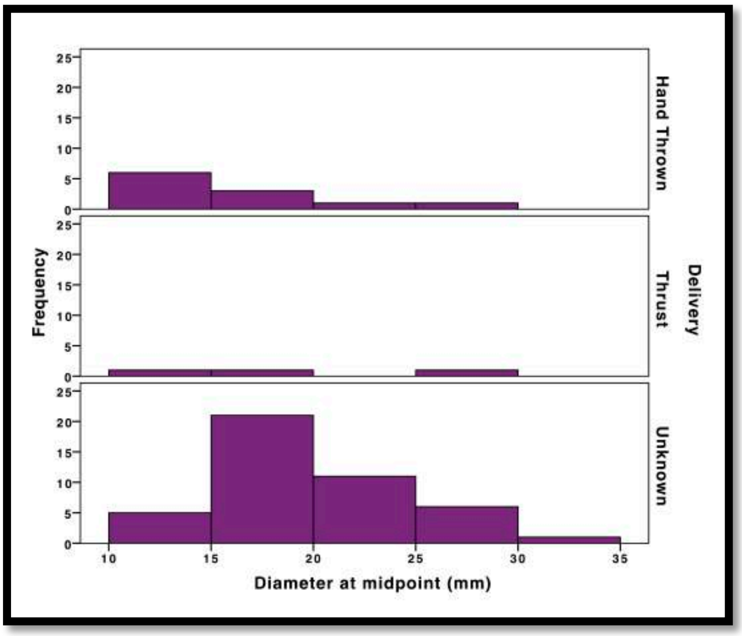


Figure 6.15. Top: histogram of mass. Bottom: histogram of mass broken down by delivery method

The histogram of spear masses show that most spears (n = 56) fall under 1500 g, with one spear weighing 2246 g as an outlier (Fig. 6.15, top). This spear comes from Coopers Creek, South Australia, which is an area that Davidson (1934) confirms hand-delivered spears predominated though spearthrowers were present, but the account does not specify whether untipped wooden spears from this area were thrust, thrown or both. Spencer's (1914) data on hand-thrown Tiwi spears confirms that spears heavier than 1800 g were thrown amongst Aboriginal Australians, which would fall in the heavier regions in the histogram. Breaking down mass by delivery system (Fig. 6.15, bottom) it is clear that there is overlap, with some of the lightest spears functioning as thrusting weapons, and some of the heaviest spears functioning as hand-thrown spears.



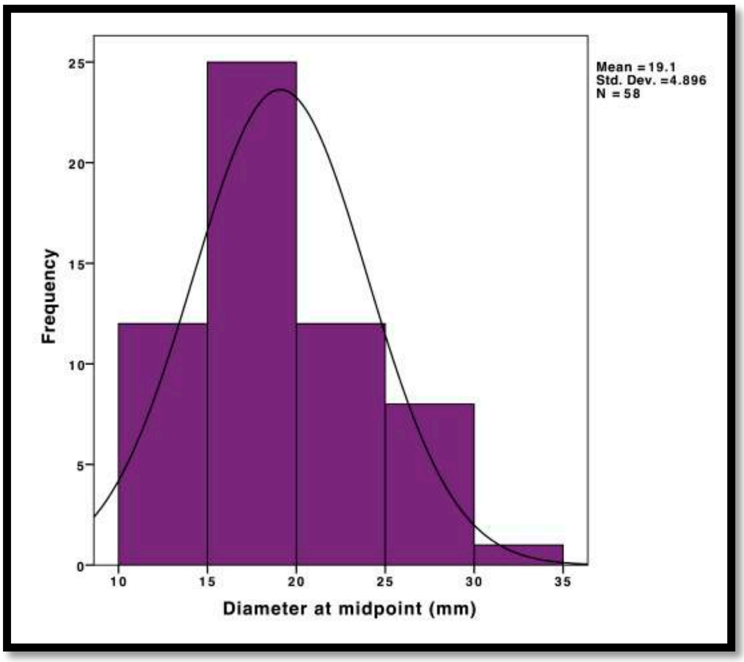
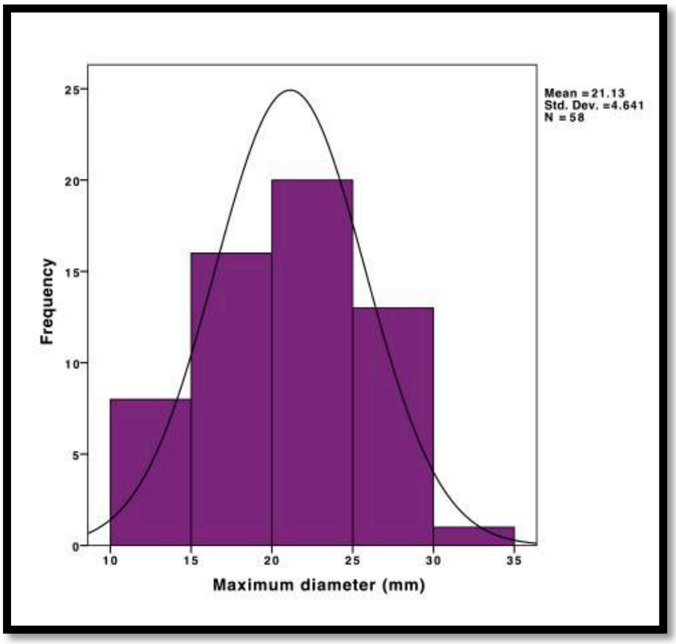


Figure 6.16. Top: histogram of diameter at midpoint. Bottom: histogram of diameter at midpoint broken down by delivery method



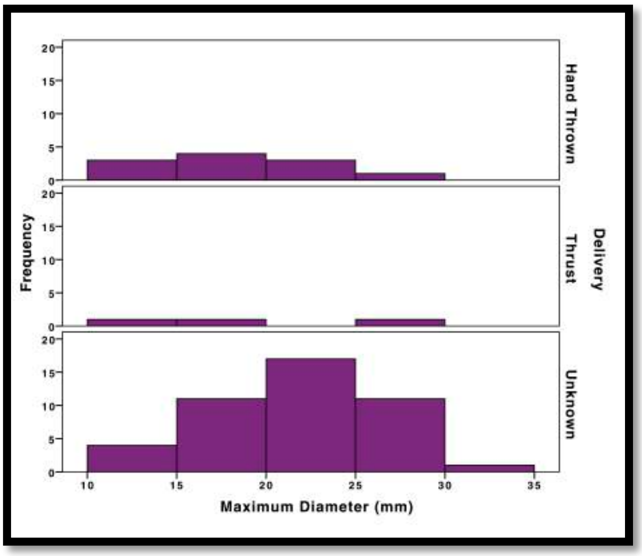
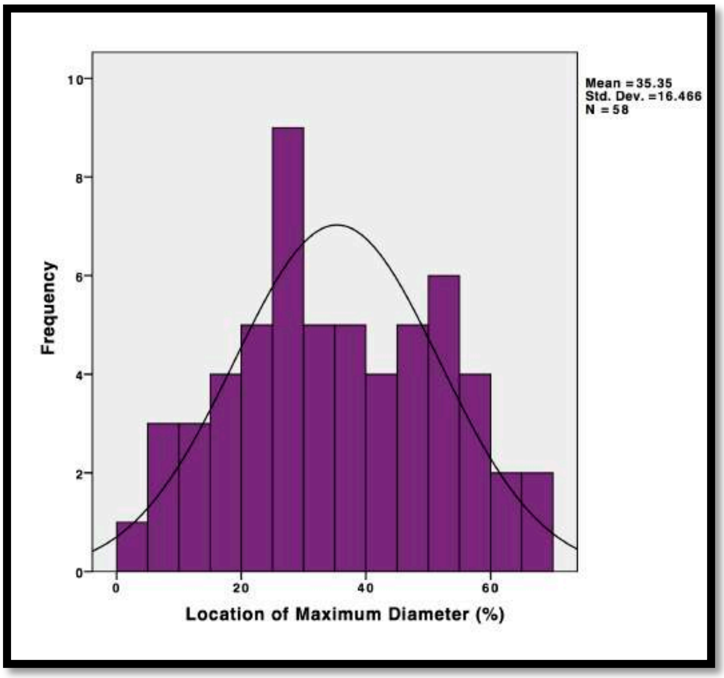


Figure 6.17. Top: histogram of maximum diameter. Bottom: histogram of maximum diameter broken down by delivery method

Diameter at midpoint is widely spread (Fig. 6.16, top), with areas of overlap by delivery system (Fig. 6.16, bottom), and no clear distinction between these. The measurements for diameter at midpoint and maximum diameter are fairly similar, and may relate to the fact that most spears have their PoB located towards the centre of the shaft and/or that most hand-delivered spears taper at both ends. Maximum diameter has a trimodal distribution (Fig. 6.17, top), with one outlier at the higher end of measurements. The outlier is the same artefact as the mass outlier, the spear from Cooper's Creek, Australia. Breaking maximum diameter down by spears with known delivery method (Fig. 6.17, bottom) shows overlap in this measurement, with thin and thick spears being used for both functions.



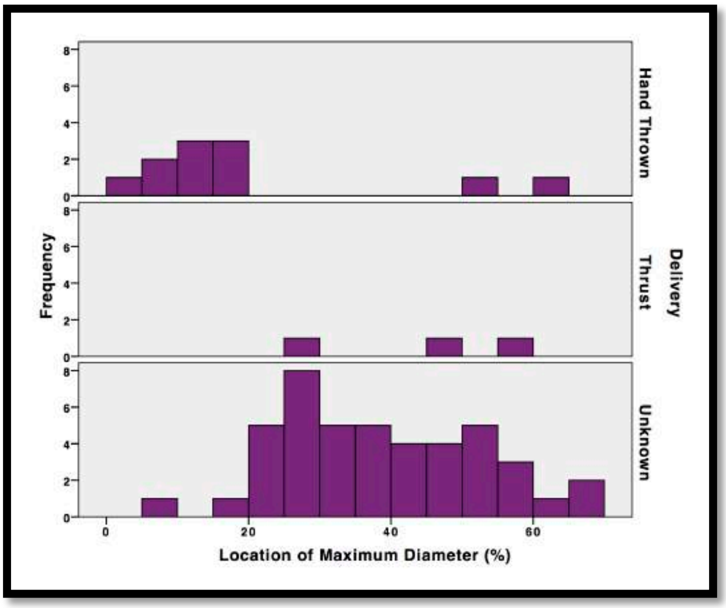
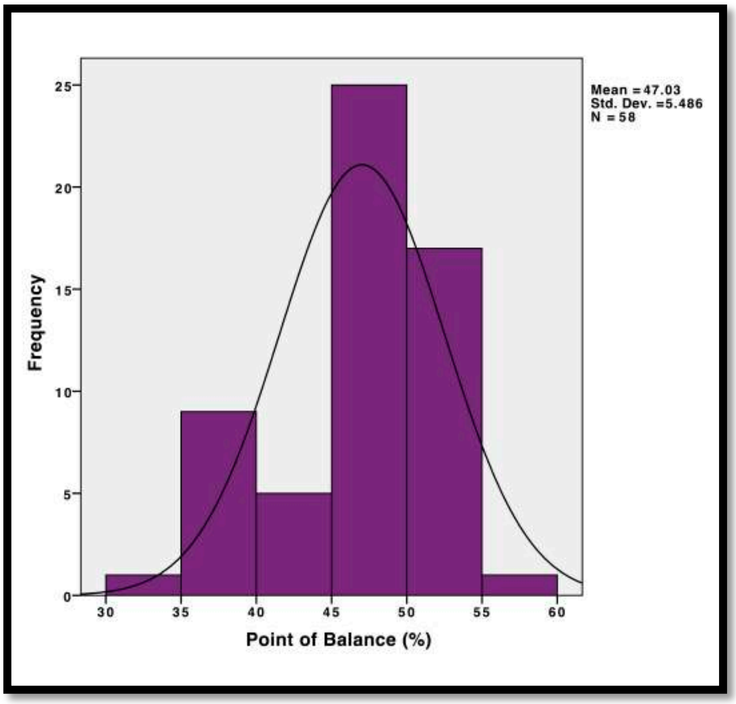


Figure 6.18. Top: histogram of location of maximum diameter. Bottom: histogram of location of maximum diameter broken down by delivery method

The location of the maximum diameter (% from distal end) has a wide spread (Fig. 6,18, top). One extreme example from an unspecified location in mainland Australia has its maximum diameter only 9% from the distal end. In this case, it is clear this is the distal part of the spear, as the proximal end is flat not pointed. The spear is long (2175 mm) but very light (200 g) and with no specific provenance, a delivery method cannot be determined. Maximum diameters are also very near the distal point for the Tasmanian spears, with these spears having the lowest percentage (4%) of location of maximum diameter. This result very tentatively suggests that spears with a maximum diameter very near the front were designed to be thrown.



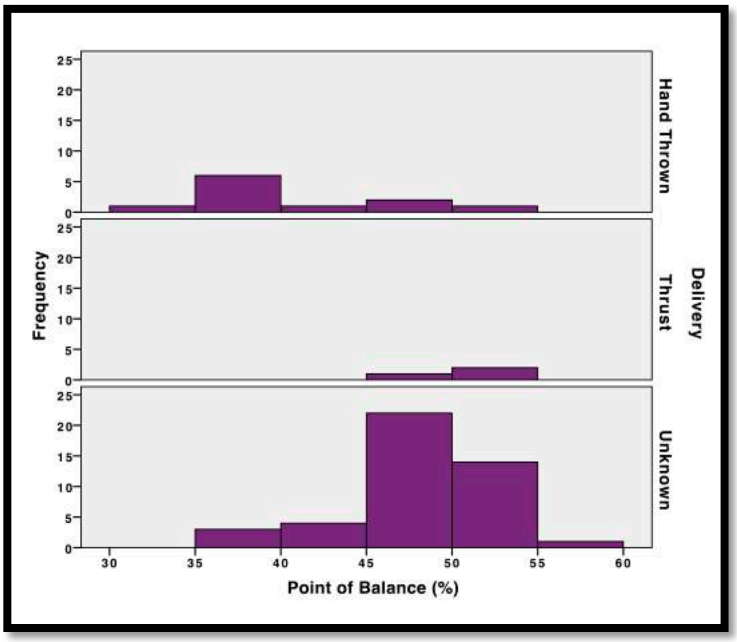


Figure 6.19. Top: histogram of point of balance. Bottom: histogram of maximum diameter broken down by delivery method

The point of balance histogram shows a concentration around the midpoint of spears (Fig. 6.19, top), with none having a point of balance greater than 56% of the way from the distal point of the spear. In contrast a number of spears have the balance point fairly far forward, including the throwing spears from Tasmania, which balance between 34% and 41% from the distal point (n = 8). Only three other spears from the sample had balance points in this range, two with only 'Oceania' marked as its provenance, and the other from New Caledonia, with an unknown delivery method. Dividing PoB by delivery method (Fig. 6.19, bottom) gives a clearer result that hand-delivered spears have their PoB around or in front of the centre point, but thrusting spears may be either behind or just in front of the midpoint of a spear.

Because histograms typically suggested the data may not be normally distributed, normalcy tests (Shapiro-Wilk) were run. The results demonstrated that length, maximum diameter, diameter at the midpoint and the location of the maximum diameter all have p>.05, confirming normality for these measures. Mass and PoB (%) did not meet the criteria. In order to correlate measures including mass and PoB (%) with other features, these were log transformed. The resulting p values for PoB (%) and mass were still < .05 (Mass p = .026; POB p = 0.32). While there are no obvious individual outliers for PoB, it is suspected that the Tasmanian spears, with a PoB very far forward may be skewing the distribution. However, as these are a particular case of design for spear throwing, these cases must remain in the analysis. For this reason regression analysis was not undertaken for PoB, but a scatterplot correlating PoB and location of maximum diameter follows (Fig. 6.20). Location of the maximum diameter and PoB have a relatively strong correlation, meaning that we can continue to make inferences about the latter on the basis of the former. This is particularly relevant for archaeological examples which are broken into segments. Scatterplots (Fig. 6.21) shows that length and maximum diameter and length and mass do not correlate particularly well. However, mass and maximum diameter have a relatively strong correlation (Fig. 6.22), which means estimates of mass on the basis of maximum diameter are possible.

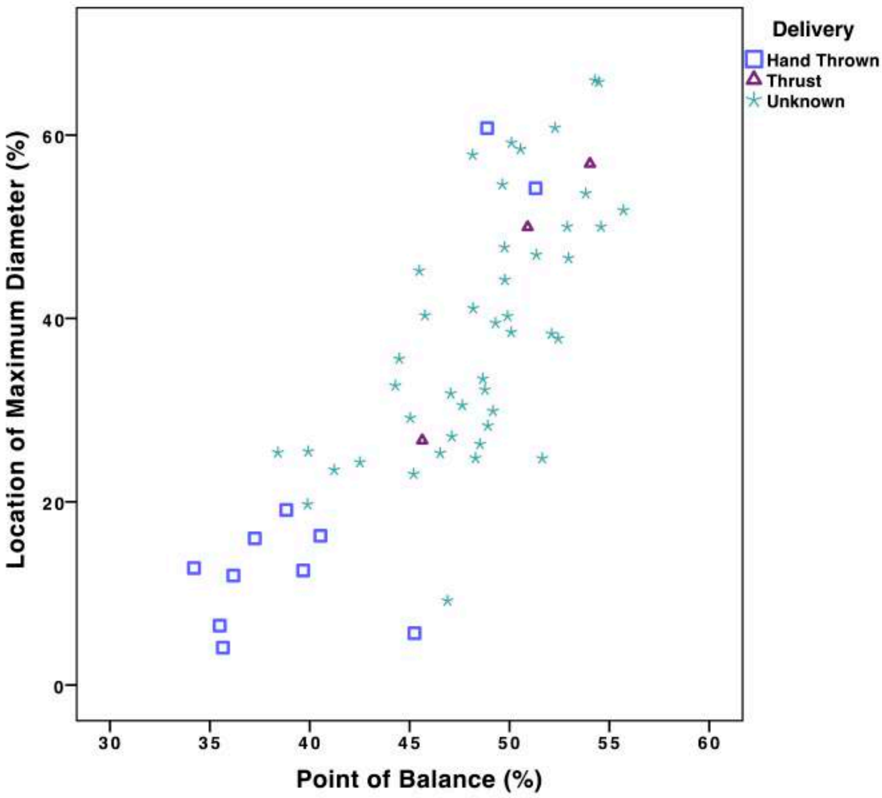


Figure 6.20. Scatterplot of point of balance and location of maximum diameter

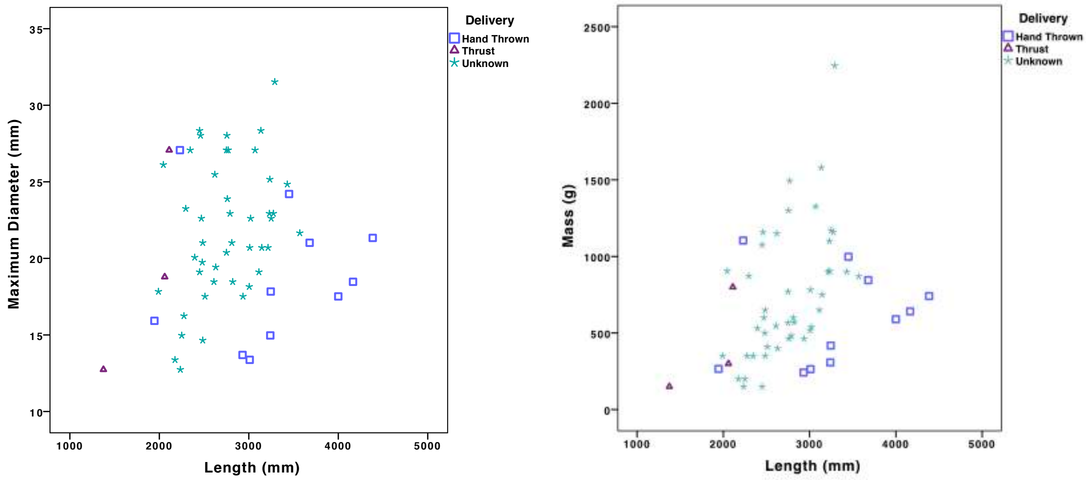


Figure 6.21. Scatterplots comparing length with maximum diameter (left) and length with mass (right) of the ethnographic spear sample

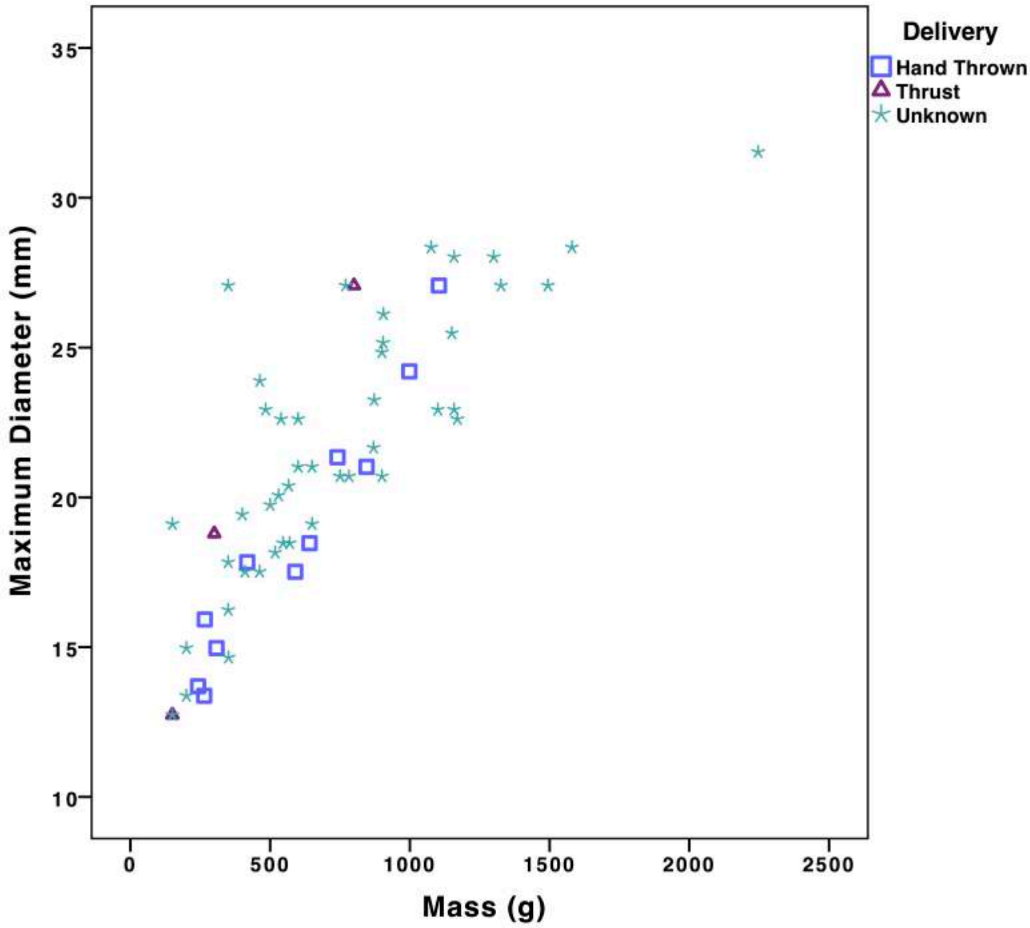


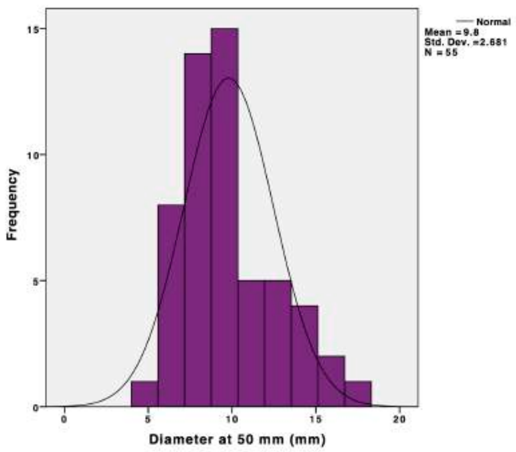
Figure 6.22. Scatterplot of maximum diameter and mass of the ethnographic spear sample

The analysis of the distal point morphometrics demonstrates that distal points of spears consistently increase in diameter along the shaft, as expected (Table 6.6). The CV value remains similar across the different locations from 50 to 250 mm, suggesting a standardisation of tip design.

Table 6.6. Descriptive statistics for tip measurements taken on sample of ethnographic wooden spears from museum collections. Diameter measurements (DIA) in mm. Opening Angle in degrees.

Measurement	Min	Max	Mean	SD	CV (%)	N
DIA at 50 mm	5	17	9.9	2.72	28	55
DIA 100 mm	6	22	12.0	3.14	26	57
DIA 150 mm	8	23	13.4	3.21	24	57
DIA 200 mm	8	23	14.6	3.17	22	58
DIA 250 mm	9	24	15.4	3.11	20	58
Opening Angle	4	13	6.9	1.81	26	57

Measurements at 50 mm are not normally distributed (Shapiro-Wilk, p = .10), whereas the other four measures all have $p > .5$, showing a normal distribution (Figs. 6.23 and 6.24). The CV at 250 mm is the lowest, showing the least amount of variation at this measurement. The range of diameters at 150 mm and 200 mm is identical, though with a slightly higher mean at 200 mm. This suggests a standardisation at the point of the spear that is crucial for DoP, and has implications for observations made about intercostal rib spacing in the Chapter 8 experiments (section 8.4.3.5). The box-and-whisker plot (Fig. 6.25) shows a gradual increase in diameter, which is to be expected, but again highlights the similarities between measurements at 150 mm and 200 mm. Fig. 6.26 illustrates a range of distal tips of ethnographic spears studied, with one of the thinnest examples on the left, an example close to the mean in the middle, and one of the largest and most robust spears in the sample on the right. Opening angles at 10 mm of ethnographic spears range from 4° to 13°, with the mean being 6.9°.



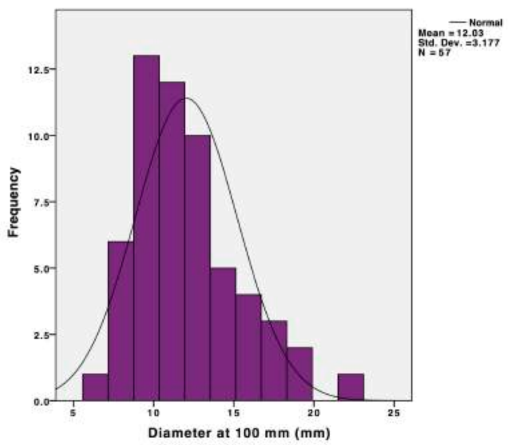


Figure 6.23. Left: histogram of diameter at 50 mm. Right: histogram of diameter at 100 mm

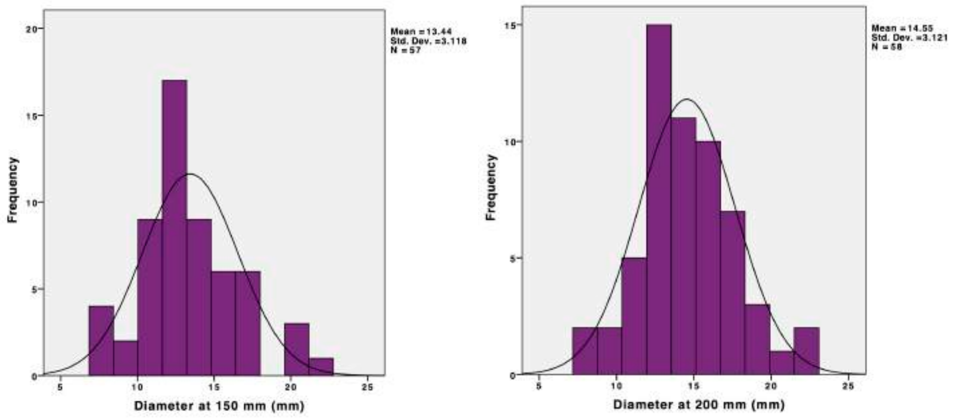


Figure 6.24. Left: histogram of diameter at 150 mm. Right: histogram of diameter at 200 mm

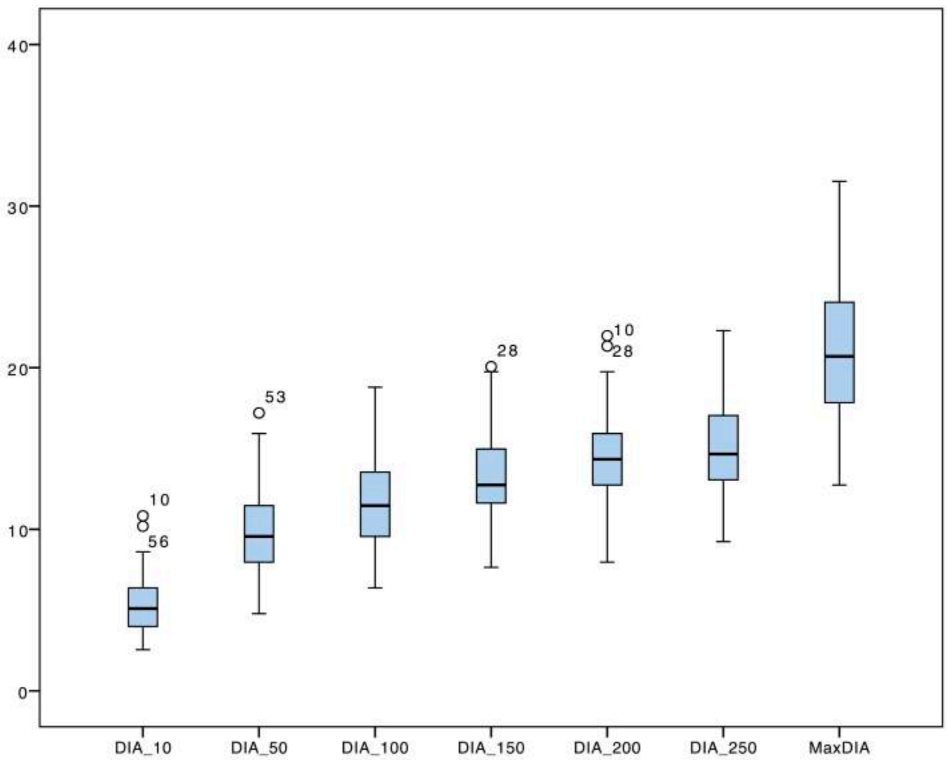


Figure 6.25. Left: box-and-whisker plot of series of diameter measurements (mm) of ethnographic spears

Figure 6.26. A selection of distal spears showing a range of morphologies. Left: one of the thinnest examples, from New Caledonia (Cambridge Museum of Archaeology and Anthropology 1917.118.91), middle: an mid-range example, from Queensland, Australia (Australian Museum E.1520), right: one of the largest spears, from South Australia (South Australia Museum A39396)

It is helpful to explore whether morphometrics of the distal tips of wooden spears can be used to predict overall length, maximum diameter or PoB of spears, as this could be fruitful for evaluating spear fragments including those from Clacton and Schöningen. None of these measurements had a strong correlation with the diameter at 200 mm (Figs 6.27 and 6.28), meaning that the diameter of the distal parts of spears cannot be reliably used to predict overall size, or design of a spear.

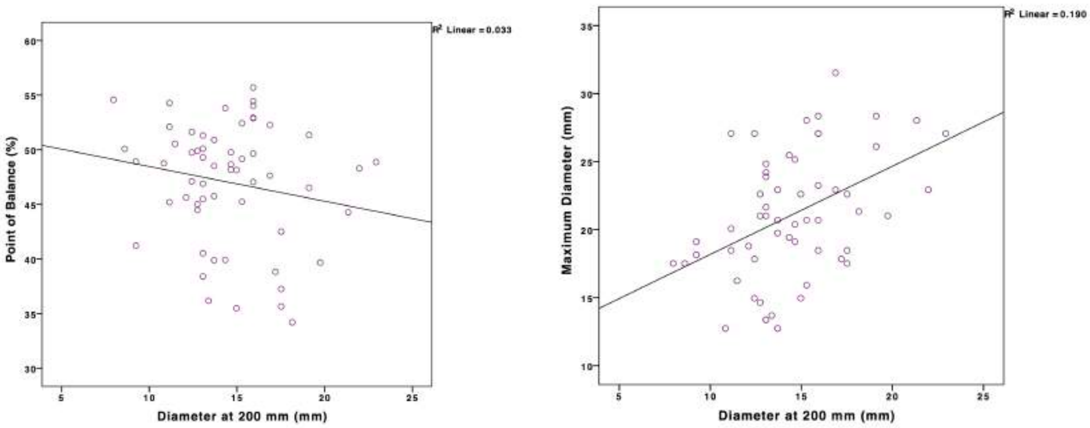


Figure 6.27. Left: regression analysis of diameter at 200 mm and PoB, R^2=0.033. Right: regression analysis of diameter at 200 mm and maximum diameter, R^2=0.190

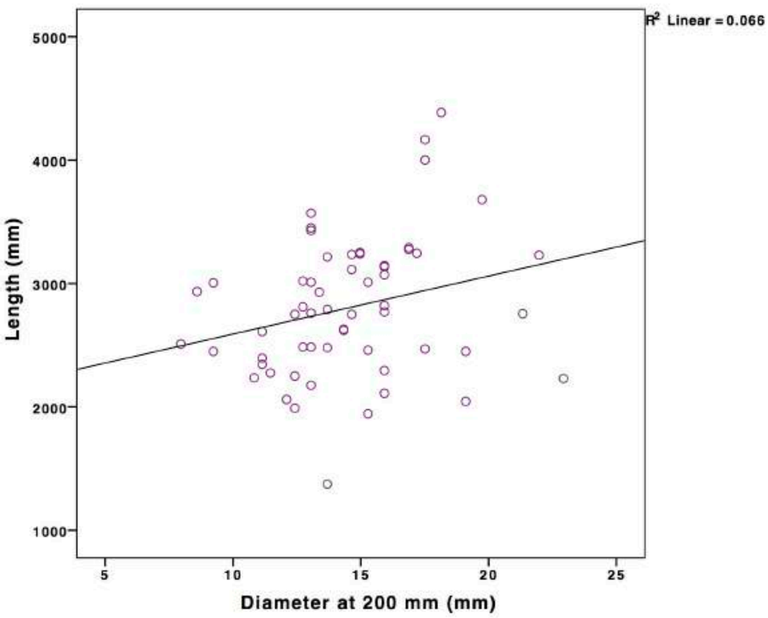


Figure 6.28. Regression analysis of diameter at 200 mm and length, R^2=0.066

6.7.2 Comparison of ethnographic sample with archaeological wooden spears

A selection of the morphometrics of the archaeological and ethnographic spear samples are now compared. The larger and more comprehensive dataset of ethnographic spears presented in this chapter facilitates an approsal of previous hypotheses, and the formation of new questions regarding the relationship between the form, delivery method and performance of hand-delivered wooden spears. The length histogram (Fig. 29) demonstrates that as a group the archaeological spears are in the shorter range compared with ethnographic examples. With most of the Schöningen spears looking possible as thrown spears by design and experimental use (see Chapter 7), this contradicts Oakley et al's (1977) suggestion that thrusting spears are longer than throwing spears. With the present data available, overall length does not appear to be a clear predictor of delivery method.

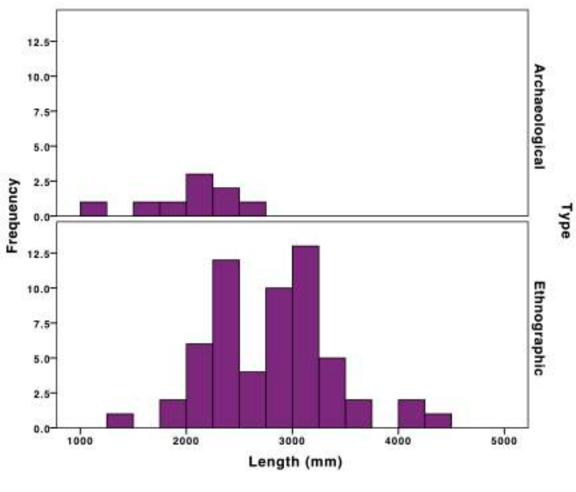


Figure 6.29. Histograms of the length of archaeological vs. ethnographic wooden spears

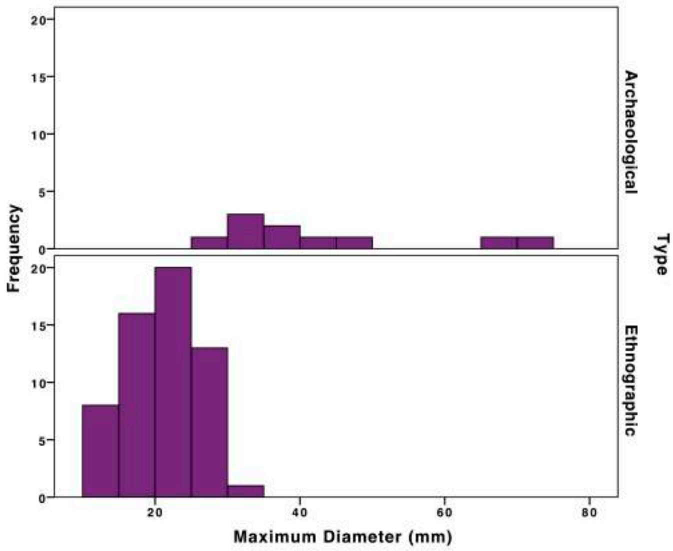


Figure 6.30. Histograms of the maximum diameter of archaeological vs. ethnographic wooden spears

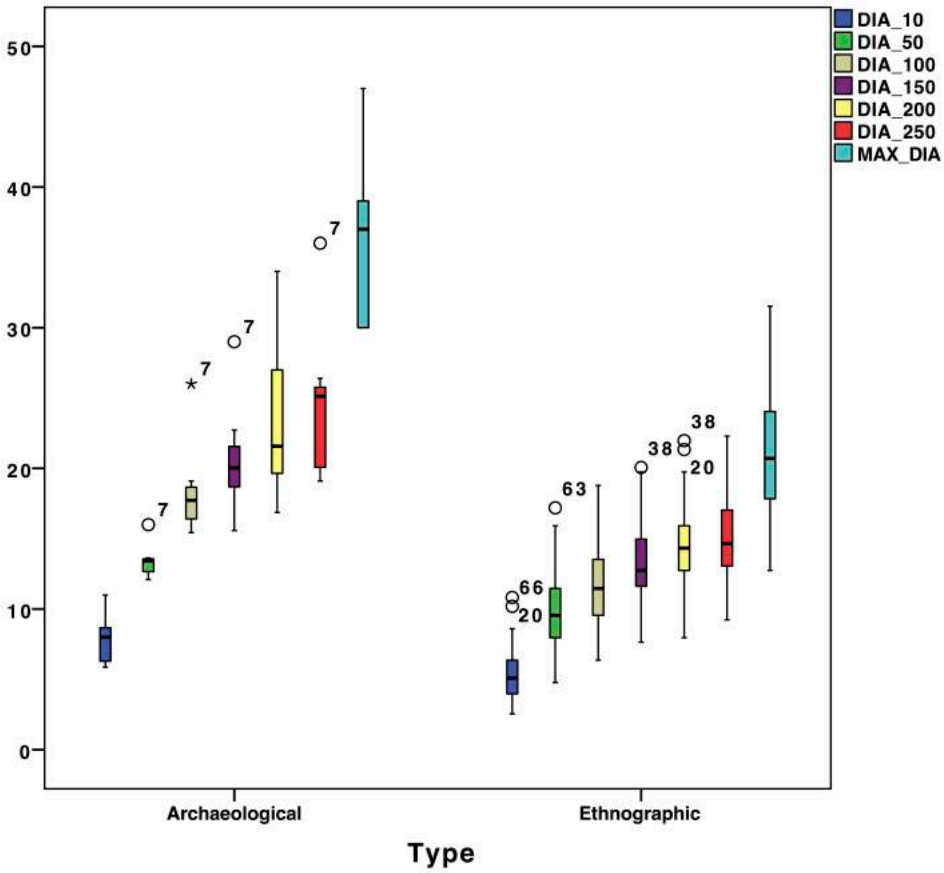


Figure 6.31. Distal and maximum diameter measurements of archaeological vs. ethnographic spears

The histogram of maximum diameters (Fig. 6.30) shows the large diameters of archaeological examples of wooden spears in comparison with the ethnographic sample, which correlates with spear mass. The implications of this are further explored in Chapter 9, but overall possible reasons for this may include:

- physiological differences between MP *Homo* and recent modern humans (stature and robusticity, adaptation for throwing)
- increased awareness over time of the relationship between design and spear mechanics
- differing delivery methods
- technological improvements making the working down of spear shafts easier to accomplish
- differences in prey and/or humans targeted with wooden spears

Due to the small sample size of archaeological examples these varying causes are difficult to test, but all are worth consideration moving forward with future research.

Distal point diameter measurements of archaeological vs. ethnographic spears shows that like maximum diameter, tip diameters are more robust overall for the archaeological sample (Fig. 6.31). However, there are areas of overlap for all of the diameter measurements. Similarly, the mean opening angle of ethnographic spears of 7º is smaller than any of the archaeological examples analysed (Table 4.5). However, all of the archaeological examples, with the exception of the Clacton spear with an opening angle of 15º, fit within the range of ethnographic spears. This highlights the previous conclusion that tip diameters for the archaeological sample were relatively standardised, and that there was intent to create a tip that balanced considerations for penetration with breakage. This result indicates that MP hominins had the cognitive capacity to understand fundamental concepts of terminal and wound ballistics. In addition to creating a sharpened point, as the spear-making chimpanzees have done with their teeth (Pruetz & Bertolani 2007), there is clear attention aimed at carefully crafting the distal parts of spears that penetrate an animal. This strongly advocates against these spears being intended solely for self-defence, because in that case a reasonably sharp but robust spear would be necessary, but clear attention to design at 150 to 200 mm would be unnecessary because the intent would be to keep a dangerous carnivore at a distance, rather than the ability to penetrate to a lethal depth.

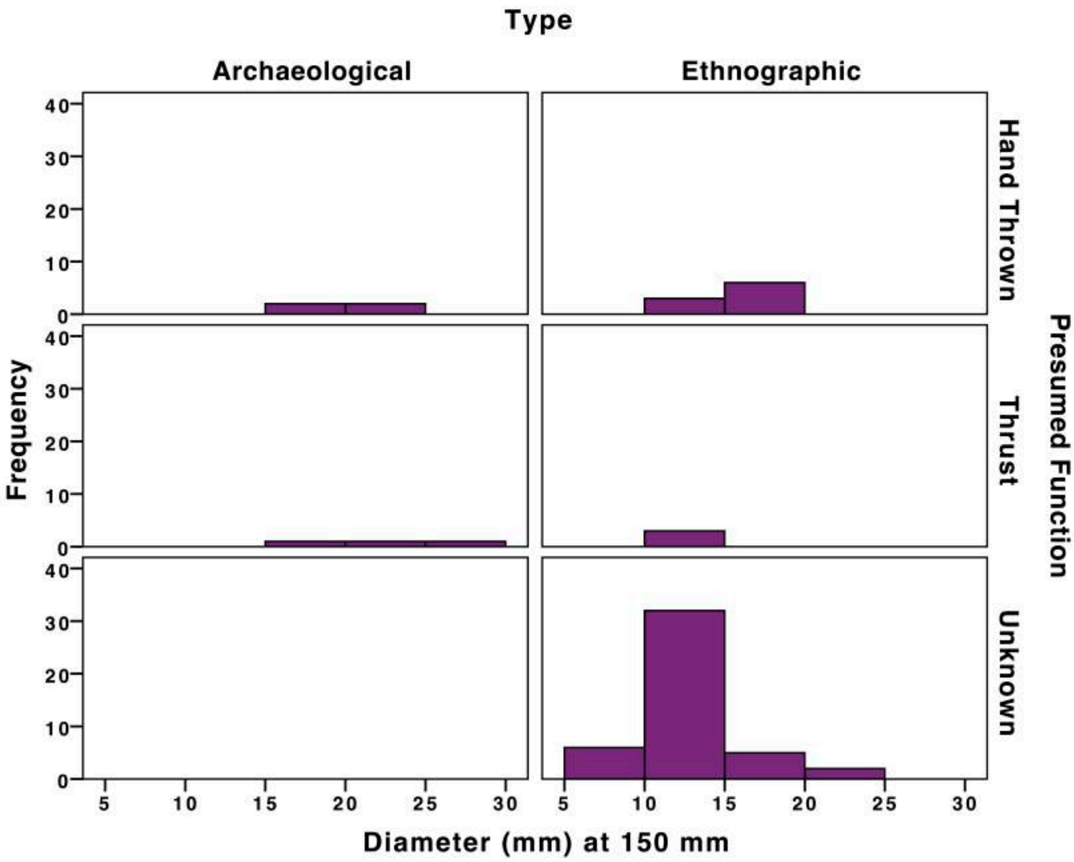


Figure 6.32. Histogram of diameters at 150 mm of archaeological and ethnographic spears, separated by presumed and/or known function

Fig. 6.32 demonstrates that any spears of presumed or known delivery method have broad areas of overlap of their diameters at 150 mm. This again supports the suggestion that distal spear points are standardised to aid penetration regardless of whether they were thrust or thrown at prey. The mass of archaeological examples of complete spears can be estimated by their maximum diameters, on the basis of the correlation between these measures for ethnographic spears (Fig. 6.22). Estimates for the archaeological sample would place the spears as roughly falling between 700 g and 2000 g, depending upon length as well as density of wood, which not only differs between trees and species, but also varies over time as the wood of the spears dry out (pers. obs.). The replicas of Schöningen Spear II crafted from spruce for experiments in this thesis (Chapters 7 and 8) fall in the lower range of this estimate, with a mean of 764 g (n = 10). Spear II falls in the middle of the range of Schöningen spear measurements, which was the reason it was chosen to replicate. Spears I and VI would likely be heavier, perhaps even approaching 1500 g; Spears III and V would probably have been lighter, again depending upon the density of the wood. This has implications for kinetic energy at impact, and it has been shown in the ethnographic review that spears of up to ca. 2000 g were known to be thrown by hand and thus their mass does not rule out their being hand-thrown, particularly considering the robusticity of European MP *Homo* (Gallagher 2013).

6.8 Discussion

The results of the morphometric analysis show wide variability in many measurements, including length, mass, and maximum diameter. Location of the maximum diameter of a spear may be the only significant measurable feature with a reasonably clear link to delivery method, with length, mass and maximum diameter having no clear correlations that could be determined in this study. Also helpful in analysing archaeological spears is the finding that maximum diameter and mass have a relatively strong correlation, making it possible to broadly estimate a mass range for a given spear based on maximum diameter without crafting replicas. While these results are preliminary, and further data linking specific spears to delivery method are necessary, the results here support the ethnographic literature review in finding a wide range of lengths and mass reported, particularly for hand-thrown spears. In contrast, tip morphologies appear to be more constrained in the sample studied, with strong links between diameters measured within the front 250 mm of the spears. This result highlights functional constraints on the design of weapon tips, which balance penetration with risk of breakage. The optimal diameter according to the sample at 200 mm appears to be somewhere between ca. 10 and 16 mm.

Compared with Oakley et al (1977) the sample studied here (n = 58) had a wider range for length. Oakley et al's (1977) suggestion that thrusting spears may be longer than hand-thrown spears is not upheld by this analysis: in fact the longest spears in the sample were certainly hand-thrown. Adding Spencer's (1914) measurements of hand-thrown Tiwi spears it is clear that hand-thrown spears can often be very long, whilst published ethnographic data on lengths of North and South American thrusting spears (See 6.3) indicate that these spears are often relatively short. Therefore, there appear to be overlaps in throwing and thrusting spear lengths, but overall throwing spears look to be longer.

Hypotheses that heavy spears do not make good hand-thrown weapons have not been supported by the data here. There is a wide range of masses that are functional and broad areas of overlap, with both heavy and light spears functioning as hand-thrown spears. Therefore hypotheses that a spear can be assigned a delivery method on the basis of mass and that heavy spears are difficult to throw have also been rejected.

Maximum diameters ranged from 13 mm - 31 mm in the present study (mean = 21.13). Oakley et al's (1977) sample contains thinner spears, which are those thrown by hand by the Bubis on Bioko. Assuming the data are correct, combining the data shows a range of 7 mm - 31 mm of maximum diameters for ethnographic hand-delivered wooden spears. The results do not at present support being able to distinguish between thrusting and hand-thrown spears on the basis of maximum diameter.

Some spears studied had flat proximal ends but at the same time other thrusting spears tapered in both directions, making clear distinctions problematic. It is suspected that some of the sample from Oakley et al. (1977) may have had function based upon this design feature, creating a circular argument. Again, further data linking spears with clear data on delivery method would help clarify this. It is improbable that spears with a thick and untapering proximal end functioned effectively as throwing spears (Cundy 1989 and references therein), but these were not seen in the sample studied. Addressing Oakley et al's (1977) hypothesis that throwing spears tend to be thinner at the distal tip than thrusting spears has not been upheld in this studythere is a spread of tip diameters, with overlaps between delivery systems. These conclusions are preliminary, but it does not appear that such a distinction can be clearly made on the available evidence. The Tiwi and Tasmanians once again provide two interesting case studies regarding design because they both functioned as hand-thrown spears for hunting, and thus can help evaluate generalisations regarding design and delivery. The groups hand-threw spears with very different masses, and overall the study here showed much variability in the mass of wooden spears. It appears that *H. sapiens* at least were capable of using both light and heavy spears.

The only design feature to 'survive' attempts to distinguish between thrusting and throwing spears in this study has been PoB, in that if a spear has a PoB behind the midpoint, it looks unlikely to have functioned as a throwing spear. The correlation between PoB and location of maximum diameter is relatively strong ($R^2 = 0.624$) which means that PoB can roughly be inferred by the maximum diameter of a weapon. Therefore, those archaeological spears with maximum diameters behind the midpoint are more likely to have functioned as thrusting spears than hand-thrown spears, supporting the hypothesis that Lehringen was a thrusting spear (Thieme & Veil 1985).

6.9 Summary of the ethnographic evidence of the use of wooden spears

The review and museum studies on ethnographic wooden spears have demonstrated together the use of these weapons for use in both hunting and violence across a variety of climatic and ecological settings. Primarily the spears were most commonly used in Oceania, but further clear examples used for hunting exist from Africa and North and South America. The analysis confirms that spears were often used in forested environments including rainforests, but that they were also used in open environments including grasslands and deserts. The prey targeted with the spears included fast and slow-moving prey, solitary and herding animals, and docile and aggressive animals. In terms of effectiveness, several groups demonstrate their performance, particularly in dispatching animals but also in hunting from a distance. The case studies of the Tiwi and Tasmanians serve to highlight the importance of considering the upper limits of performance. The fact that these weapons appear effective in these case studies, including the use of lightweight and heavy spears as hand-thrown hunting weapons, demonstrates not that they are ineffective as weapons, but rather that there are likely other constraints on their use. The review here agrees with Cundy's (1989) hypothesis that these constraints in terms of delivery likely relate to time involved in mastering the use of hand-thrown spears. As far as the effectiveness of wooden spears in material and ballistic terms, these questions will need to be addressed experimentally. These questions form the focus of the following two chapters, which consist of a series of experiments aimed at better understanding the functionality of untipped wooden spears.

The morphometric analysis has demonstrated the variability of wooden spears. Overall there are poor correlations between delivery method and morphometrics, apart from location of maximum diameter and PoB. Further research connecting delivery method with examples in museum collections may clarify such questions, but preliminarily there appear to be large areas of overlap, calling into question many of the morphometric features used to argue to represent function as a thrusting vs. a throwing spear. Such conclusions in the future will need to be empirically tested and underpinned with further data. In relation to the archaeological examples, ethnographic spears studied were overall longer, thinner and by extension probably lighter on average.

While the ethnographic data from the literature review have limitations, the aim here was both to create a wider dataset pertaining to use as well as collecting multiple sources regarding use by key groups known to have only used hand-delivered spears in absence of complex projectiles. This has aided in redressing the problems involved in selectively presenting data, which have led to characterisations of the use of both hand-delivered and untipped wooden spears which do not represent the variability or effectiveness of these weapons. Challenging oft-cited figures on effectiveness is key to re-evaluating the lethality of these weapons and thus understanding their persistence through time, which is not to say that later innovations did not provide advantages, but rather that much remains in the quest to understand differences between weapon systems. The data here aid in setting up the experimental approach (Chapters 7 and 8), which empirically tests ideologically-driven interpretations of the performance of wooden spears.

Chapter 7. Exploring the mechanics of hand-delivered spears: Human performance trials in thrusting and throwing

7.1 Introduction

Chapter 7 presents two human performance trials designed to better understand the mechanics and performance parameters of hand-delivered weaponry. It is necessary to experimentally expand our understanding of the performance of hand-delivered spears prior to conducting replicative experiments on wooden spears (Chapter 8) because as will be demonstrated in this chapter a poor understanding of the weapon mechanics of hand-delivered spears has led their being inaccurately replicated. Proceeding with replicating wooden spears as thrusting and throwing spears before establishing these performance parameters would result in low levels of confidence about the outcomes of their terminal and wound ballistics, and the performance of a weapon cannot be separated from its delivery method. After this introduction and a detailed background on these previous experiments (7.1.1), an exploration of potential spear thrusting and throwing techniques follows (7.1.2). This is followed by the spear thrusting trial (7.2) and spear throwing trial (7.3), each structured to follow the classic format of materials and methods, results and discussion. Section 7.4 provides a summary of the two trials, including conclusions from both, and proposals of future research questions to test.

The first trial is aimed at a richer understanding of performance in two-handed spear thrusting and used 11 males trained in military bayoneting to record impact velocities and force profiles. The second trial was designed to provide data on release and impact velocities of hand-delivered throwing spears, as well as an evaluation of effective distance and flight trajectories. The resulting data creates a baseline that enhances our understanding of their performance, facilitating an interpretation of archaeological and ethnographic data presented in this thesis (Chapters 4 and 6). Not only do the results of the trials underpin the experimental design for a second phase of experiments presented in the following chapter (8.3), they also provide appropriate data for researchers interested in replicating hand-delivered weaponry and a means of evaluating previous experimental results.

As was discussed in Chapter 1, the theoretical basis for replication studies in archaeology sits firmly within a systematic approach to the artefact record. The start for all such replication studies, whatever their nature, is the archaeological evidence. This evidence is contextualised by ethnography, consisting of both historical accounts and formal studies. It is worth re-stating here that the aim of experimental research is to interpret the archaeological evidence, and to take an approach to this evidence that is firmly rooted in empirical data, with interdisciplinary approaches proving particularly useful for interpreting archaeological phenomenae with limited datasets.

7.1.1 Previous experimental work on the mechanics of hand-delivered spears

To replicate prehistoric weaponry, experimental protocols should be underpinned by a sufficient understanding of mechanics and performance, and this section will outline in detail how our existing understanding is still insufficient to design controlled replication experiments of hand-delivered spears. Many foundational studies on prehistoric weapon performance focused on complex projectiles and involved both formal archaeologically-oriented research alongside those with broader interests in weaponry; experimenters and replicators had a wide range of skill levels in weapon use, and these have primarily focused on testing replicas of prehistoric bow/arrow and spearthrower technologies (e.g. Pope 1923; Howard 1974; Bergman & Newcomer 1983; Fischer et al. 1984; Odell & Cowan 1986; Raymond 1986; Bergman et al. 1988; Hutchings & Brüchert 1997; Whittaker et al. 2017). Setting aside limitations of some of the data resulting from unskilled participants to evaluate performance, these experiments and others (e.g. Browne 1940; Peets 1960; Mau 1963; Baugh 1998; Whittaker & Kamp 2006; Whittaker et al. 2017) which specifically focused on mechanics and performance have built up a comparatively rich understanding of complex projectile performance including their mechanics, velocities, effective distances and more recently wound ballistics. In search of ever greater control over variables, some researchers have replaced the 'freehand' firing of weapons in experiments in favor of mechanically projecting them (e.g. Carrère 1990; Shea et al. 2001; Pargeter 2007; Sano & Oba 2015), but the former remains a popular replicative method (e.g. Sisk & Shea 2009; Pétillon et al. 2011). Probably because there were few archaeological examples of Middle Pleistocene or early Late Pleistocene weaponry that had been discovered or identified before the 1980s, there was less interest in the mechanics and performance of hand-delivered spears. Since the discovery of the Schöningen spears and the possible hunting lesion from Boxgrove, a small selection of experimental studies were performed to better evaluate hand-delivered spears, encompassing untipped wooden, composite, and non-representative (e.g. aluminium poles) examples (Rieder 2001; Shea et al. 2001; Shea et al. 2002; Schmitt et al. 2003; Smith 2003). With some of these studies, the use of calibrated crossbows for hand-delivered weaponry was introduced as a means of increasing experimental control, but without an understanding of velocities and spear thrusting mechanics, the calibration of mechanical propulsion devices has continued to rely on estimates (Shea et al. 2001; Shea et al. 2002; Wilkins, Schoville & Brown 2014a; Sano & Oba 2015). These estimates come from a diversity of sources that are often not directly relatable to prehistoric weapon use (see references in Tables 7.1 and 7.3). While many have continued to use human participants to deliver thrusting and hand-thrown spears (e.g. Parsons & Badenhorst 2004; Hutchings 2011;

Sano & Oba 2015) research aims for these studies have typically related to impact damage to either the weapons or bone, and have not generally captured aspects of spear or human performance during use such as velocities, forces and distances thrown (but see Connolly et al. 2001; Rieder 2001). As a result, compared with complex and composite weaponry, we do not have as rich a picture on performance of either more generally hand-delivered or more specifically untipped wooden spears. Costs of experimental research, and particularly for the equipment required to capture such data, alongside difficulties organising ‘experts’ in these weapon systems have probably contributed to this.

The lack of data on thrusting spears, including both design and performance has been noted by previous researchers (e.g. Hughes 1998; Shea et al. 2001; Iovita et al. 2016). This has led to the referencing in experimental work for spear thrusting of data produced in knife stabbing studies (Table 7.1), which were aimed at designing appropriate clothing for law enforcement officers (Miller & Jones 1996; Horsfall et al. 1999). The weapon from these cited trials (a knife) differs from thrusting spears in mass, morphology and material, and the mechanics and biomechanics of one-handed stabbing are different from two-handed spear thrusting, and therefore the use of these data may not be appropriate. Schmitt et al. (2003) conducted a two-handed spear thrusting experiment with aluminium poles on a padded target, designed to understand the forces on the body to facilitate the identification of spear use on human fossil material. Different research aims to those pursued here meant that impact velocities were only briefly reported, and the data presented on forces in that study related to the human body rather than the spear itself making the application of these data to replication studies problematic. The use of untrained participants in that study provides an interesting comparison, at least for impact velocities. A different study, which was designed to evaluate variations in grips for one-handed spear thrusting, captured forces and velocities with a force transducer and accelerometer. The study used one participant, who produced small number of thrusts (n = 11) with a knife-tipped spear (1350 g) and padded target (Connolly et al. 2001). In controlled experiments, attempts to accurately replicate force in spear thrusting are rare (but see Iovita et al. 2016). When replicated by hand, thrusting is often executed by the authors of the study, many of whom are unlikely to have formal training in the weapon or similar weapon systems (e.g. Huckell 1982; Smith 2003; Parsons & Badenhorst 2004). More problematically, thrusting spears are sometimes replicated as projectiles (e.g. Shea et al. 2001; Shea et al. 2002; Wilkins, Schoville & Brown 2014a), missing out important mechanics unique to this weapon system. A relatively wide range of velocities has been used to model spear thrusting, from 1.0 m/s to 10.3 m/s (Table 7.2) (e.g. Shea et al. 2001; Wilkins, Schoville & Brown 2014a; Wilkins, Schoville & Brown 2014b; Iovita et al. 2016).

Table 7.1. Impact velocities from previous studies relevant to two-handed spear thrusting. m/f stands for male and female.

Type experiment	Type of instrument	Total mass (g) of instrument	Velocity (range)	Velocity (mean)	Velocity Estimated or Filmed	Firing mechanism	Source
Human Performance One-handed stabbing: overarm and underarm	knife	600	6 - 10 m/s	5.8 m/s (underhand) 8.9 m/s (overhand) (n = 203)	Calculated acceleration data, verified with hsv for some trials	Human participants (sample size not reported), mixed m/f	Horsfall et al. 1999
Human Performance One-handed stabbing: overhand, short forward thrust, side sweep	knife	1000-4500	2.6 - 9.2 m/s	5.8 m/s (n = 600)	Six-camera VICON motion analysis system	Human participants (n = 20), mixed m/f, mixed students and trained police	Chadwick et al. 1999
Human Performance One-handed stabbing	knife	192	5.8 - 12.0 m/s	6.6 m/s short underhand; 7.0 long underhand; 9.1 short overhand; 12 m/s long overhand (n = 10 stabs per type)	Filmed, standard video recorder (Panasonic M10 video recorder)	Human participants (n = 10), mixed m/f	Miller & Jones 1996
Human Performance One-handed slashing	knife	Not reported	Minimum not reported; maximum 14.88 (all directions)	5.94 m/s	Estimated calculating length of slash on paper and time	Human participants (n = 87) mixed m/f	Bleetman et al. 2003
Human Performance Two-handed spear thrusting	aluminum rod	Not reported	1.7 - 4.5 m/s	Not reported	Filmed, standard video recorder, 60 fps	Human participants (n = 7), mixed m/f (untrained)	Schmitt et al. 2003
Human Performance One-handed spear thrusting	instrumented spear tipped with knife blade	1350	3.3 - 6.7 m/s	4.7 m/s (n = 11 stabs total)	Calculated via acceleration data	Human (n = 1) male (trained)	Connolly et al. 2001

Table 7.2. Estimated and filmed velocities from known archaeological experimental replication studies on spear thrusting

Type experiment	Type of spear	Total mass (g) of spear	Velocity (range)	Velocity (mean)	Estimated or Filmed	Firing mechanism	Source
Controlled Archaeological Experiment	lithic points on wooden shafts	Not reported	1.0 - 1.5 m/s	N/A	Estimated	Crossbow 28 kg draw weight	(Shea et al. 2001; Shea et al. 2002)
Controlled Archaeological Experiment	glass points fixed onto wooden foreshafts & aluminum tube	Various due to mass added to firing mechanism	1.1 - 2.7 m/s	Not reported	Transient recorder, light curtains	Pendulum, swinging metal arm with added mass	(Iovita et al. 2016)
Controlled Archaeological Experiment	lithic points on wooden shafts; wooden spears	526-630 (mean = 570, n = 10)	7.8 - 10.3 m/s	8.9 (untipped) 9.4 (tipped) (n = 23)	Filmed Bushnell Speedster III radar gun	Crossbow 20 kg draw weight	Wilkins, Schoville & Brown 2014a; 2014b

Table 7.3. Summary of published data from previous studies related to estimates of hand-thrown spear performance

Spear Type	Total mass (g) of spear	Length (mm)	Distance thrown (m)	Release Velocity (m/s)	Impact Velocity (m/s)	Kinetic Energy (J)	Estimate or Filmed	Participants	Source
spearthrower dart	186	2134	*	13.9 ¥	*	18.0 ¥	Estimated	*	‡ Van Buren 1974; Velocity & KE estimates by Hughes 1998: 352
spearthrower dart	182	1829	*	13.7 ¥	*	17.1 ¥	Estimated	*	‡ Van Buren 1974; Velocity & KE estimates by Hughes 1998: 352
spearthrower dart	166	1930	32 (mean, n = 20)	18.3 (mean, n = 20) ¥	Not known	27.8 †	Estimated	Two males, probably untrained	Howard 1974; Velocity estimate by Hughes 1998: 352; KE recalculated by Milks
Schöningen Spear II replica	500 (hardwood, species unspecified)	2300	5	Not reported	mean 23.8 (n = 10)	140 †	Filmed, 200 fps	One male javelin athlete	Rieder 2001
Men's javelin	800	2600 - 2700	99.72	32.3 (n = 1)	Not known	417 †	Filmed, 200 fps	One male javelin athlete (record setting)	Gregor & Pink. 1985
Men's javelin	800	2600 - 2700	83.84–89.5; (mean = 86.46, n = 7)	28.1– 29.7 ; (mean = 29.01, n = 7)	Not known	316– 353 †	Filmed, Two synchronized SVHS Panasonic video cameras, operating at 50 fps.	Seven male javelin athletes	Campos et al. 2004
Men's javelin	800	2600 - 2700	45.25–87.17	≈18 m/s to ≈32 m/s (n = 57) ★	Not known	130– 410 †	Filmed, video cameras, 60 fps and 200 fps (different events)	male athletes (n = 57)	Murakami et al. 2006
Men's javelin	800	2600 - 2700	75.00– 87.82, excluded throws under 75 m distance. (mean = 79, n = 155)	25.3– 29.1 (mean = 27.1, SD = 0.7)	Not known	256– 339 †	'Filmed', infrared photocell gate	26 male javelin throwers	Viitasalo et al. 2003
Men's and women's javelins	male javelin = 800	2600 - 2700 (male)	84.6 (mean, males, n = 15 throws)	29.3 m/s (males n = 15 throws)	Not known	343 †	Filmed,100 fps	javelin athletes male (n = 3)	Rich et al. 1986

	Female javelin = 600	2200 (female)	55.0 (mean, femaies, *n* = 13 throws)	21.8 m/s (females n = 13 throws)		143 †	Filmed,100 fps	female (*n* = 5)	(Rich et al. 1986 cont'd)
Women's javelin	600	2200	5	Not reported	mean = 23.3 (*n* = 10)	163 †	Filmed, 200 fps	One male javelin athlete (same as for spear replica in same paper)	Rieder 2001
Women's javelin	600	2200	55.00 - 66.00, excluded throws under 55 m distance (mean = 59.04, *n* = 93)	21.8– 25.3 (mean = 23.0, SD = 0.7)	Not known	143– 192 †	'Filmed', infrared photocell gate	15 female javelin throwers	Viitasalo et al. 2003

‡ Repeated attempts to find this source failed, so some of the data are missing. ¥ Data estimated by Hughes. † Data estimated by A. Milks, and assumes a relatively similar impact velocity to release velocity. As will be seen, this is a fair assumption given the comparison of release and impact velocities in the trial presented in this thesis shows overall a slight increase from release to impact velocity. ★ Velocity data taken from regression graph as range not provided in publication. Note: Estimates provided in Hughes on data from Butler's (1975) paper are not included here because they are based upon secondary data, including those from Howard 1974, which is already presented here, and the publication is concerned with spearthrower performance not hand-delivered spears. Rich et al. accessed online: https://ojs.ub.uni-konstanz.de/cpa/article/viewFile/1426/1288.

Table 7.4. Summary of published data from controlled archaeological experiments of hand-thrown spears.

Type experiment	**Total mass of spear (g)**	**Distance (m)**	**Release Velocity (m/s)**	**Impact Velocity** (m/s)	**Kinetic Energy (J)**	**Velocity measurements: Estimated or Filmed**	**Firing mechanism**	**Source**
Lithic tipped spears	137.4– 296.4 g, (mean = 192.7, *n* = 45)	Not reported	mean = 25.1	Not reported, but likely to match release velocity	≈43.3– ≈97.0	Speedtach Chronometer	Mechanically projected from custom designed device	Hutchings 2011
Lithic tipped spears	≈136	1.5	17.8 (± 1)	Not reported, but likely to match release velocity	≈22 †	Estimated	Calibrated Crossbow	Sano & Oba 2015
Lithic tipped spears	Not reported	4– 5	Not captured	Not captured	*	N/A	Thrown by hand, untrained throwers	Odell & Cowan 1986

Lithic tipped spears		3– 4	Not captured	Not captured	*	N/A	Thrown by hand, untrained throwers	Parsons & Badenhorst 2004
Lithic tipped spears	≈266	.93	7– 30 ‡	Same as release velocity due to distance	≈7 – ≈120	Transient-recorder and light curtains	Mechanically projected from an air gun	Iovita et al. 2014; Iovita et al. 2016
Lithic tipped spears	292	4	Not captured	Not captured	*	N/A	Mechanically projected using a specially built machine	Pargeter 2007
Lithic tipped spears	≈176.3– ≈214.4 (mean = 189.9, *n* = 8) ¥	5.83– 21.93 (mean = 14.18, *n* = 69)	Not captured	Not captured	*	N/A	Thrown by hand, untrained male participant	Rios-Garaizar 2016
Lithic tipped spears	86– 194 (mean = 120, n = 28)	1	Same as impact velocity due to distance	11– 26 (mean = 21.2, *n* = 28)	5.5– 47.7 (mean = 27.71, *n* = 28)	High speed video camera, 6000 fps	Mechanially projected from an air gun (between 2 and 6.7 bar)	Milks 2010
Wooden spears	Estimated at ≈800	6	Not captured	Not captured	*	N/A	Thrown by hand, female javelin athlete	Smith 2003

Data from publications where spears were experimented with at spearthrower or bow/arrow velocities were not included in the data table, as these do not directly compare with hand-delivered spear velocities. † Data estimated by A. Milks. * Not possible to calculate due to missing data. ‡ Study designed to replicate both hand-thrown and spearthrower velocities, and so the upper range represents spearthrowers. ¥ Point and shaft mass data combined, with 2 extra grams added for hafting materials. Data kindly shared by Rios-Garaizar.

There are more published velocity data for hand-thrown spears than for thrusting spears, resulting from studies on and with javelin athletes as well as archaeologically-oriented studies of spear use in the past (e.g. Rieder 2001; Rieder 2003; Campos et al. 2004; Murakami et al. 2006; Rieder 2007; Rios-Garaizar 2016). As discussed in detail in Chapter 6, both hand-delivered spears in general and wooden spears in particular are characterised as heavy, unwieldy and incapable of being projected at velocities or distances sufficiently high to be effective. While many conjectural claims are made about performance, some (Sano & Oba 2015) have noted the poor understanding of hand-thrown spears, including of the relationship between release and impact velocities.

Rios-Garaizar published distances achieved with hand-thrown lithic-tipped spears weighing between ca. 176.3 g and 214.4 g (Rios-Garaizar 2016; J. Rios-Garaizar pers. comm.). The thrower was an inexperienced male throwing for distance, achieving maximum distances of 22 m, with a mean of 14.18 m (n = 69). This is significantly above the suggested distance of 5-10 m, though this study was throwing for distance, rather than target shots. While Churchill (2014 p.63) reported a hit rate of 13.6% at a distance of 15 m by untrained throwers using replicas of Schöningen spears II and III at a hay bale, Rieder's (2001) experiment demonstrates that in the hands of an elite javelin athlete, a Schöningen spear replica can reliably hit a 200 mm wide target at a 7-8 m distance, although statistics on 'reliability' are unreported. There are no known published experimental data regarding the reliability of the weapons in the hands of trained throwers to hit a target with hand-thrown spears at a series of distances, establishing 'effective distance' experimentally.

Table 7.3 summarises a selection of relevant published data on hand-delivered spear velocities and distances, including from studies of javelin athletes and archaeologically-oriented research. Problems with those data relate to the experience of throwers, differing research objectives, and a wide range of spear designs and mass. Most problematic are the velocity estimates for hand-delivered spears based upon inexperienced throwers launching spearthrower darts by hand (see Hughes 1998). Spearthrower darts are considerably different from hand-thrown spears in length, diameter, mass and features such as fletching (Palter 1977). Table 7.4 summarises relevant data from prehistoric weaponry experiments replicating hand-thrown spears and highlights the range of masses and velocities being tested for hand-delivered spears, as well as different launching mechanisms and data capture.

For comparative purposes, Table 7.5 presents a selection of data pertaining to complex projectile performance studies. This is not intended to be comprehensive, but rather to provide a selection of published data enabling comparisons with data in Tables 7.1 through 7.4. These performance parameters are currently under debate (see Whittaker et al. 2017) underlining the need for more human and performance studies in all of prehistoric weaponry. The summary of experimental research here confirms that hypotheses regarding the performance of hand-thrown spears require systematic testing.

Table 7.5 Summary of selected performance data of complex projectiles for comparative purposes

Weapon type	Mass (g) range	Velocity (m/s) range §	KE Range (J)	KE mean	Source
Spearthrower darts	21.3 - 193.0	19.5 - 26.9	7.7 - 51	32.5 (n=11)	(Hughes 1998, p.352)†
Spearthrower darts	81.9 - 545.3	27.4 - 64.0	52.5 - 771 ¥	ca. 350	(Hutchings & Brüchert 1997)
Spearthrower darts	68 - 190	ca. 34 - 46	ca. 39 - 201 ¥	NA	(Tolley & Barnes 1979)
Spearthrower darts	50 -150	25.4 - 32.9	ca. 16 - 81.2	ca. 5 - 43.8	Carrère & Lepetz 1988, in Hutchings & Brüchert Δ
Spearthrower darts	44 - 195	14.8 - 38.8	ca. 11 - 87.9	34.8 (n=54)	Whittaker et al. 2017*
Bow/arrows	19.3 - 49.0	30 - 65.5	13.5 - 42.5	29.9 (n=11)	Hughes 1998, p. 352 †
Bow/arrows	20 - 47	35.8 - 45.1	12.8 - 29.5	48.3 (n=3)	(Whittaker et al. 2017)*

Data in table includes human replicative and controlled experiments. § Often velocities captured are release velocities, and therefore not necessarily representative of impact velocity. † Estimates in Hughes come from a range of sources, see Hughes 1998 p 352 for detailed data. Corrections to Hughes' data have been made where calculation errors occurred. Data also presented in Churchill et al. 2009, Table 1. ¥ Kinetic energy estimated from data in publication. Δ Velocities and mass data as reported in Hutchings & Brüchert 1997. KE estimated based on those data provided, therefore range should be treated with caution * Calculated from pooled data in Whittaker et al. 2017, Table 2. See equation 7.1 for kinetic energy.

7.1.2 Spear thrusting and throwing techniques

Spear thrusting is often characterised and replicated in a one-dimensional way, as a two-handed bayonet-style thrust (e.g. Churchill 1998; Schmitt et al. 2003). Kortlandt (Kortlandt 2002) briefly presented some observations of alternative thrusting techniques used by Mandari pastoralists and Bambuti foragers, including a two-handed grip held at shoulder height. Connolly et al. (2001) also described some alternative grips that are depicted graphically in historical contexts, including a shoulder-level hold, an over-arm and under-arm grip. Churchill (2002) points out that data on spear thrusting techniques from studies of foragers are rare and ethnographic analogies have little to offer regarding spear thrusting biomechanics and mechanics. Churchill (2002) theorised that two-handed under-arm grips would provide more power than an overhand posture, while Connolly et al's (2001) study of one-handed spear grips suggested that the over-arm hold resulted in the highest peak forces and velocities. Although martial arts spear use relates to interpersonal violence, and thus differences need to be assumed due to differences between hunting animals for food and violent person-to-person encounters, studies of these techniques including those on pre-industrial societies can supplement those on foragers, illustrating and describing alternative hand orientations, placements, gestures and footwork (e.g. Lessa & Velez-I 1978; Hallander 1981; Lowry 1983; Evans 2002; R. Knutsen & P. Knutsen 2004). Although this thesis is not aimed at understanding the biomechanics of spear use, because it aims to better understand performance both in terms of parameters relating to human use, as well as replicating use on animals, a martial arts specialist was consulted with the aim of defining and illustrating a selection of the myriad hand orientations and placements, footwork, and thrusting gestures. Krishna Godhania is an expert practicioner, teacher and researcher of sharp force weapons including spears. Collaboration with Mr. Godhania resutled in the following defintions and photographic illustrations, and are intended to provide defintions for discussions on spear thrusting both in this thesis and for researchers studying prehistoric spear use. While we cannot know directly how prehistoric humans would have used spears, researching these alternative grips has implications for understanding spear thrusting in terms of future studies on biomechanics and the human fossil record.

Thrusting hand orientation

1. Single Hand Holds
    - Several variants (see Fig. 7.1)
2. Double Hand Holds (Figs. 7.2 - 7.4)
    - Forward Grip (leading hand = overhand, trailing hand = underhand)
    - Reverse Grip (leading hand = underhand, trailing hand = overhand)
    - Combination Grip (both overhand)

Thrusting hand placement

1. Spear Point Grip (Japanese Bayonet jab) (Fig. 7.5)
2. Middle Grip (Fig. 7.6)
3. Blunt End Grip (Palm assist) (Fig. 7.7)

Thrusting gestures

1. Corkscrew Thrust (twisting the spear on its axis while thrusting)
2. Power assist Thrust (double pointed spear) (Fig. 7.8)
3. 'Pool Cue' (trailing hand driving, lead hand sliding back)

Thrusting footwork

1. Leaping
2. Stepping or Running
3. Rooting (slippery terrain)
4. Kneeling (one knee)

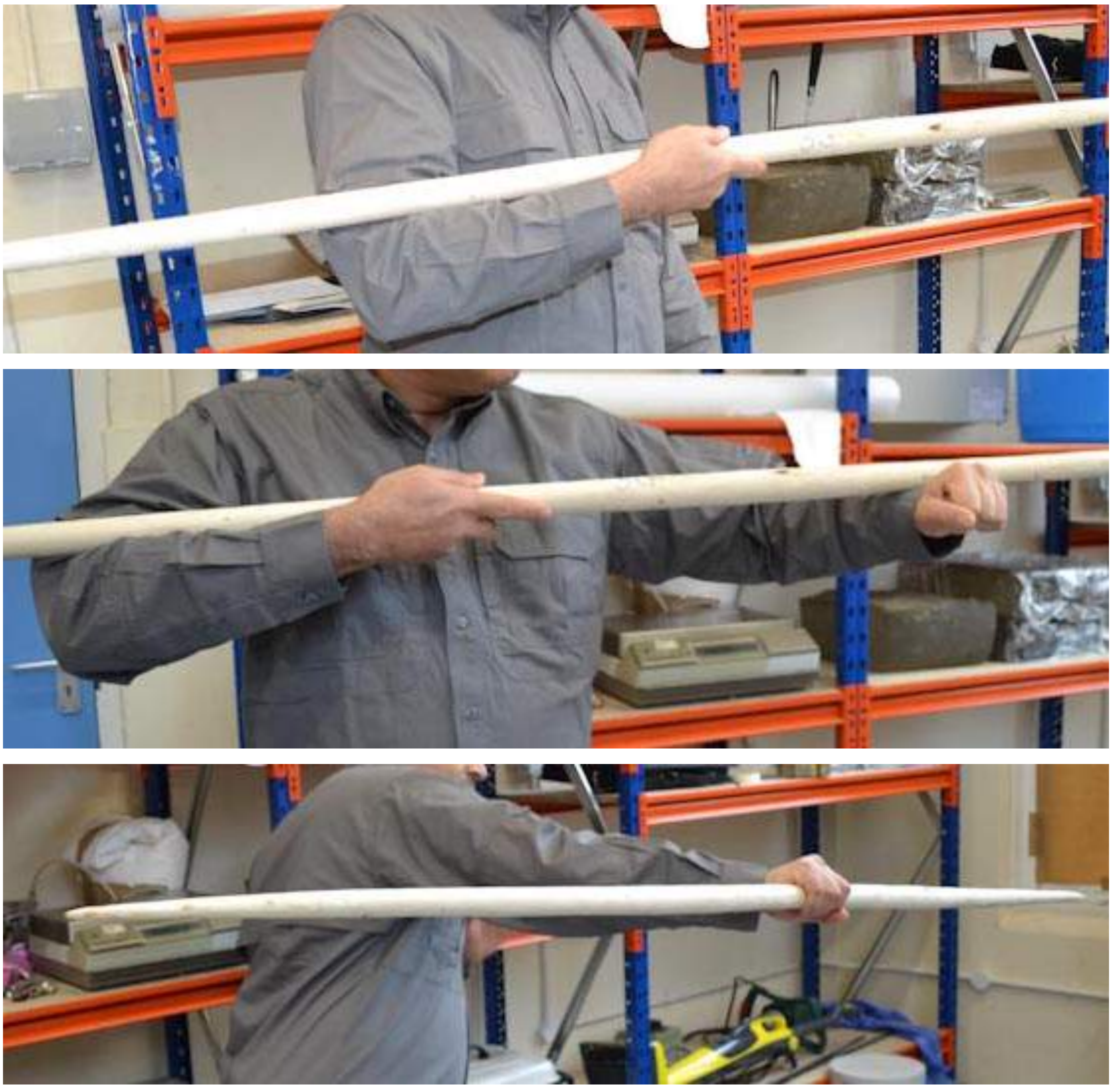


Figure 7.1. The above three photos are variations on the single hand hold for spear thrusting.

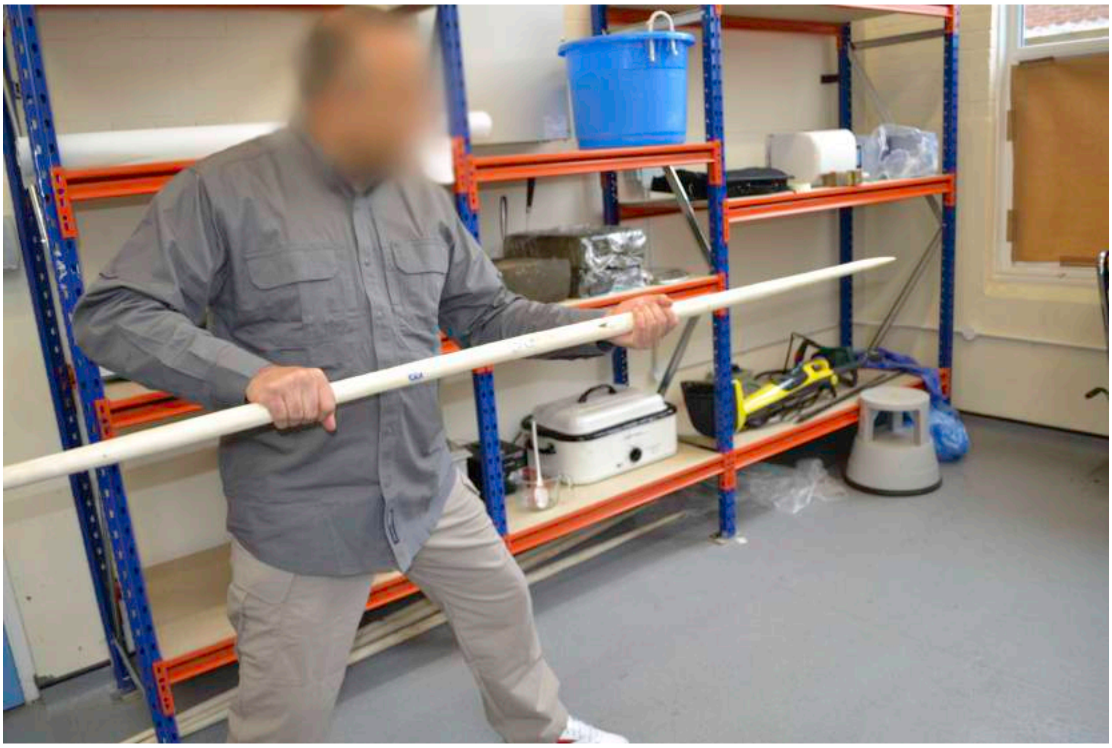


Figure 7.2. Forward grip

Figure 7.3. Reverse grip

Figure 7.4. Combination grip

Figure 7.5. Spear point grip

Figure 7.6. Middle grip

Figure 7.7. Blunt end grip (palm assist). Note that this grip is demonstrated with a double pointed spear, but would only be used with a spear with a blunt proximal end

Figure 7.8. Power assist. The foot anchors the spear to the ground, which would provide opposing power and stabilisation to an attacking/charging prey or predator

The modern javelin grip, called ‘Greek’ or ‘orthodox’, is a single-handed underhand hold at the centre of the spear, using the dominant hand with small variations in finger positioning (Fig. 7.9) (Johnson 1987). ‘Free-style’ javelin throwing in the 20th century involved various throwing techniques, including throwing with two fingers from the rear of the javelin, or slinging it like a discus (Johnson 1987 p.6).

Figure 7.9. One variant of the single-handed javelin grip

More comprehensive reviews of the mechanical or biomechanical principles of spear throwing can be found elsewhere (Hubbard 1984; Gregor & Pink 1985; Johnson 1987; Cotterell & Kamminga 1989; Cundy 1989; Campos et al. 2004). The key factors governing spear flight include

- length and mass of spear
- design of spear including flexibility, distribution of mass and surface features
- release velocity
- angle and height of release (Fig. 7.10)
- spin and yaw
- gravitational acceleration (a constant at 9.8 m/s^2)
- drag and lift (Fig. 7.10)
- aerodynamic factors including wind speed and direction
- skill of user

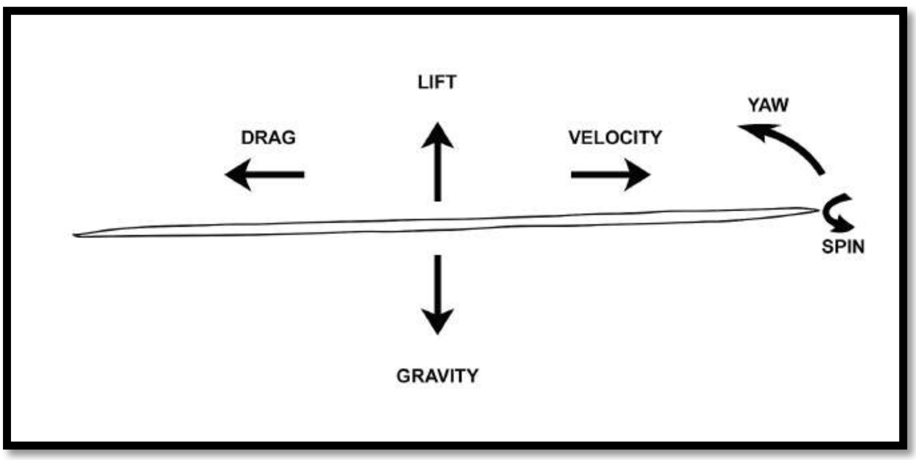


Figure 7.10. Schematic drawing showing forces and aerodynamics affecting a spear during flight.

Design of modern-day javelins is based on the effects of the mass and centre of mass, the length, and flexibility, among other parameters (Hubbard 1984). A men's olympic javelin must be 800 g in mass, between 2600 mm and 2700 mm in length, with a centre of gravity between 35% and 39% from the distal point (Terauds 2015). An athlete can further affect the throw by the release height, release velocity, and release angle (Hubbard 1984), as well as spin (i.e. rotation of the javelin around its longitudinal axis), yaw (rotation of the javelin about its vertical axis) and pitch (Viitasalo et al. 2003). Release velocity is considered to be the most important factor determined by the athlete affecting distance (Komi & Mero 1985; Viitasalo et al. 2003; Campos et al. 2004). External forces acting on the javelin during flight include lift, drag and gravitational acceleration (Fig. 7.10). Drag is the air resistance on a projectile, and is proportional to the surface area of a projectile while lift is a vertical force that acts perpendicularly to the direction of flow (Johnson 1987; Cotterell & Kamminga 1989 p.162). Assuming an upward trajectory at the moment of release, a javelin will follow a parabolic arch as lift, drag and gravitational forces act upon the projectile (Hubbard 1984). At shorter distances, spears may be thrown at flat trajectories, affecting angle at impact. This is explored in further detail below.

7.2 Human performance trial: spear thrusting

7.2.1 Introduction: experiment questions and secondary aims

Section 7.2 of this thesis has been published in part, as a co-authored research article (Milks et al. 2016).

The human performance trial in two-handed spear thrusting was designed to evaluate the impact velocities and forces in two-handed spear thrusting by trained male participants. Setting benchmarks of these parameters was deemed essential in the design of Phase 2 experimentation using spear replicas on animal carcasses. The research questions are:

1. What are impact velocities in two-handed spear thrusting?
2. What are peak forces, and force profiles in two-handed spear thrusting?
3. How does using male trained participants compare with studies using mixed male/female untrained participants?
4. How do velocities and forces compare with previous studies on one-handed knife stabbing and previous archaeological experimental research replicating spear thrusting?

Secondary aims of the experiment are:

1. An enhanced theoretical understanding of different spear thrusting techniques, including grip.
2. Establishing an experimental reference sample of damage to spears from use.

7.2.2 Materials and Methods

7.2.2.1 Spear replicas

Schöningen spear II was chosen as the template for spear replicas in this trial, and for all experimental work throughout this thesis. Basic measurements were available via published data on this spear and can be found in Chapter 4 (Thieme 1999a; Thieme 1999b; Thieme 2005). Because measurements for the distal tip were unavailable at the point in time that this experiment was designed and executed, actual tips replicated measurements taken in Adobe Photoshop® CS6 from a published scaled photograph (Thieme 1999a; Thieme 1999b; Thieme 2005). Spear II was chosen as it represents a complete example and has measurements closest to mean values of the sample of published measurement data on complete spears from Schöningen (Thieme 1999b). Four replicas were initially made (e.g. Fig. 7.11), with measurements for three of them presented (Table 7.6). The fourth replica, (3A) was not used in the study but was cut in half and used for pre-experiment testing and setup.

The trial used two spear shafts with three removable spear tips, which were joined by a device consisting of aluminium caps containing a load cell, described below. The shaft of 2A was not used. Points of 1A, 2A and 4A were used. Measurements were taken of all replicas and were all within 1 mm of those published for Schöningen spear II (Table 7.6). Internal variations in the wood contribute to differences in mass.

Table 7.6. Measurement data for spear replicas (SR) compared with published measurement data on Schöningen Spear II at the time of replica manufacture

Replica	Length	DIA at 10 mm	DIA at 50 mm	DIA at 800 mm	DIA at 1150 mm (midpoint)	DIA at 1530 mm	Mass	Point of balance*
Schöningen Spear II†	2300	‡	‡	37	35	34	‡	‡
Replica 1A	2300	5	16	37	35	34	752	1080 (47%)
Replica 2A	2300	5	17.5	36	35	34	827	1100 (48%)
Replica 4A	2300	5	15	36	35	33	806	1095 (48%)

All measurements are in mm except mass, in g. * Measurements are distances measured from distal end. † Measurement data from (Thieme 1999b, p.389). ‡ Data not published.

Wood for the replicas came from a stand of Norwegian spruce (*Picea abies*) that was planted on limestone/clay soil in the mid 1980s at Bedgebury Pinetum in Kent, England (Fig. 7.12). The trees were in a natural forested stand, grown in warm conditions. For this reason, trees with a circumference larger than necessary for the finished product were chosen so that the use of heartwood provided the use of higher density wood by avoiding the soft sapwood. This helped replicate the density of the original, as the Schöningen weapons were manufactured from dense slow-growing spruce (Thieme 1997; Schoch et al. 2015). Like the Schöningen spears, the distal ends of the spears were created from the bases of the trees, providing the hardest wood (Thieme 1999b, p.391) and tips were offset from the soft medullary canal. Replicas were made within three months of culling the trees, and were made manually using metal tools by Owen O'Donnell, as the current study was not designed to examine usewear and spear thrusting is not affected by aerodynamics.

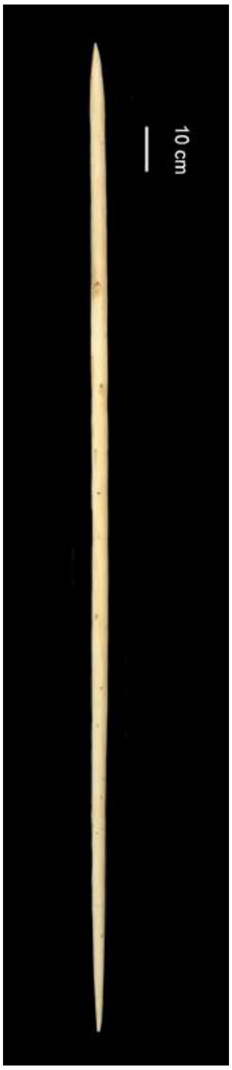


Figure 7.11. Replica of Schöningen Spear II. Scale is by distal end

Figure 7.12. Stand of Norwegian spruce at Bedgebury Pinetum, from which the trees used for replicas were cut

A custom-made device, fitted between the spear shaft and point, contained a load cell (Kistler; 1-Component Force Sensor 9031A, serial number 490937; maximum range = 60 KN); two aluminium caps fitted to the spear shaft and point, enclosing the load cell (Figs. 7.13 and 7.14) (Horsfall et al. 1999). The device weighed 452 g and measured 224 mm in length. While adding the mass of the load cell to the spears increased the total mass of the spears by approximately 58%, the replicas' total masses of 1258 g (SR1) and 1204 g (SR2) fit comfortably within the range of masses of ethnographic wooden spears presented in Chapter 6 (Table 6.5). The difference in total mass between the two spear replicas was 54 g, an increase of 4%. Such a small difference between the two replicas used in the experiment is unlikely to have greatly affected results.

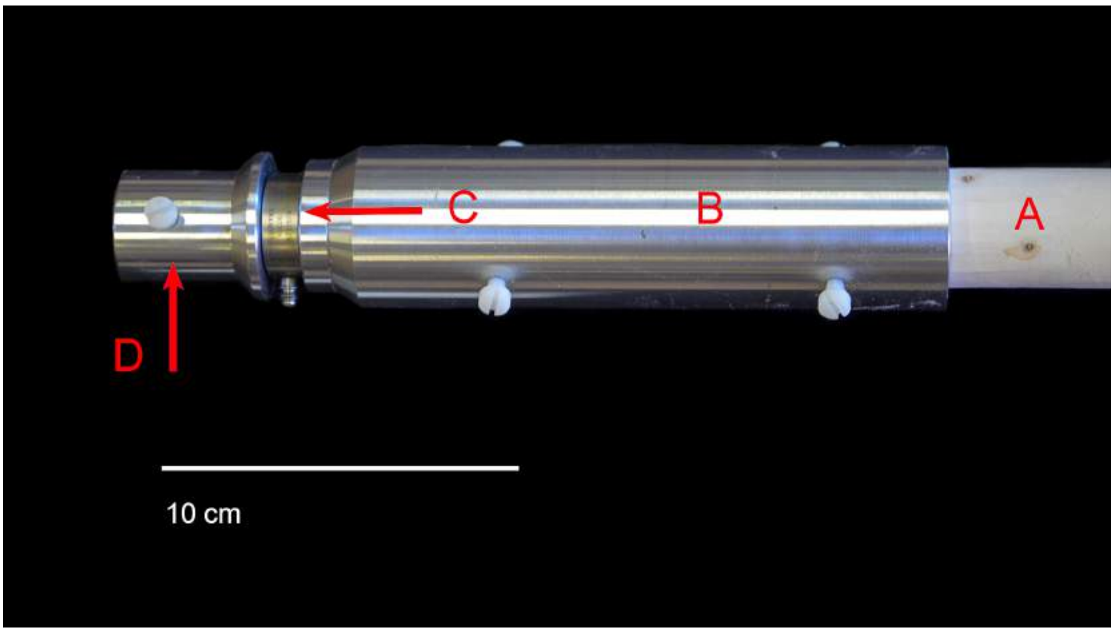


Figure 7.13. Load cell mounted on a spear shaft. (A = spear shaft, B = custom made mount, C = load cell, D = spear point mount)

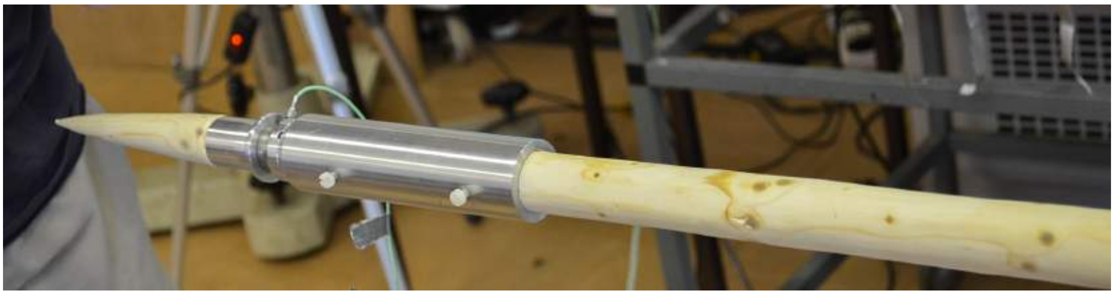


Figure 7.14. Spear replica with load cell

Because three removable spear tips were used for the experiment, a potential issue with the methodology was that small morphometric variations between these tips could have affected results. Therefore, a guided free-fall impact drop test was designed to compare variability between these three tips. 100 mm long casts were made of the spear tips used. Moulds were made using a high quality silicone moulding agent (Prevest DenPro® Hiflex Putty) and casts were made using liquid polyurethane resin (Prevest DenPro® EasyFlo 60) (Fig. 7.15). A guided free-fall impact test was undertaken for the casts made from the three spear tips used in the trial. A 2 m long, 0.03 m diameter polymeric pipe was used for the impact test. To reduce air resistance holes were drilled along the pipe, and a plumb bob was used to ensure the pipe was vertical. A metal bar (150 g) was attached to the rear of each cast to create adequate kinetic energy, with Plastiline® added to the bar to create masses of exactly 175 g for each point. The casts were dropped 2.21 m down the tube (including space below the pipe) into a block of Plastiline® sculpting compound (softness 50) with the air temperature at 16° C. Each cast was dropped 10 times, measuring the depth of penetration (DoP) to the nearest mm for each drop into the Plastiline®. This test was to examine whether slight morphometric variations in the removable spear points affected the results of the trial.

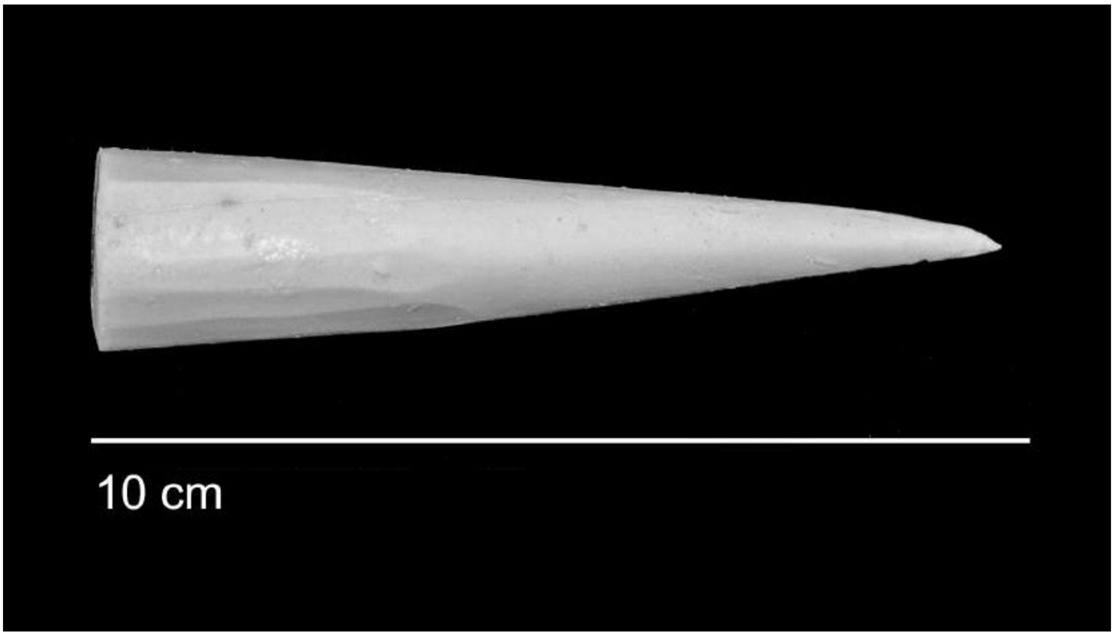


Figure 7.15. Resin cast of a spear point for use in drop tests

7.2.2.2 Target

This trial was designed to understand the humans using wooden thrusting spears with a two-handed grip, and so a homogenous target was chosen for experimental control. Targets consisted of three blocks of PermaGel^{TM} (440 mm x 290 mm x 130 mm; weighing ~13 kg) (Fig. 7.16).

Figure 7.16. Block of PermaGel^{TM} with a spear thrust 'wound' track visible, indicated by red arrows

7.2.2.3 Human participants

11 males volunteered as participants and were recruited from military staff at the Defence Academy of the United Kingdom (Shrivenham Station, Wilts, UK) took part in the trial (July 22, 2014). Ethical approval was waived by UCL, and was obtained from the Science and Engineering Research Ethics Committee of Cranfield University, Shrivenham, UK (approval number 004_2013). Experimental work was conducted on Shrivenham Station in a Laboratory run by Cranfield University. Participants were not paid, and were not allowed a practice thrust. All the volunteers had received training in bayonet use (two-handed thrusting with a sharp weapon), as part of their military training. Participants were verbally briefed, provided signed informed consent and were aware they could withdraw at any stage of the work without penalty. Each participant performed at least three thrusts taking approximately ten minutes total. Self-reported heights of participants ranged from 1.68 m - 1.95 m (mean = 176.8 m; SD = 7.7 m) and self-reported masses were 61 kg - 100 kg (mean = 81.2 kg; SD = 10.3 kg). These means correspond well with estimates for *H. heidelbergensis* (Froehle et al. 2013; Trinkaus et al. 1999; Stringer et al. 1998).

7.2.2.4 Experimental setup and data collection

Participants were not coached on spear stance or hold, and were asked to thrust the spear into a PermaGel™ target with maximum force. Although as discussed in 7.1.3 myriad thrusting techniques exist, a uniform approach that would be easily comparable to earlier studies (e.g. Schmitt et al. 2003) was desired, thus replicating a two-handed bayonet thrust. After producing unusual force profiles, two participants were coached on their technique to understand whether this affected force profiles. Participants stood behind a foot plate, and thrusts were from a standing position (Fig. 7.17). They were requested to perform a 'strike hold', avoiding previous thrust areas, thrusting the spear into the target with as much force as possible, and then holding the spear in the target until DoP of the spear into the target was measured (in mm) using a calibrated ruler.

Figure 7.17. Participant performing a spear thrust

The load cell was connected to a data acquisition system (Fig. 7.18), and force (N) and time (ms) profiles were captured using Imatek Impact Analysis (version 3.3.7) (maximum recording time = 100 ms; 8000 data points were collected). Each event was recorded with a Phantom V7 high speed video (HSV) camera (1000 fps) enabling velocity to be calculated using Phantom 675.2, software. Video 7.1 shows one of the recorded thrusts.

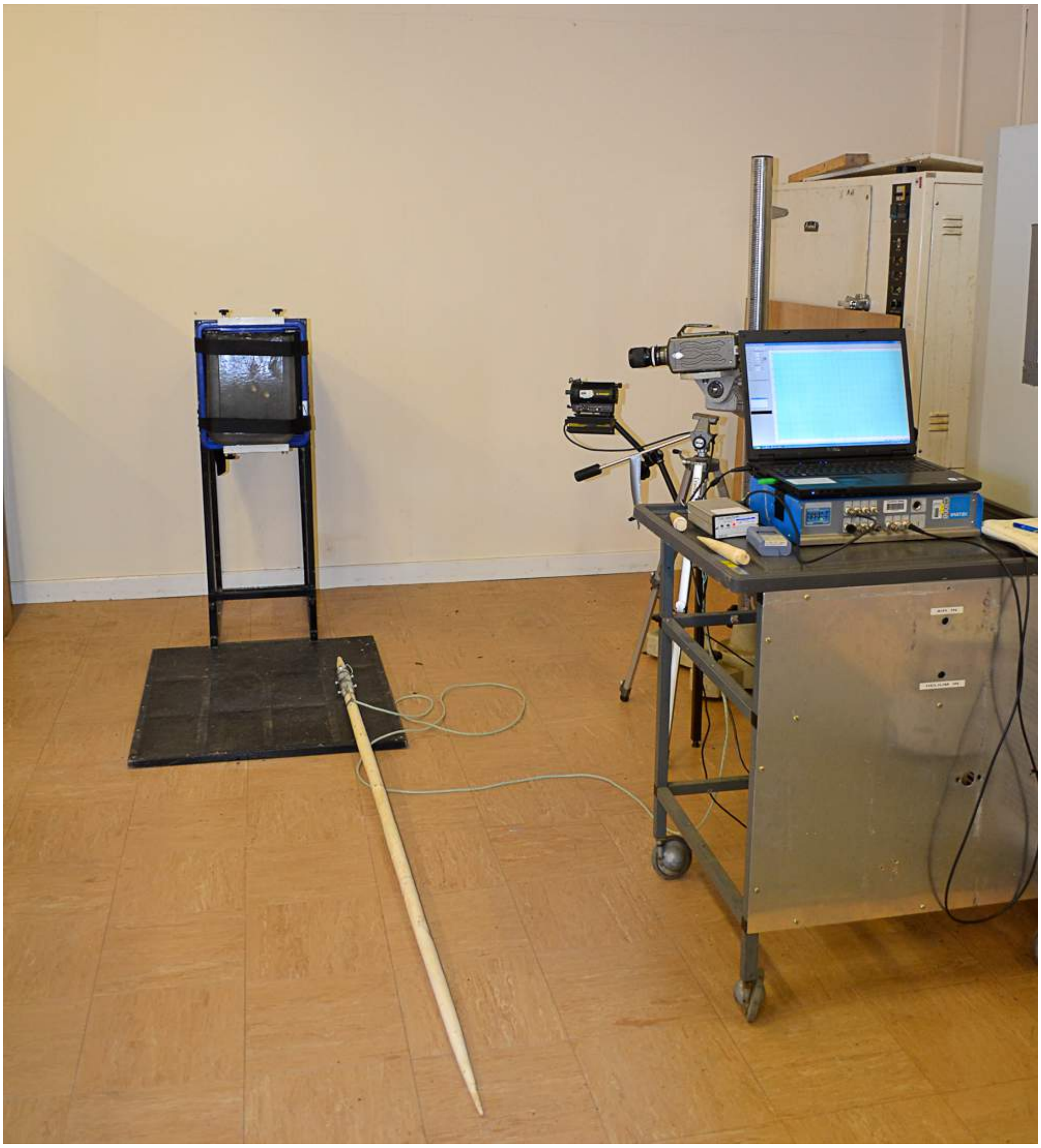


Figure 7.18. Experiment setup showing spear, hsv camera, PermaGel^{TM} target, and data acquisition system

7.2.2.5 Data analysis

Analysis of the video footage used the software package Phantom Cine Viewer v2.5.744.0. Impact was defined as the video frame in which the spear first interacted with the PermaGel^{TM} block and was designated as frame = 0. Impact velocity then was defined as the mean velocity calculated from frames -2 to -22 before impact (Fig. 7.19). Statistics were calculated using the software package SPSS (22). Force/time profiles were produced in Excel (12.3.6).

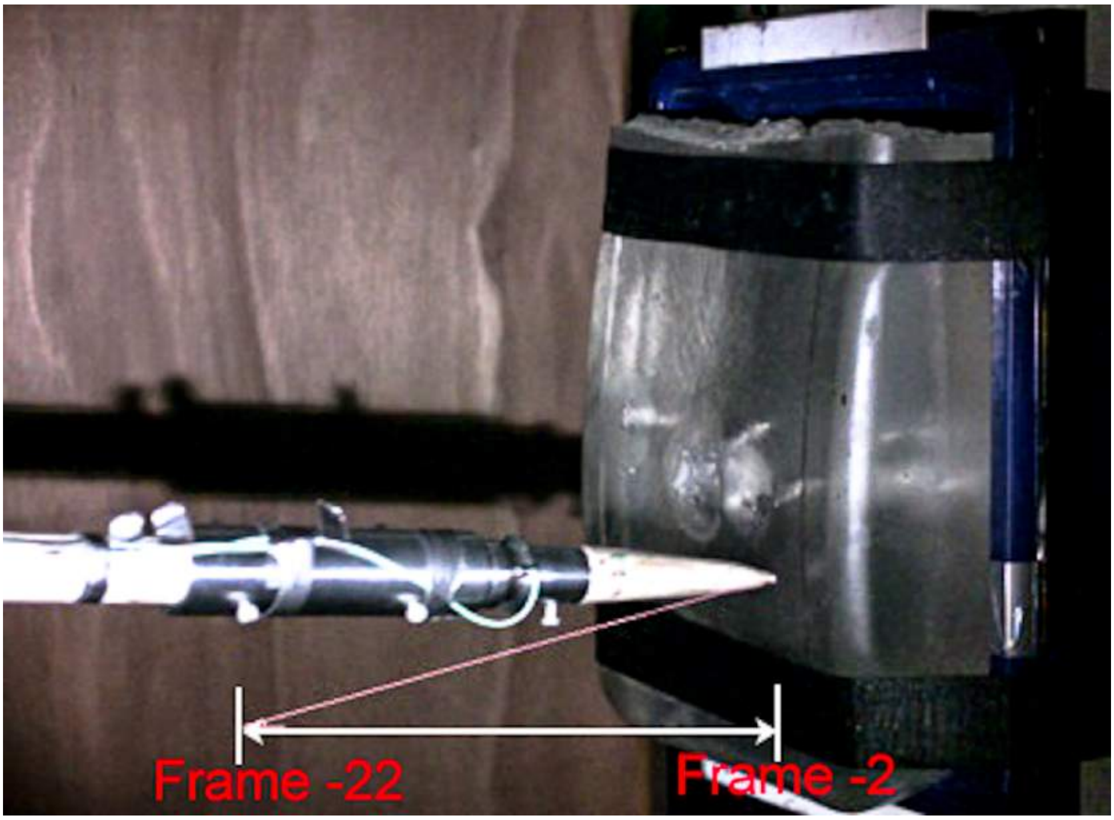


Figure 7.19. Still frame from HSV analysis. The pink line indicates the distance traveled from the beginning of the analysis (Frame -22) to 2 frames before impact

7.2.3 Results

Thirty-nine thrust events took place, capturing force (N) and impact velocity (m/s). One video was unsuitable for analysis, as it did not contain enough frames to adhere to the method established, which left a sample of 38 videos for velocity calculations.

7.2.3.1 Spears

The first shaft, Replica 1A broke after 22 thrust events, and was thereafter replaced with 4A. 1A broke in the front half of the spear where several knots conjoined in the wood (~1000 mm from distal end), forming a point of weakness in the wood.

Table 7.7 presents the results of the free-fall impact tests of the tip casts. The mean DoP into the Plastiline® block (measured to the nearest mm) had little variation among the points. A Shapiro-Wilk test ($p > .05$), and visual inspections of the skewness and kurtosis measures and standard errors, histograms, normal Q-Q plots and box plots showed that the data were not normally distributed. A nonparametric Levene's test was used to verify the equality of variances in the samples (homogeneity of variance, sig=1.000). This confirms an equality of variance in DoP. Thus interchanging the spear tips in the human thrusting experiment had a negligible impact on DoP into the PermaGel™.

Table 7.7. Results of impact drop tests

Spear tip cast	Mean DoP* (mm)	SD	Min DoP (mm)	Max DoP (mm)	n
1	22.9	0.74	22	24	10
2	23.9	0.74	23	25	10
3	22.8	0.79	22	24	10

***DoP = Depth of Penetration**

7.2.3.2 Depth of penetration into PermaGel^{TM}

Depth of penetration (DoP) was measured to further understand the interaction of impact velocities and forces (Table 7.8). However, the spear thrusts frequently impacted into the foam backing behind the PermaGel^{TM}, and the implications of this will be further discussed below.

Table 7.8. Descriptive Statistics for Depth of Penetration (mm)

Mean	SD	Min	Max	n
119.4	13.0	93	145	39

7.2.3.3 Participants

There were both right-handed (n = 8), and left-handed (n = 3) participants. Most (n = 10) chose their dominant hand as the trailing limb, but Participant 6 (P6) used the right hand as the trailing limb. The participant reported that he was trained to use a bayonet right-handed regardless of handedness. Grips varied more widely but stayed constant by participant. Variations included reverse grip (n = 9), forward grip (n = 1), and combination forward/reverse grip (n = 1). The impact event associated with the highest peak force involved one of the unusual grips, forward grip. Location of hands on the shaft varied, with some participants changing this between replicates (e.g. P8).

7.2.3.4 Impact velocity

The impact velocities recorded ranged from 2.8 m/s - 6.3 m/s (Table 7.9). A histogram of the velocities (Fig. 7.20) shows a bimodal distribution, requiring normality tests. The Shapiro-Wilk test was chosen as it is suitable for small sample sizes. The *p*-value of 0.627 confirmed a normal distribution. Fig. 7.21 shows impact velocities achieved by participant.

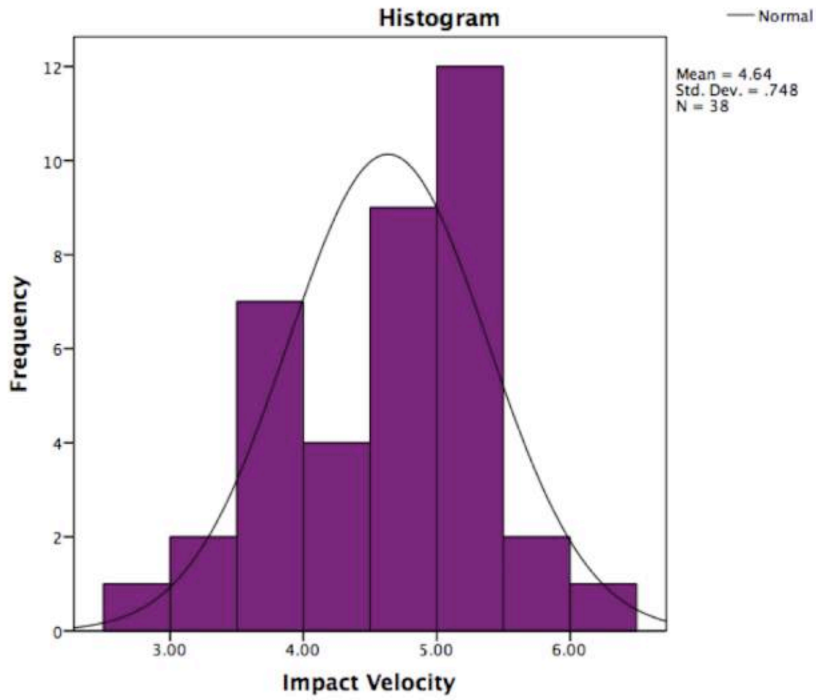


Figure 7.20. Histogram of the frequency distribution of impact velocities (m/s)

Table 7.9. Descriptive Statistics for Impact Velocities (m/s)

Mean	SD	Min	Max	n
4.65	.748	2.80	6.26	38

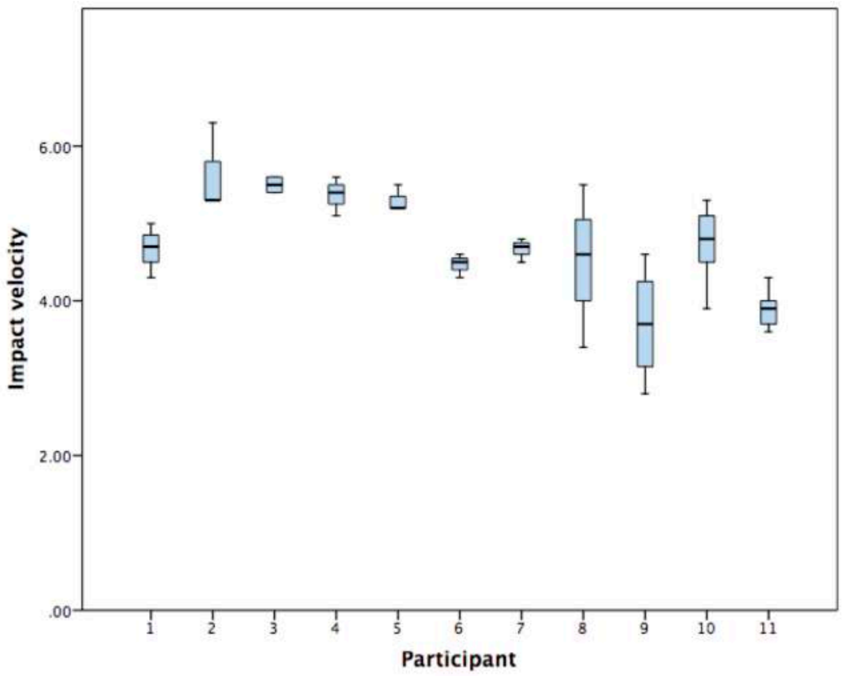


Figure 7.21. Boxplot of the impact velocities by participant

7.2.3.5 Force

Peak forces ranged from 362 N - 1120 N, (mean = 661 N; SD = 186.2 N) (Table 7.10). A histogram showed a bimodal distribution (Fig. 7.22) but the Shapiro-Wilk test had a *p*-value of 0.056 confirming its normal distribution. The boxplot in Fig. 7.23 visualises the peak forces achieved by participant, with the median (vs. the mean in Table 7.11).

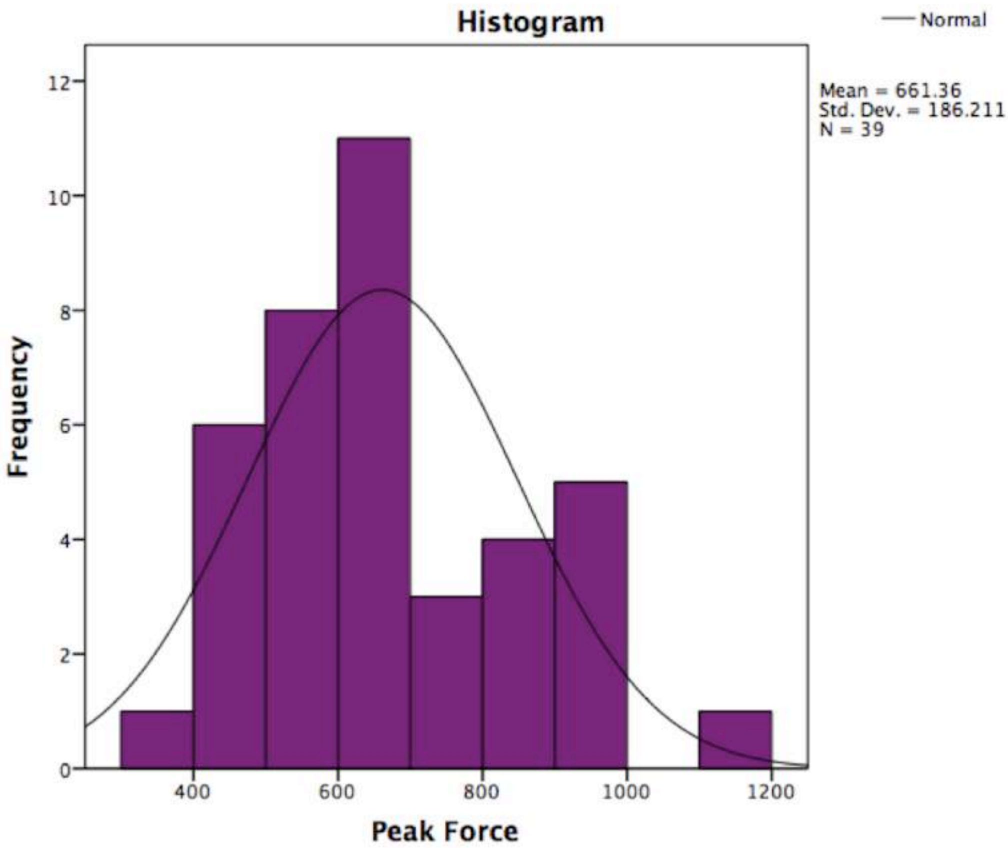


Figure 7.22. Histogram of the frequency distribution of peak force per thrust

Table 7.10. Descriptive statistics for peak forces (N)

Mean	SD	Min	Max	n
661.4	186.2	362	1120	39

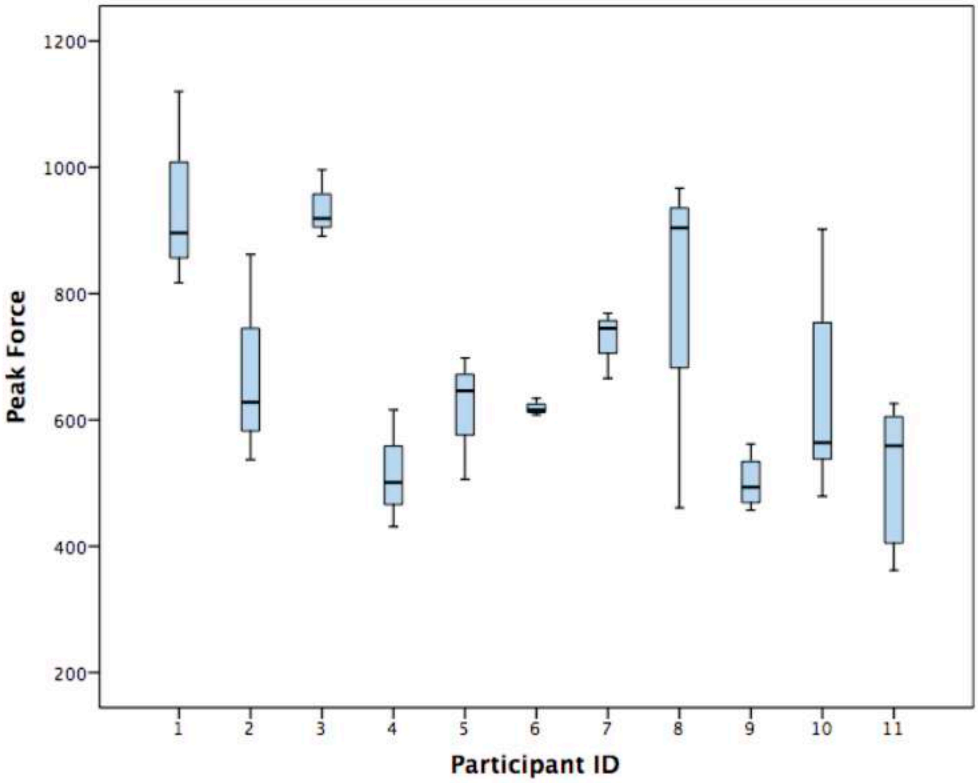


Figure 7.23. Boxplot of the peak force per thrust by participant

Impact events recorded force over time. Generalised categories of the resulting thrust profiles were created, designating profiles as ‘single peak’, ‘double peak’, or ‘push’ to enable an analysis of thrusting techniques. The most typical force profiles (n = 29) have a single peak of force which is followed by a tail as the spear was held in the target (Fig. 7.24). Double peak profiles were more unusual (n = 3), showing two peaks roughly similar in force (Fig. 7.25). A third category were labeled ‘push’ force profiles (n = 7), achieving peak force at the end of the thrust (Fig. 7.26) where a participant pushed their body mass into the target. Profiles tended to cluster by individual, and upon discussion, individuals (e.g. P10 and P11) changed their thrusting method to produce different profile types. P9 performed two ‘single-peak’ profiles, one a ‘push’ profile, and a further ‘single peak’ profile. P10 created two ‘single-peak’ profiles, while their third and fourth tries were ‘push’ thrusts; following discussion, he produced a further ‘single-peak’ thrust. P11 made three ‘push’ profiles, and subsequently produced two ‘single peak’ and one additional ‘push’ profile. P1 produced all three ‘double peak’ profiles one of which resulted in the highest peak force value of all the participants (P1_1). It is notable that all three participants who used this technique produced their highest individual force profiles with it (P9_3, P10_3, P11_2), with one (P10_3) producing a relatively high peak force. Table 7.11 shows the number of thrusts per participant, along with their individual means (vs. the median in the boxplot in Fig. 7.23) and standard deviations. The results in this table underline the fact that the SD per participant was not related to variation in number of thrusts. In other words, the difference in sample size of thrusts between those participants executing three and those executing six thrusts did not affect the spread of peak forces around the mean, with small and large SD found both for participants executing three thrusts, as well as for those executing more than three thrusts.

Table 7.11. Descriptive statistics of peak force by particpant

Participant	n	Mean	SD
P1	3	944	157.2
P2	3	676	167.7
P3	3	935	54.4
P4	3	516	93.4
P5	3	617	99.3
P6	3	619	13.3
P7	3	727	53.9
P8	3	777	275.8
P9	4	502	45.0
P10	5	647	175.7
P11	6	519	112.3

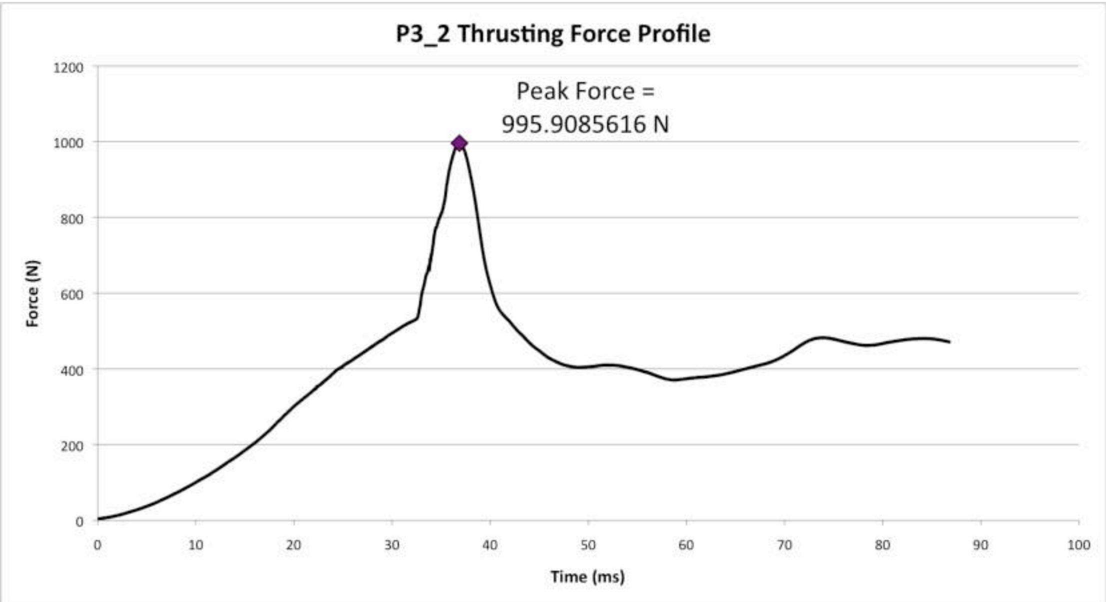


Figure 7.24. A force-time profile showing a typical 'single peak' (participant 3, replicate 2)

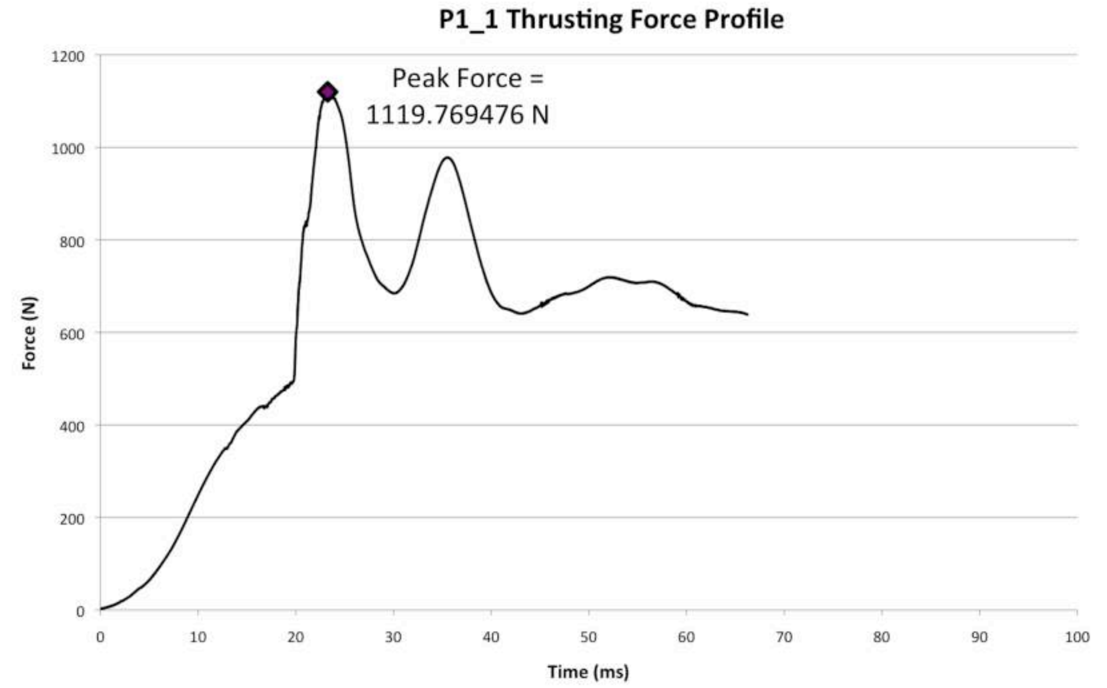


Figure 7.25. A force-time profile showing a typical 'double peak' (participant 1, replicate 1)

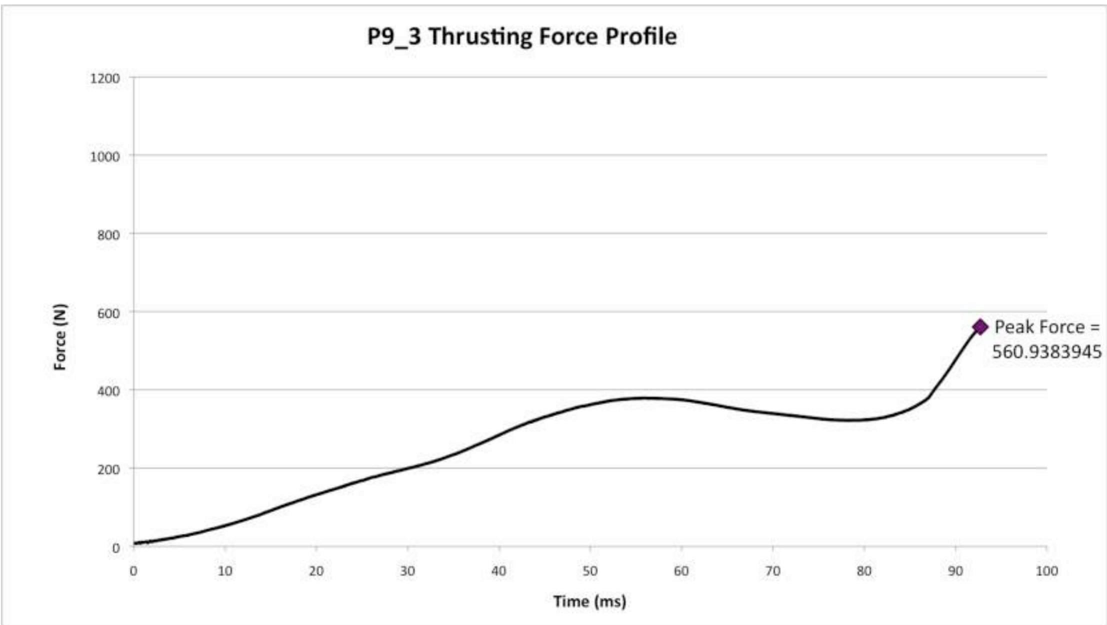


Figure 7.26. A force-time profile showing a typical 'push' (participant 9, replicate 3)

The PermaGel^{TM} blocks were replaced after replicates P4_3 and P8_3, with a mean of 13 thrusts per block. It is important to examine whether the use of a target for multiple thrusts, given the relatively large diameter of the spears, did not greatly affect the results. Fig. 7.27 indicates the lack of a downward trend from initial impact until the final replicate into each block. In one case (replicate P10_1, case number 28) the thrust overlapped with that of a prior impact, and this was noted at the time. For the second and third blocks, the final thrust into the block was greater than the mean of thrusts by that block. For block one the mean peak force was 756.6 N (n = 12) and the final thrust for the block was 616 N. For block two the mean peak force was 685 N (n = 12) and the final thrust for the block achieved 904 N. For block three the mean peak force was 557 N (n = 15) and the final thrust for the block was 600 N. Therefore the use of blocks for up to 13 thrusts is unlikely to have greatly affected the force results, as multiple thrusts in the same place should demonstrate a decrease in the forces needed to impact the target.

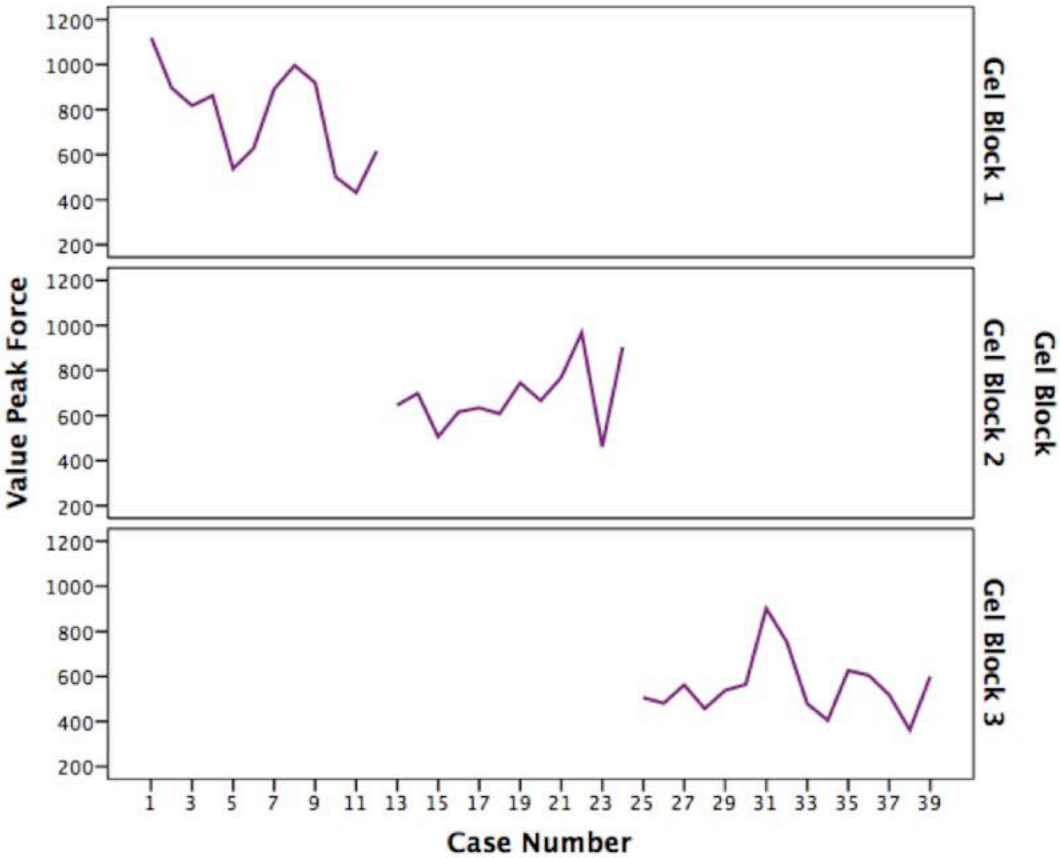


Figure 7.27. Sequence of peak forces separated by block of PermaGel™

7.2.3.6 Force and velocity relationship

Impact velocities did not predict peak force in two-handed spear thrusting, as indicated by a regression analysis ($R^2 = 0.139$) (Fig. 7.28). There was also a poor correlation between peak force and other variables such as body mass ($R^2 = 0.012$) and DoP ($R^2 = 0.034$). This can be explained both by the variability in human performance, and the complexities of the biomechanics of the two-handed thrust.

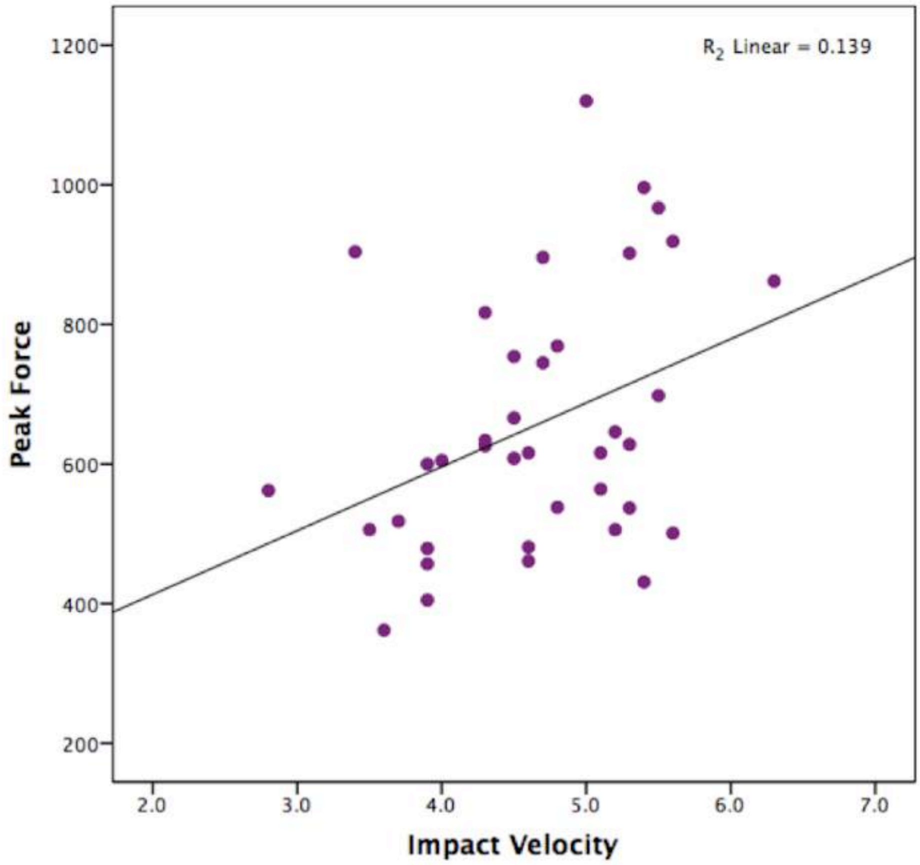


Figure 7.28. Regression analysis of impact velocity and peak force

7.2.4 Discussion of human performance thrusting trial

Although impact velocities fell within the relatively wide range reported for one-handed stabbing, the mean was lower than those from stabbing studies (Table 7.3). Connolly et al.'s (2001) range and means from one-handed spear thrusting compare well with results obtained here. The hypothesis that two-handed spear thrusting results in higher impact velocities than one-handed stabbing (Wilkins, Schoville & Brown 2014a) is not supported; this is likely due to the heavier mass of these spears in comparison with knives (Horsfall et al. 1999). The velocities achieved in this study suggest that the use of trained males results in faster impact velocities, if compared with velocity results using a mix of male and female untrained participants (Schmitt et al. 2003).

When compared with data from the present study, Table 7.4 shows that researchers are both under- and overestimating impact velocities. Furthermore, in relation to experimental 'firing', Wilkins et al. (Wilkins, Schoville & Brown 2014a; Wilkins, Schoville & Brown 2014b) fired spears from a crossbow at a 20 kg draw weight and filmed impact velocities resulted in a mean of 8.9 m/s. These filmed velocities indicate that Shea et al.'s (2001; 2002) *estimated* velocities of 1.0 m/s to 1.5 m/s when fired with a 28 kg draw weight were possibly incorrect, particularly if taking into account the probability that the design of their replicas were light in mass compared with Wilkins et al.'s (2014a). The wide range of impact velocities in experimental work creates questions around the results of some experiments aimed at understanding lithic wear patterns and thrusting spear ‘effectiveness’, and also - in combination with the evaluation of forces - highlights the unsuitability of calibrated crossbows in replicating thrusting spear use, as others have indicated (Hutchings 2011; Iovita et al. 2016; Sano et al. 2016).

Maximum and mean peak forces captured in this trial are similar to those from Connolly et al.’s (2001) study on one-handed spear thrusting. Connolly’s target was a 1 m square piece of plywood, and therefore has significant differences to the PermaGel^{TM} target used in the current work. Some participants in this trial remarked that the avoidance of previous impacts in the target hindered the ability to attack with maximum force, which is helpful in considering hunting strategies.

It is apparent that peak force and impact velocity correlate poorly in two-handed spear thrusting. Stabbing, slashing and thrusting have demonstrated that technique affects performance (e.g. Miller & Jones 1996; Connolly et al. 2001; Bleetman et al. 2003). Similarly, previous human performance studies show high variability, as human behaviors and skills are not static (e.g. Horsfall et al. 1999; Viitasalo et al. 2003; Dyer 2004; Horsfall et al. 2005; Cowper et al. 2015). Finally, body mass, fitness of the individual, and techniques including hand placement, orientation and gestures, all contribute to the variability in performance achieved in this study. Variability in human performance using other prehistoric weapon technologies has also been demonstrated, influenced by many factors including body morphology and stature, skill, fitness, and potentially gender (Whittaker & Kamp 2006; Maki 2013; Apicella 2014). Adrenaline would almost certainly have played a role in spear use in the past. The adrenaline response is triggered by challenging situations, which improves athletic performance (Blascovich et al. 2004). Spear thrusting whether in human-human or human-animal conflict would have been dynamic (e.g. Bleetman et al. 2003; Rots & Plisson 2014) and either or both parties would have potentially been moving in complex ways. Multiple factors would have coalesced with some diminishing and others enhancing ‘effectiveness’.

Both body mass and muscular effort are involved in spear thrusting, whatever the techniques used. Regardless of technique and approach, a pushing movement carries on after initial impact in spear thrusting due to momentum of the moving human body and a desire to ‘follow through’, and although stabbing studies show deceleration after impact (Horsfall et al. 1999), thrusting still differs from thrown projectiles. Projectiles lose momentum immediately on impact and rely entirely upon the object’s tip design and kinetic energy to penetrate the target. Conversely with penetrating contact weapons, the weapon user responds to the target, potentially carrying on producing momentum after impact, either until satisfied with DoP or until failing to push the weapon in further (Hutchings 2011).

Because of these mechanical differences between contact weapons and projectiles, impact velocity alone does not accurately replicate thrusting spear use (Hutchings 2011; Iovita et al.

2016; Sano et al. 2016). Therefore, while firing a spear as a projectile, whether by air cannon or crossbow may mimic impact velocities, it cannot replicate momentum after impact. Adding mass to a firing mechanism to imitate loading (e.g. Iovita et al. 2016) is an improvement on controlled methods to replicate spear thrusting mechanics. Unlike calibrated crossbows at high draw weights, air cannons and drop towers can simulate low impact velocities, but they still do not simulate momentum. Sacrificing the experimental control from using mechanical methods and using humans to conduct the spear thrusting (e.g. Lombard et al. 2004; Parsons & Badenhorst 2004; Hutchings 2011; Clarkson 2016; Rots 2016; Sano et al. 2016) best replicates spear thrusting mechanics at the present time, and humans are frequently used in impact and armour research (Bleetman et al. 2003; Cowper et al. 2015; Kemp et al. 2009). Using a small cohort of similarly-trained individuals will help introduce improved control, and measuring parameters such as velocities and forces would further elucidate techniques and the range of such parameters. The hypothesis that trained participants will influence outcomes of experimental weapon research (e.g. Rots & Plisson 2014) is supported. No known studies have previously linked impact velocities and forces for this weapon system, and the results show a complexity even when the cohort has similar training. The trial provides the first dataset with benchmarks for understanding of the parameters necessary in accurately replicating two-handed spear thrusting and creates a solid foundation for experiments presented in Chapter 8.

7.3 Human performance trial: spear throwing

7.3.1 Introduction: experiment questions and secondary aims

The spear throwing trial was designed to evaluate a set of questions pertaining to the performance of untipped wooden spears, and specifically of a replica of Schöningen spear II when thrown by males trained in the javelin throw (see Appendix 2 for limitations). The experiment questions pertain to understanding velocities (delivery and impact) of hand-delivered spears in order to facilitate setting up Phase 2 experimentation using spear replicas on animal carcasses. These are:

- What are release and impact velocities at given distances of a replica of Schöningen spear II when thrown by trained athletes?
- What is the relationship between release and impact velocities?
- What are the flight trajectories of a replica of Schöningen spear II when thrown by trained athletes?

Secondary aims of the experiment were to shed some light on the discussion of 'effective distances' and accuracy of hand-delivered weaponry by asking:

- What is the 'effective distance' of a replica of Schöningen spear II when thrown by trained athletes?

- What are the maximum throwing distances of a replica of Schöningen spear II when thrown by trained athletes?

7.3.2 Materials and Methods

7.3.2.1 Experiment location, setup and data acquisition

The experiment took place at the outdoor Steve Backley National Throws Centre, Loughborough University over a five hour period on the afternoon of January 17th, 2015. Participants were located under a covered area, with the throwing field uncovered. The mean air temperature was 3° C, precipitation was 0.0 mm and the range of wind speed was between 14.8 - 31.5 km/h in a southwesterly direction (weather data accessed via Weather Underground website https://www.wunderground.com/). Participants threw towards the northeast in the direction of the wind. Throws included those at a target set at a series of distances, as well as throws to achieve maximum distance. One hundred and twenty throws were undertaken.

Release and impact velocities were filmed using two HSV cameras (Fastec TS3 TS3100-S) at a frame rate of 1000 Hz (Fig. 7.29). High speed video captured 92% of the target impacts. Due to the time needed to save large HSV files, most target misses were not saved. Four videos were retained for misses at longer distances, in order to understand velocities at these distances regardless of the hit/miss data. Release velocities were not captured for distance throws (n = 12) due to low light. Digital photographs and standard video recordings (n = 14) were made throughout the experiment to capture examples of throwing techniques and flight trajectories.

Figure 7.29. Photo of throwing trial setup. A shows the target. B indicates the location of the HSV technician and camera for impact velocities, and C indicates the location of the technician and camera for release velocities

7.3.2.2 Spear replicas

Spear replicas were crafted in the same way and from the same materials as described 7.2.2.1 for the spear thrusting trial. Additionally as the surface texture affects aerodynamics in flight, the surface was worked at the final stage with lithic tools, creating a surface that accurately replicating the surface of a Pleistocene wooden spear. Four replicas were created, but only two were selected for use in the experiment. These two had the most similar masses and points of balance to each other within the sample. Replicas were labeled numerically per individual spear, and with a B representing this experiment. Basic measurement data for the replicas, including replicas that were rejected, are in Table 7.12. Location of maximum diameter proved a problematic measurement, as in fact this measurement, which was 37 mm, extends over a distance of the shaft.

Table 7.12. Selected measurement data of the spear replicas.

Replica	Length	DIA at 10 mm	DIA at 50 mm	DIA at 800 mm	DIA at 1150 mm (midpoint)	DIA at 1530 mm	Mass	P.O.B.
1B	2300	6	19	35	33	37	760	1091 (47%)
2B	2300	7	17	37	34	34	800	1084 (47%)
3B†	2290	6	14	37	35	34	1020	1105 (48%)
4B†	2300	6	14	37	34	34	860	1050 (46%)

*** As measured from distal point of spear. † Replica not used in this experiment. Length, DIA and P.O.B. measurements in mm, mass in g.**

7.3.2.3 Target

This study was designed to understand human performance and spear flight mechanics using replicas of MP spears, and not to evaluate the effectiveness of these spears on an animal target or damage to wooden spears when used as throwing weapons (though the resulting breaks are presented below). The trial therefore did not require a complex target, and a soft target was chosen to protect spear replicas from damage. A large target, corresponding with a size class 3 animal (after Bunn 1982) would have provided a more accurate target in terms of size. However, in reality the ‘kill zone’ or primary target area on an ungulate is relatively small (Guthrie 1984), although other target areas such as the vertebrae exist. Therefore, a hay bale (105 cm x 55 cm x 50 cm) represented a target similar in size to the target area of an adult size class III ungulate. The hay bale was rested horizontally on the ground at a series of distances from a throwing line for the aimed throws. These distances were 5, 10, 15, 20 and 25 m from the designated throwing line. A series of additional throws took place at 10 m with the hay bale turned on its end to be vertical, in order to assess whether the height of the target was affected the ability to hit the target.

7.3.2.4 Human participants

Six males aged 18 to 34 years old were recruited by javelin coach David Parker, lead throwing coach at Loughborough University and a coach with England Athletics and British Athletics (Participants 1-6, P1-P6). Males were chosen as they achieve around 30% greater distances in their throws due primarily to higher release velocities (e.g. Viitasalo et al. 2003; LeBlanc & Mooney 2004) and possibly have better accuracy in throwing than females as well (Westergaard et al. 2000). Ethical approval from UCL was waived on the basis that no data were collected covertly, the data were fully anonymised, participants provided full informed consent, were all over 18, and were not vulnerable. Participants were orally briefed, provided signed informed consent, and were aware they could withdraw at any stage of the work without penalty. Participants volunteered to take part in the throwing trial, and were not paid. All have experience and have received formal coaching in the javelin throw, varying from one year to 24 years (mean = 8 yrs; SD = 8.3 yrs) and were chosen to reflect a range at a reasonably high skill level (Table 7.13). Participants rotated throwing to combat fatigue. Self-reported heights ranged from 1.73 m - 1.89 m (mean = 1.82 m; SD = .628 m) and body masses ranged from 65 kg - 93 kg (mean = 81.7 kg; SD = 9.9 kg). Body mass and height of javelin athletes are a significant factor for throwing they are not as high on average as for other throwing events such as the shot put and discus and hammer throws, with technique proving a significant influence on successful distance throwing (http://www.track-stats.com/track-and-field-body-types/ accessed 21/2/2018; Čoh et al. 2002). Mean height and body mass of the participants correspond well with estimates for *H. heidelbergensis* (Stringer et al. 1998; Trinkaus et al. 1999; Froehle et al. 2013). Personal bests (PB: distance of throw) were also self-reported, ranging from 33 m to 78.33 m (mean = 53.4 m; SD = 16.1 m). The maximum PB (P2) had an associated release velocity of 27 m/s, but the other PBs did not know associated velocities.

Table 7.13. Participant personal data

Participant	Age	Height (m)	Weight (kg)	Personal Best (m)	Years throwing experience	Dominant Hand
1	19	1.83	83	57.27	5	R
2	34	1.89	93	78.33	24	R
3	19	1.78	78	60.62	9	R
4	19	1.73	90	39.73	5	L
5	18	1.78	65	33	1	R
6	18	1.88	81	51.42	4	R

No coaching was provided on the day. Sometimes adhesives are used for the javelin throw, most typically a turpentine mixture with a honey-like consistency (Johnson 1987) but for this study participants threw without any aids such as gloves or grips. Participants were not permitted a run-up, but up to three steps were allowed to facilitate body position at release. In addition to the target throws, each participant threw twice for maximum distance, and for these a small approach of up to five m was permitted, though not always used, to facilitate the throwing action.

7.3.2.5 Data analysis

HSV analysis was conducted using the software package Phantom Cine Viewer v2.5.744.0. Due to the dynamic nature of the spear throwing and issues with the availability of light when filming outside, the video analysis methods had to be more flexible than those from the thrusting trial, in order to adapt to variation in what the filming captured. Some of the issues encountered in analysis were:

- For release videos there is no 'point of impact' with a target as there is for impact videos. Poor lighting occasionally made identifying the spear in the final frame problematic. In combination this made it difficult to identify a single frame across all release videos that represented the final frame in calculations.
- Poor lighting, complicating the identification of the distal point of the spear in certain frames
- For one impact video it was difficult to identify precisely the frame of impact with the target
- Variation in flight trajectories complicated identifying 'point of impact' in impact videos. For example, Impact Video 15, the spear landed rear first, but still impacted the target

In order to address these limitations in analysis, general rules were established, but adjustments were made when necessary. Overall, the longer the distance calculated in a video, the more reliable the velocity measurement, although this must be this must be balanced by the fact that velocity varies over distance traveled (D. Carr, pers. comm.). Therefore in each video, the first general rule was to capture the largest number of frames possible in each video. Distances calculated are in the 'HP Throwing Trial' file. The spear served as the measurement value in the analysis, with a known length of 2300 mm for both spears. If the point of the spear was difficult to see in the video due to lighting, the rear of the spear was used instead. For release videos, velocities were calculated from the frame that the spear left the hand, in order to ensure that release velocities of the spear were calculated, rather than velocity of the throwing arm. For release videos, the final frame was as close to the moment when the point or rear of the spear (depending upon which was used in calculations) reached the edge of the video frame. A further parameter captured in video analysis was angle (radians), measured as the difference from a vertical line on the video frame, spanning from the first to the last frame for which velocity measurements are calculated (Fig. 7.30).

Where possible, standard and HSV were also analysed for spear flight paths and spear performance, for example to assess not only whether flight paths followed a parabolic curve, but also to understand whether the spear turned on its axis or twisted distal-proximally in flight, and how the spear landed. As the angles of release determine the flight trajectory (flat vs. parabolic) and distance achieved, the angles were calculated in the Cine Viewer analysis as well for both release and impact videos. The angles, expressed as radius, do not represent 'angle of release' of the javelin at the exact moment of release, but rather the angle of the flight trajectory captured across the distance measured in the release velocity video frame (Fig. 7.30). The impact angles reflect angle of the spear at impact. This measurement provides additional data pertinent to evaluating flight trajectories.

Figure 7.30. Throwing video analysis. The pink line represents the distance measured in the video frame. The angle of this distance in comparison to the short pink line results in the angle measurements automatically calculated by CineViewer (expressed as radians). 'A' represents the starting point of the measurement in the video and 'B' the end point of measurement taken

Kinetic energy (KE) is a further important variable for understanding the effectiveness of projectile technologies (Hughes 1998). Results for solving KE (J) follow the equation:

Equation 7.1 Kinetic energy

$$KE = \frac{1}{2} m\mathbf{v}^2$$

Where

m = mass (kg)

v = velocity (m/s)

Therefore, increases in velocity are more influential on KE than mass. However, the relationship is exponential, meaning that increases in mass at lower velocities are more influential on KE than increases in mass at higher velocities (Fig. 7.31).

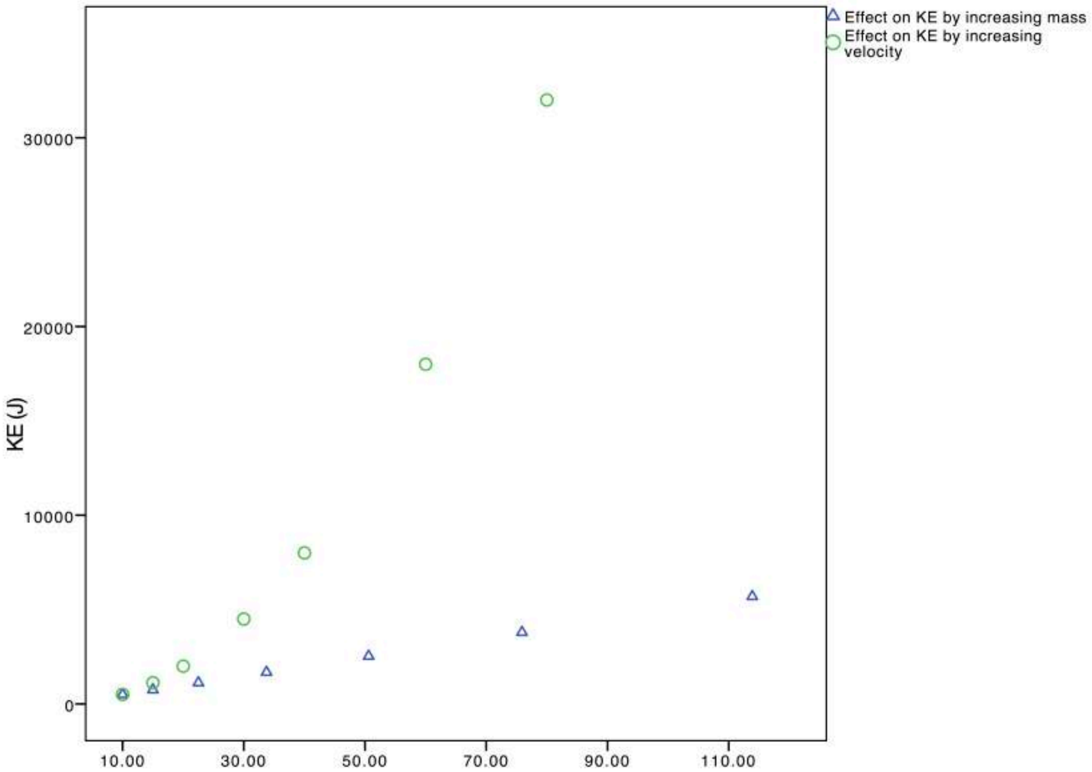


Figure 7.31. Theoretical scatterplot comparing effects of increases of velocity (green circles) and mass (blue triangles) on kinetic energy (y axis). Values begin at 10 (m/s and kg) and increase by factors of 1.5.

7.3.3 Results

A total of 120 throws took place by the six participants, for which hit/miss data or throwing distance were manually recorded depending upon throw type. Each participant performed 20 throws. One hundred and eight throws were aimed throws (18 per participant) and 12 were distance throws (2 per participant).

7.3.3.1 Velocity and kinetic energy

Thirty six recorded events (REs) were captured on HSV, providing velocity data, either for release, impact or both. Eighteen REs captured both release and impact velocities, facilitating an analysis of their relationship. Release velocities were captured for 19 aimed throws, while impact velocities were captured for 31 throws (aimed and distance).

A histogram of release velocities showed a multimodal distribution (Fig. 32). A Shapiro-Wilk test (p = 0.999) along with a visual inspection of the Q-Q plot confirms a normal distribution. Descriptive statistics for release velocities are presented in Table 7.14.

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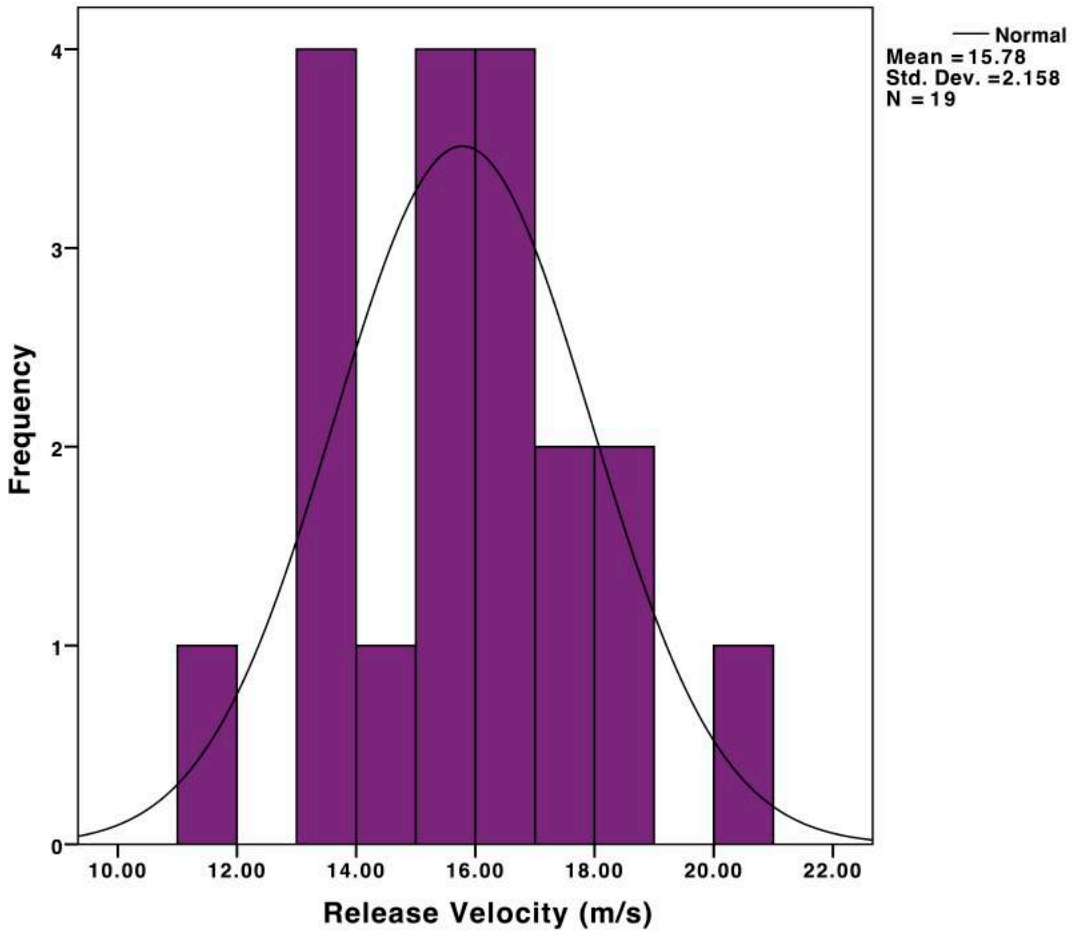

Figure 7.32. Histogram of release velocities

Table 7.14. Descriptive statistics for release velocities

Mean	Median	SD	Min	Max	n
15.78	15.80	2.158	11.8	20.11	19

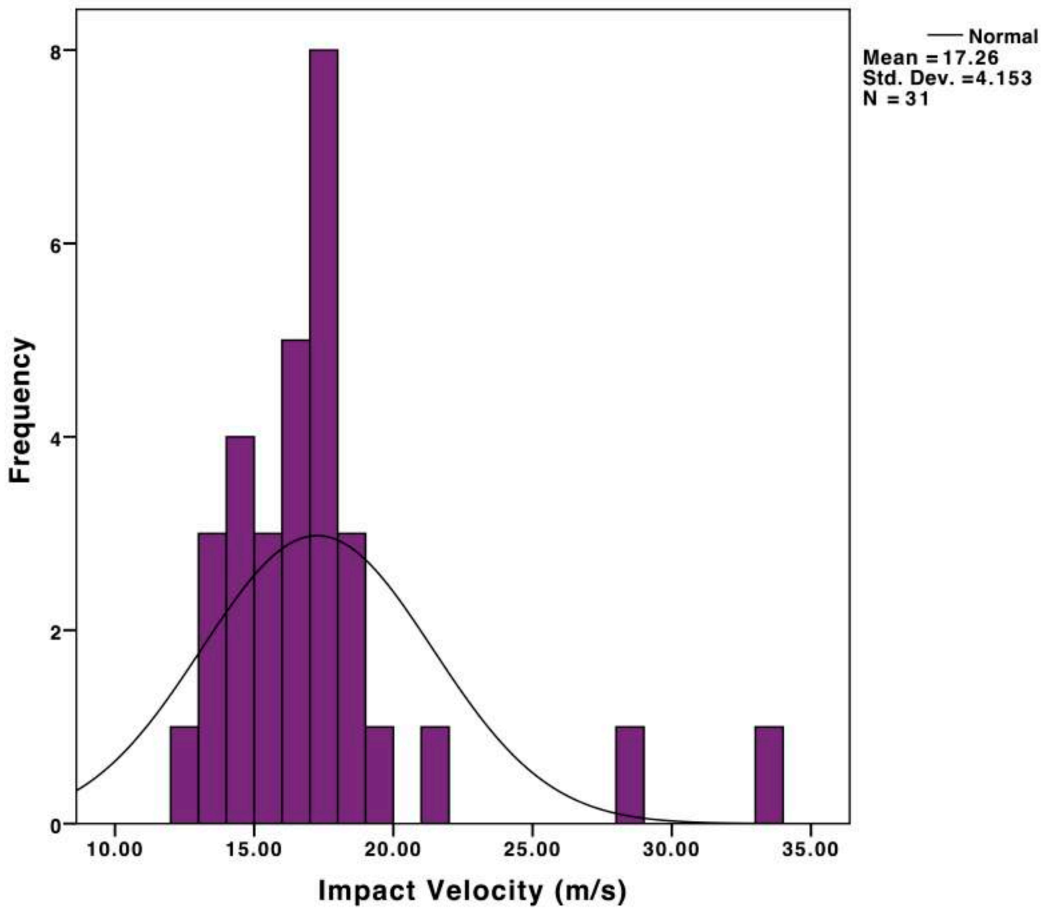

Figure 7.33. Histogram of impact velocities, combined target and distance throws

Table 7.15. Descriptive statistics for impact velocities

Mean	Median	SD	Min	Max	n
17.26	16.8	4.153	12.7	33.3	31

A histogram of impact velocities (Fig. 7.33) demonstrates the presence of outliers in the dataset, and a non-normal distribution, confirmed by a visual inspection of the Q-Q plot and a Shapiro Wilk test (p=0.000). Descriptive statistics in Table 7.15 include these two outliers. Removing the two outliers creates a normal distribution with a Shapiro Wilk test confirming this (p=0.472). This has significance only for the regression analysis presented below, as that dataset does not include those two outliers, as there are no corresponding release videos for these two distance throws. Impact velocities for aimed throws only ranged from 13.5 m/s - 21.7 m/s (mean = 16.61 m/s; SD = 1.885 m/s), demonstrating a close relationship to the combined impact velocity dataset. The two outliers with values of 28.4 m/s and 33.3 m/s both belong to distance throws, (Table 7.19) and their significance will be discussed below.

Fig. 7.34 presents a box-and-whisker plot of impact velocities by participant of combined throws (aimed and distance), including the two outliers. These data show variability by participant. For example, the participant with the least number of years' experience (P5) also produced the lowest impact velocities. The two participants (P1 and P4) with the highest percentage of 'hits' (Table 7.18) also produced the highest impact velocities. Impact velocities by distance showed overall a fairly even distribution across the distances (Fig. 7.35). However, those at the distance of 20 m are high in relation to those at other distances, and the two outliers also occur at longer distances.

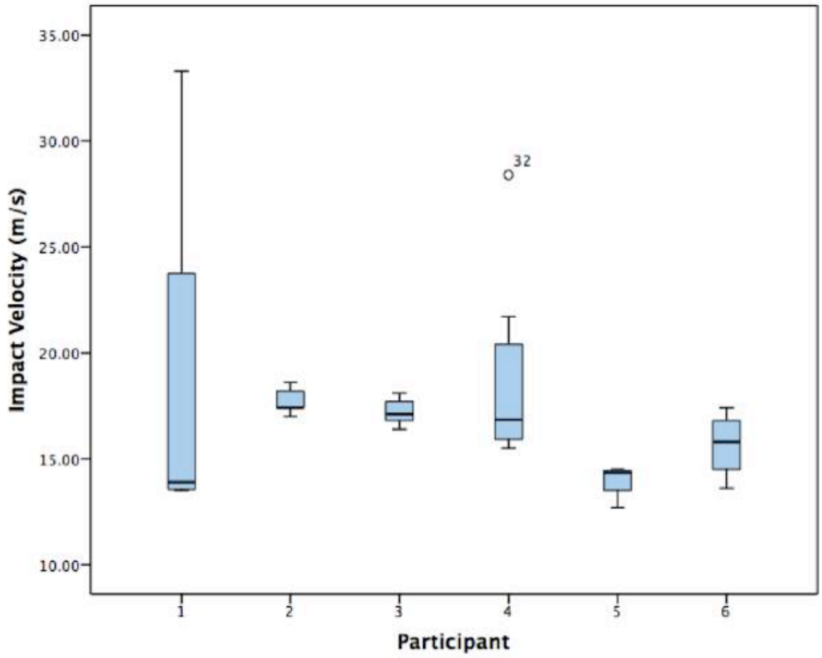

Figure 7.34. Boxplot of impact velocities by participant

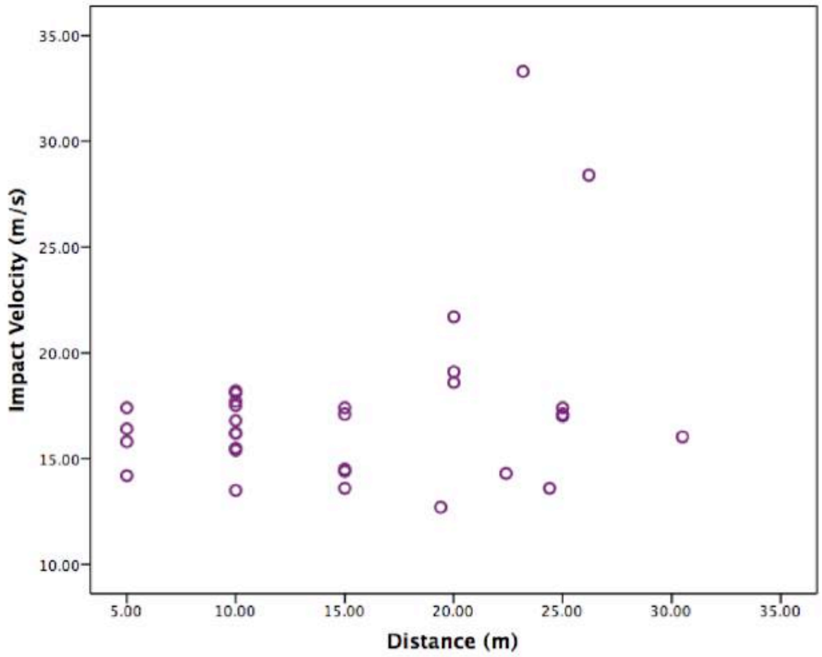

Figure 7.35. A scatterplot of impact velocities by distance

A regression analysis of the 18 RE for which there are both release and impact velocities, which as stated above is a dataset with a normal distribution, showed a somewhat weak correlation (R^2 = 0.498) between the two (Fig. 7.36). The relationship is visibly stronger for slower velocities and weakens for the faster velocities. The three highest impact velocities occurred for the 20 m distance throws, with each of these having a weak relationship to release velocity according to the fit line. Relationships for 25 m throws are also relatively weak, whereas those from 5-15 m distances have a stronger relationship to the fit line than further distances.

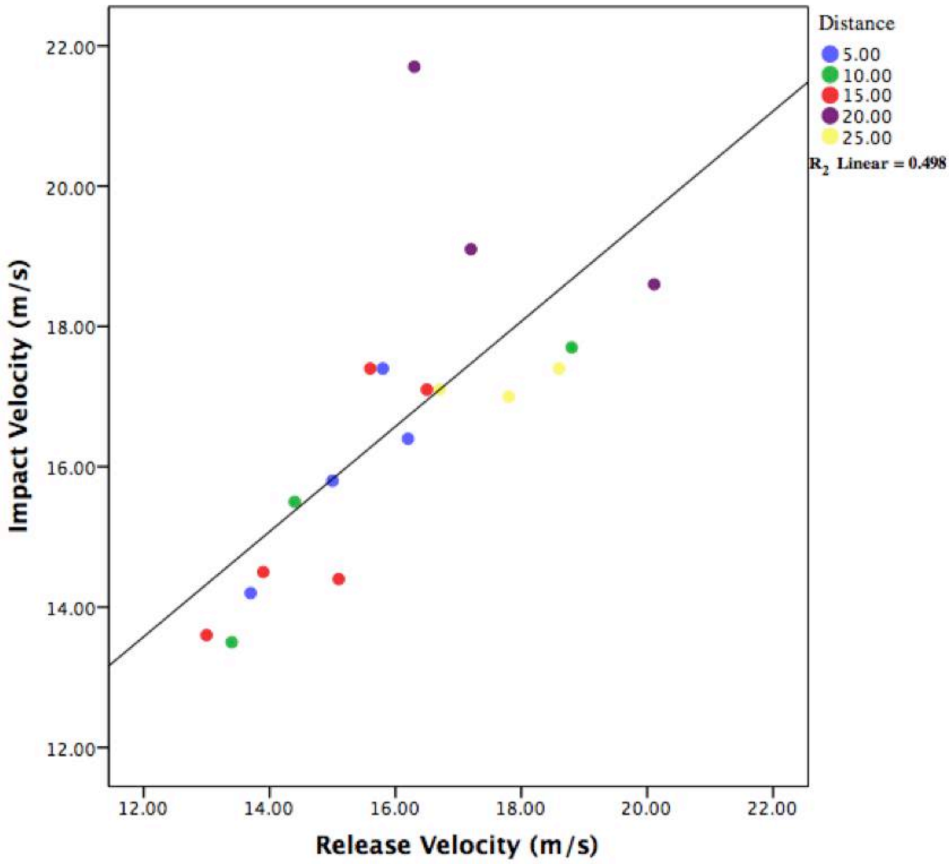

Figure 7.36. Regression analysis for release and impact velocity data

The relationship between release and impact velocities in this trial demonstrated a trend for an overall increase in velocity from the point of release to the point of impact. Five of the 18 RE for which there are both release and impact velocities demonstrated a slight decrease in impact velocity, while 13 RE showed an increase in impact velocity. The rate of change from release to impact velocities varied from -1.51 m/s to 5.4 m/s (mean = 0.57 m/s; SD = 1.57 m/s). Both slight decreases and increases occurred across the range of distances, with the largest increase occurring at the distance of 20 m (Fig. 7.37).

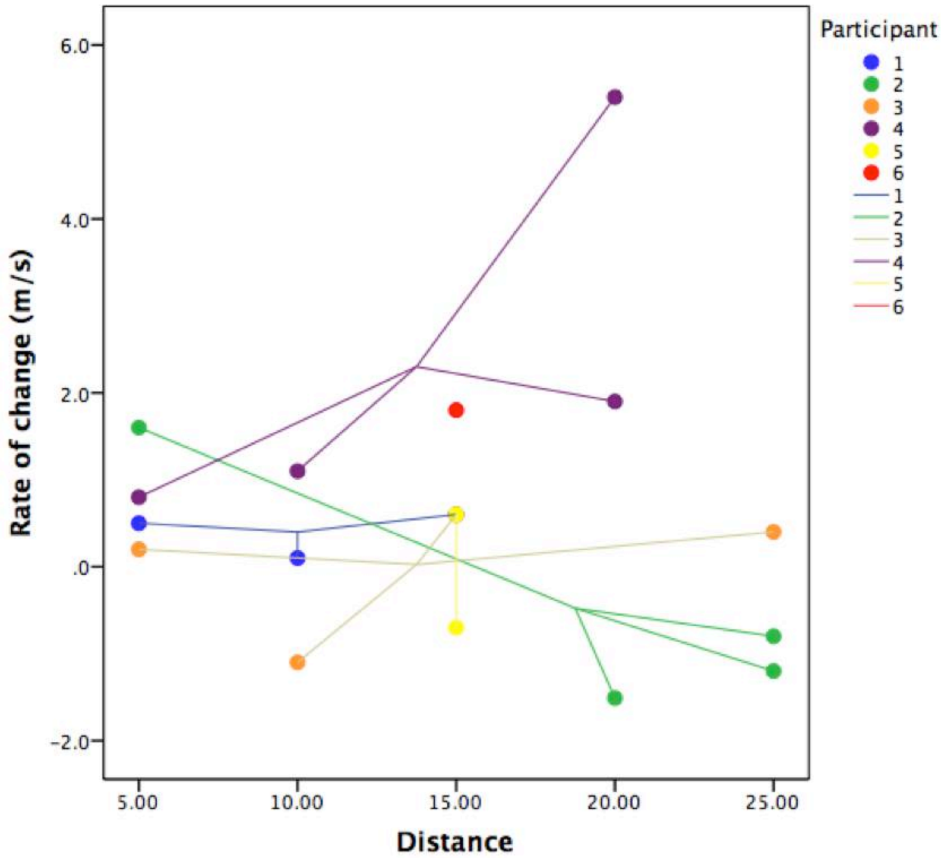

Figure 7.37. Scatterplot showing rate of change (in m/s) by distance and participant. Note that there are four identical points for the 15 m distance, an increase of .6 m/s. This can be seen by the lines connecting participants' data points

It was not possible to capture impact velocities for three of the distance throws, and three further videos were unsuitable for analysis due to problems with clearly identifying the entire spear in the frame. This left six HSVs from which to analyse velocities from distance throws, though several videos didn't capture moment of impact with the ground, and so velocities captured in those cases are only to be considered as estimates for impact velocities (Table 7.19). Velocities ranged from 12.7 m/s to 33.3 m/s for the distance throws (mean = 19.72 m/s; SD = 8.83 m/s). Not all of the spears landed point first, with many falling flat (discussed in 7.3.3.3). In one of the throws, the spear did clearly land point first, with an associated velocity of 33.3 m/s. Given the high release velocities in the literature for elite javelin throwing (Table 7.3), the hypothesis that thrown spears experience a loss in velocity and therefore kinetic energy over distance was not supported. Gravitational acceleration (9.81 m/s^2) explains the larger increases at the greater distances, with spears thrown in a parabolic trajectory and achieving greater heights than flat trajectory throws.

The descriptive statistics of KE (J) in this experiment are presented in Table 7.16. Kinetic energies in this trial are significantly higher than previous estimates from archaeologically-oriented human performance trials using spearthrower darts as hand-thrown spears (Table 7.3) due to both the higher mass of the Schöningen replicas over spearthrower darts not intended as hand-thrown spears, as well as the higher recorded impact velocities here than those estimated in the literature. The mean KE in this trial is lower than the mean estimated from Rieder's (2001) trial, which used a lighter replica of Schöningen spear II alongside higher mean impact velocities resulting in a mean KE of 163 J (Table 7.3). Whittaker et al.'s (2017) extensive trials with spearthrower darts, and comparisons with other trials suggest that the highest velocities elsewhere published for spearthrowers (Hutchings & Brüchert 1997) may be a result of recording errors (Table 7.5). Taking out these extremely high velocities, spearthrower energies appear to range from ca. 8 J to ca. 88 J (Table 7.5). Bow and arrow velocities look to range from ca. 30 m/s to 60 m/s, with energies ranging from ca. 13 J to ca. 43 J (Table 7.5). The data on complex projectiles are not intended to be comprehensive in scope, but nevertheless it is clear that hand-thrown spears used in this study had a range of 65 J up to 444 J, with a mean of 123 J. Therefore we see overlaps in KE between these three systems, but the mean KE of heavier hand-thrown spears easily surpasses KE of complex projectiles.

Table 7.4 highlights the importance of accurately replicating mass in experimental work, as experiments using appropriate impact velocities for lighter hand-thrown spears (e.g. Milks 2010; Hutchings 2011; Iovita et al. 2016) will not accurately represent KE of heavier hand-thrown spears, which will in turn have influence both terminal and wound ballistics.

Table 7.16. Descriptive statistics for kinetic energy (J)

Mean	Median	SD	Min	Max	n
122.5	110.0	75.28	65	444	31

7.3.3.2 Effective distance

Of the 108 aimed throws, 25 successfully hit the target (23%), while 83 (77%) missed. Fig. 7.38 illustrates a sequence of an example throw. A breakdown of the hit/miss data by distance confirms the correlation between target distance and accuracy (Table 7.17, Figs. 7.39 and 7.40), which has been demonstrated in previous studies (e.g. Westergaard et al. 2000). When combining the data of all throws at 10 m, the percentage of hits follows a clear descending pattern by distance (Fig. 7.40).

Figure 7.38. An example of a target throw at 15 m, starting top left to right, then bottom left to right. The spear landed beyond the target

Table 7.17. Hit and Miss data by distance

Distance (m)	Total Throws	Hits	Misses	% Hits
5	12	7	5	58
10*	18	3	15	17
15	24	6	18	25
20	18	3	15	17
25	25	0	25	0

*** Not including throws with vertical hay bale**

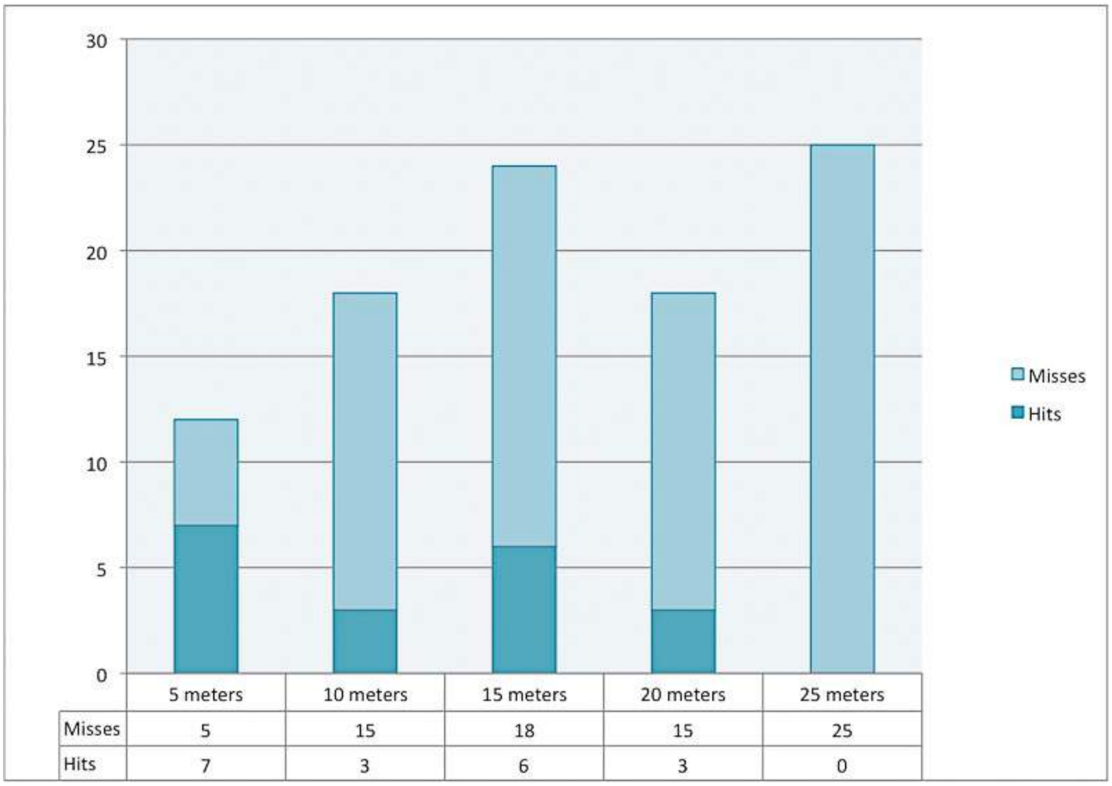

Figure 7.39. Bar chart of hits and misses per distance. 10 m distance does not include throws at altered target height, and corresponds with Table 7.17

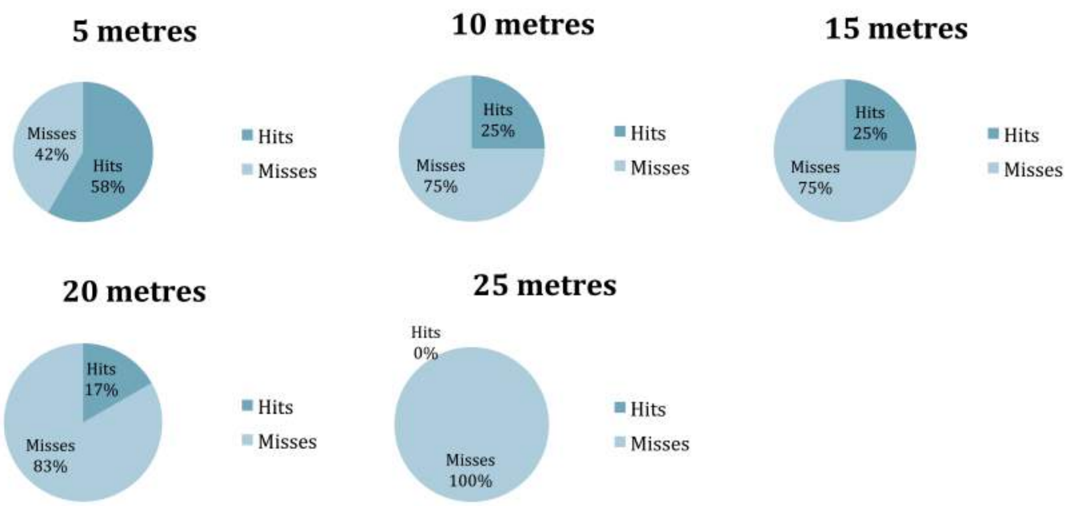

Figure 7.40. Hits and misses per distance expressed as percentages of total number of throws. 10 m distance includes all throws at this distance, including those with altered target height

Although the sample size of throws at 10 m is small, an increase in height of the target set at 10 m from the initial horizontal position to the vertical position looks likely to have increased the number of hits: 17% of throws were hits at 10 m with the hay bale horizontal on ground, while 67% resulted in hits when vertical, which is an increase of 50% in hit rate. Altering the height of the target may well increase the ease of hitting the target, also suggesting that an animal lying on the ground may be more difficult to hit with a hand-thrown spear than one standing up. Similarly, smaller animals closer to the ground would also potentially be more difficult to hit. This must be considered when addressing the issue of effective distance, with further studies encouraged.

Participants showed variability in their ability to hit the target. Percentage of total hits broken down by participant range from 11% to 33% (Table 7.18). The participant with the fewest years' throwing experience (P5) had the lowest percentage of hits, though the participant with the most years throwing experience (P2) did not achieve the highest number of hits. The fact that P5, with one year of throwing experience had both the lowest impact velocities and poorest hit rate again underscores the significance of training.

Table 7.18. Hit and Miss data by participant

Participant	Years throwing	Total number aimed throws	Number of hits	% of total resulting in a hit
1	5	18	5	28
2	24	18	4	22
3	9	18	4	22
4	5	18	6	33
5	1	18	2	11
6	4	18	4	22

Each participant threw two distance throws, throwing the furthest distance possible without aiming for a target. All the distance throws used replica 2B. An approach of up to 5 m was permitted, though not all participants took advantage of this. Distance throws ranged from 19.4 m to 31.2 m (mean = 26.33 m; SD = 3.981 m). The most experienced participant (P2) achieved the farthest distance, while the one with least experience (P5) performed the poorest.

Table 7.19. Recorded distances from distance throws and associated impact velocities where applicable. * indicates that impact velocity could not be calculated

Participant	Distance (m)	Observations	Associated impact velocity
1	26.33	No video	*
1	23.18	Landed point first into ground	33.3
	31.2	video unsuitable for analysis	*
2	28.38	video unsuitable for analysis	*
3	26.8	video unsuitable for analysis	*
3	30.8	No video	*
4	26.2	Didn't capture landing but direction was point down by end of video clip	28.4
4	30.5	Didn't capture landing but direction was rear down by end of video clip	16.03
5	19.4	Landed rear first	12.7
5	22.4	Landed rear first	14.3
6	24.4	Didn't capture landing but direction of spear tip was vertical by end of video clip	13.6
6	28.6	No video	*

7.3.3.3 Flight trajectories

Throughout the experiment, a variety of flight trajectories were noted. They will be presented and briefly discussed. In general, flight paths for throws at 5 m tended to have a downward-directed flat flight trajectory, which can be observed in photographs, videos, and angles measured in HSV. Participants adjusted the angle of release according to distance, with a maximum upward angle of release for the farthest distances (Figs. 7.41 to 7.44). Example trajectories can also be observed in Videos 7.2 and 7.3.

Figure 7.41. Example of a flat flight trajectory of a spear throw directed at a 5 m distance

Figure 7.42. Example of a throw directed with a high attack angle for a distance throw. This angle results in a parabolic flight trajectory, though the orientation of the spear upon landing is variable

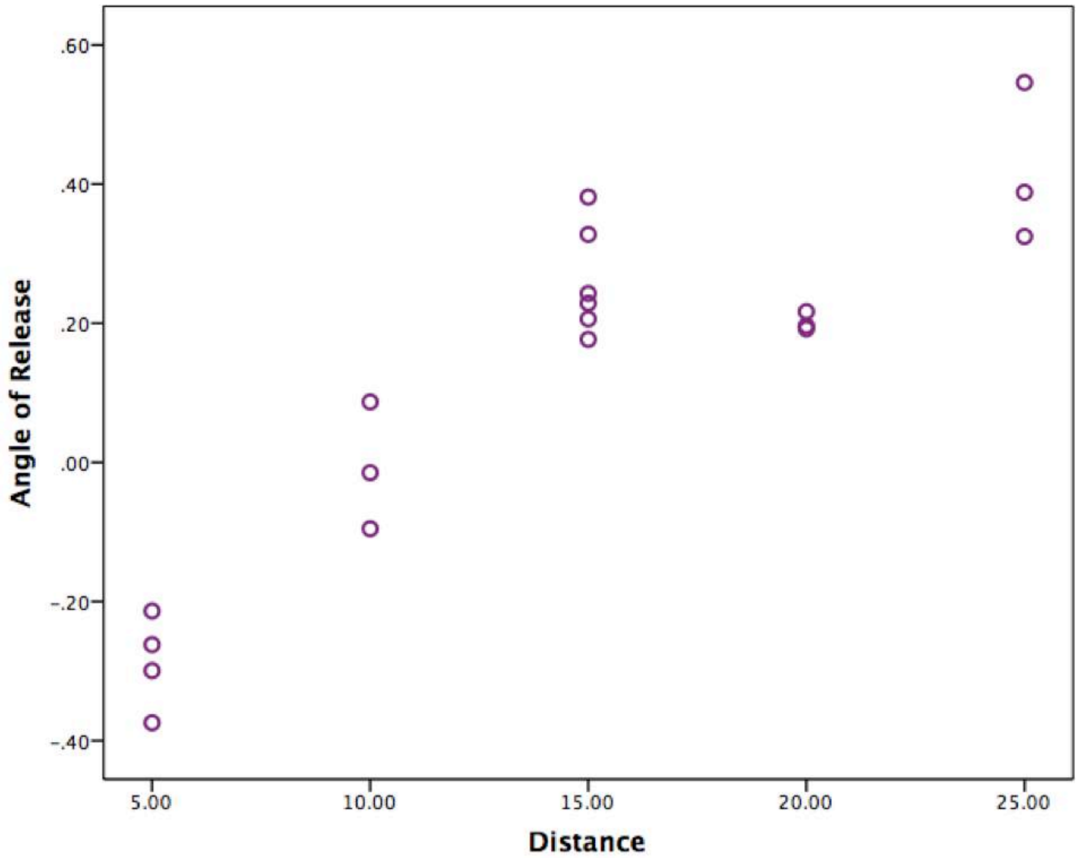

Figure 7.43. Angle (rad) measured in release video footage, separated by distance of targets

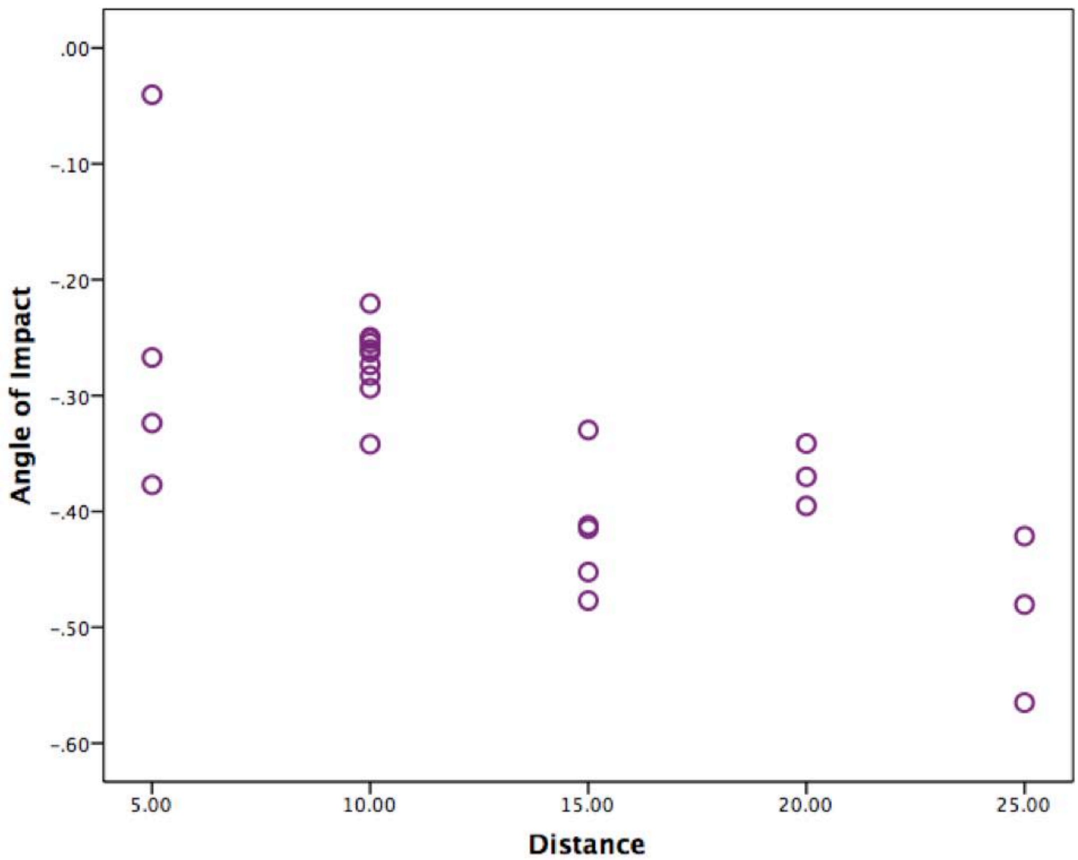

Figure 7.44. Angle (rad) measured in impact video footage, separated by distance of targets

At 5 m distance throws, the angle of release and impact fall within -.20 and -.40, ranging from --11° to -23° confirming that these throws follow a downward and flat trajectory (Figs. 7.43 and 7.44). By 10 m and beyond we can see an inverse relationship between release and impact angles, with angles increasing upwards at release, and decreasing by impact. These results show a clear correlation between release and impact angles, reflecting a shift from flat flight trajectories at close distances to parabolic trajectories at the farther distances. The maximum release angle is .55 rad, which is a 35° angle, corresponding to a 25 m throw. Impact angles ranged from -.57 rad to -.04 rad, translating to impacts between -33° and -2°. The largest impact angle occurred for a 25 m throw (miss), while the lowest impact angle occurred for a 5 m throw (hit). Fig. 7.45 shows schematic drawings of flight trajectories.

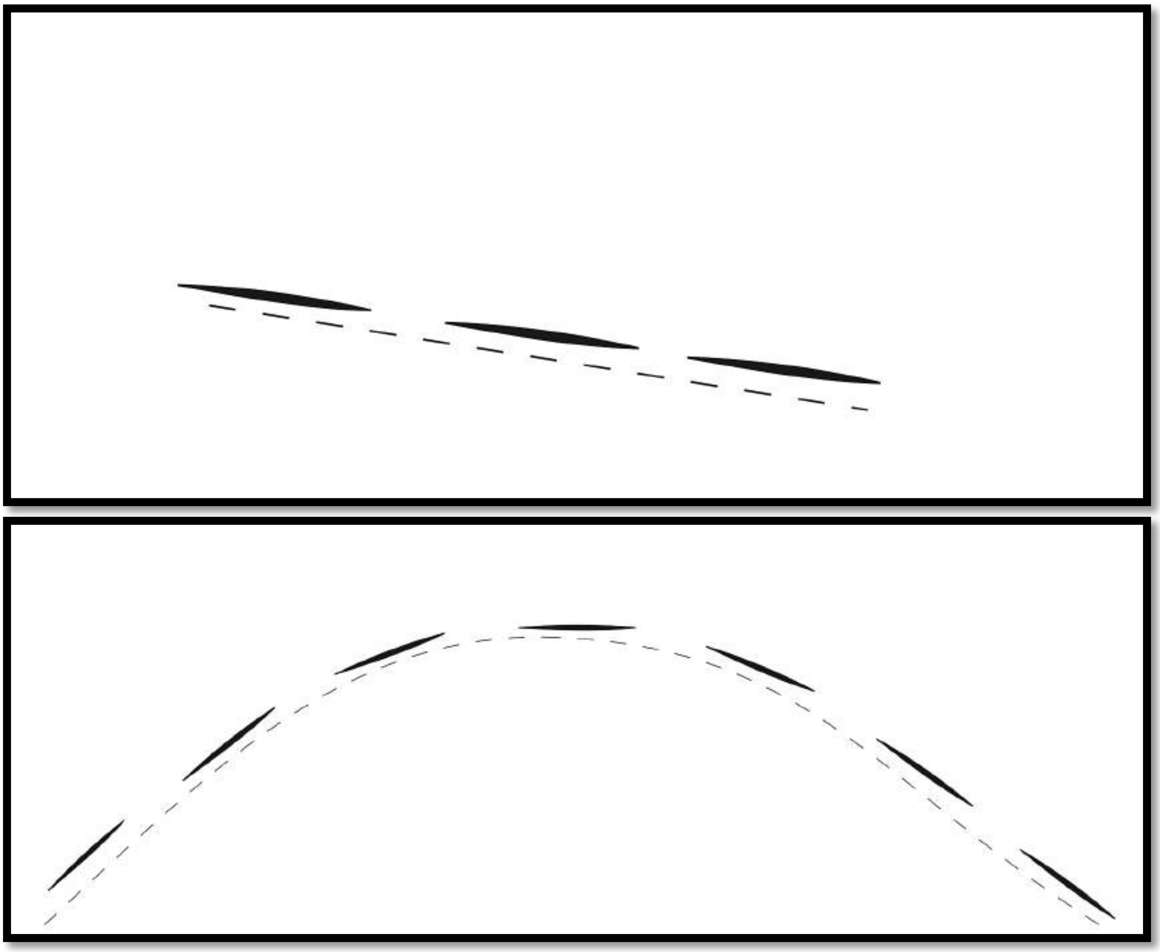

Figure 7.45. Top: schematic drawing of flat flight trajectories, which occurred for 5 m throws. Bottom: schematic drawing of parabolic flight trajectories, which began at 10 m distances, with increased angles of release by each distance. Not all spears landed point first, regardless of trajectory.

Spears oscillated in flight and upon impact with the target, with this visible in the HSV footage (Videos 7.4 and 7.5). Spears were also seen to spin in flight (Video 7.5), a result of the thrower imparting spin in order to stabilise the flight. Javelin athletes reportedly spin Olympic javelins between 19 and 24 revolutions per second (Terauds 1975) and this technique was potentially practiced by the Tasmanians when hand-throwing spears as well (Roth 1890, p.71). Examples of every possibility in terms of how the spear landed are seen in video footage. Of the 25 suitable target impact videos (including both hits and misses), 84% (n = 21) landed point first, 12% (n = 3) landed rear first and 4% (n = 1) landed flat. In distances 20 m and beyond, both for target and distance throws, some examples of the spear turning completely distal-proximally can be seen, as well as an example of a spear falling completely vertically (Table 7.18). These throws would be unlikely to be successful in a throwing situation. The turning of spears in flight may reflect limitations of design, but could also reflect differences in flexibility of the material and a lack of familiarity with this design feature. This is discussed further below in 7.3.4.3.

7.3.4 Discussion of human performance throwing trial

7.3.4.1 Velocity

Results of the impact velocities in the experiment largely confirm both estimates and recorded velocities presented in Tables 7.3 and 7.4. Hughes' (1998) mean of estimates of 17.8 m/s is similar to the mean achieved here (17.26 m/s for all throws combined). However it is worth noting that those estimates were primarily based on velocities from studies using spearthrower darts with much lighter masses (166 g - 186 g), with energies estimated as between 17 and 28 J. Considering the extremely light mass of spears for those estimates, associated throwing velocities should be higher according to the principle that the greater the mass of an object, the greater the work to propel that mass (Toyoshima & Mitsumasa 1973). It seems clear that the low velocity estimates in previous reflects a combination of the lack of skill of the participants throwing those spears, the unsuitability of spearthrower darts to be thrown by hand, and/or estimate errors.

A further significant finding from recording impact velocities is that the range captured may well overlap with velocities recorded for other prehistoric weapon technologies. Previous publications have suggested velocities of over 60 m/s for spearthrower darts, with much variability (Hutchings & Brüchert 1997; Whittaker et al. 2017). By recording spearthrower velocities over many years by a large number of participants, Whittaker et al. (2017) are skeptical that spearthrowers would have achieved velocities much beyond 35 m/s. While the majority of the impact velocities from the current trial fall under 20 m/s, three throws exceeded that, and that is with a relatively heavy spear. Elite javelin athletes are capable of release velocities of over 30 m/s (Table 7.3), resulting in distances >80 m, far exceeding ranges reportedly thrown by the Tiwi and Tasmanians (Spencer 1914, p.365; Roth 1890, p.71). If the increase in velocities from release to impact is supported by further experimentation, the kinetic energy of such throws can be considered to be extremely high compared with spearthrower energies. Taking into account release velocity measurements from other publications on javelin throwing using javelins of similar masses to the replicas used here, and the current findings here that impact velocities do not show a loss from release velocities, it is clear that there is overlap of impact velocities of hand-delivered spears and spearthrown spears. Running prior to release, which was not undertaken in the present study, would likely further increase release velocities. Prehistoric weapon systems look increasingly unlikely to have discreet velocity brackets, with higher hand-thrown spear velocities overlapping with complex projectile velocities. With relatively high mass and overlapping velocities, the KE, which is the factor that influences both terminal and wound ballistics, exceeds those of complex projectiles. This finding is significant for those looking to experimentally identify fractures to lithic points on the basis of discreet categories of weapon delivery systems. Further studies exploring the extent of this overlap would help in designing controlled experiments and assessing previous experimental results.

The higher variability of impact velocities compared with release velocities reflects the numerous additional factors acting upon the spear during flight, including the angle and direction of projection, the resulting flight trajectory, wind and drag. Other studies have also found interindividual as well as intraindividual variability (e.g. Viitasalo et al. 2003) a result of the complex interaction of individual performance, release velocity and aerodynamic parameters. The two highest velocities recorded in the present trial are outliers, and indeed removing them results in a normal distribution for impact velocities. However, these are measured results with spears in distance throws landing point first, and could have been successful thrown into a herd of animals from a distance. Furthermore, it is suspected that such velocities as these highest values are not unreasonable given other published results of release velocities, the height achieved in the throws, and gravitational forces accelerating the spear downwards. Finally, hypotheses that heavy hand-thrown spears rapidly lose velocity and therefore KE in flight has not been supported by this trial, with overall slight increases in velocity from release to impact.

7.3.4.2 Effective distance

This trial confirmed that farther distances make a target more difficult to hit with hand-thrown spears. There was a steady drop by distance, and no throws at 25 m resulted in a hit. Participants in this study were able to hit the target at 15 m and 20 m, though logically less easily than at 5 m and 10 m distances. While they could achieve distances of over 30 m, our participants were not able to successfully hit the target beyond 20 m. Their inability to hit a target at farther distances may relate in part to their inexperience with target throwing and potentially also to target height. With practice and/or with higher targets it is expected that this would improve rapidly. This point is supported by the fact that with the same size target and the replicas of the same spears, the participants in this study, who are experienced in throwing but not necessarily at hitting targets, had an 11.4% improvement at the 15 m distance (25% hit rate) over the untrained participants in the experiment that Churchill describes (13.6% hit rate) (2014, p.63).

Based on the results of ethnographic review in Chapter 6, in the hands of throwers trained to hit targets, accuracy of hand-delivered spears can be estimated as greater than the results from this study. Aimed throws at distances from the ethnographic literature of those highly skilled in throwing, ca. 20-40 m, would be compatible with all of the hunting strategies outlined in Chapter 2 (section 2.2.3.1), depending upon the distance chosen, the terrain, prey size and behaviours, and other factors. Although where possible it is likely that hunters would approach as closely as they could, greater distances than those typically cited for hand-thrown spears were likely utilized in the past. At the shortest distances, straight throws at the target would be an effective technique, and would have impacted with significant kinetic energy. An additional strategy not often considered would involve non-aimed distance throws with a larger group of hominins, each possessing a number of spears, approach hunting at longer distances of around 25-30 m, throwing a volley of spears at a herd of prey. As these distance throws have been shown here to achieve significant impact velocities and therefore KE, this would likely prove a successful hunting strategy, particularly if the herd were already disadvantaged in some way by a landscape feature such as a cul-de-sac or a lake shore. This demonstrates hand-throwing spears to be a flexible hunting weapon. The data from this trial, combined with ethnographic data of groups who only used hand-delivered weaponry, provides revised estimates of effective distances.

7.3.4.3 The mechanics of wooden spears in flight

The orientation of the spear in flight (point up, flat or down) affects aerodynamic lift, which in turn affects the distance achieved. Because Olympic rules do not dictate that javelins need to land with the point sticking into the ground, but just rather that the point lands before any other part, the design of Olympic javelins are clearly not optimised for hunting. Throwing spears designed for hunting would need to hit the target point first in order to penetrate - at whatever angle, whether from above the animal, or from the side. However, any part of a spear hitting an animal at a velocity of ca. 30 m/s may very well stun an animal for long enough for a hominin to approach closer to for subsequent throws. Flight paths assessed to have a 'rating too low' or 'angle of attack too high' (Johnson 1987 p.8) would prove more effective in hunting scenarios than a flight rated 'perfect' for javelin throwing.

Olympic javelins were made of wood until the 1960s, with the Finnish birch javelins thought to represent optimal stiffness, limiting vibration in flight (Johnson 1987 p.7). Today, javelins are 'distance rated', i.e. designed to match the thrower's ability (Johnson 1987 p.21), with flexibility and weight distribution as key factors (Johnson 1987 p.17). Lower distance throwers use more flexible javelins, rendering them more stable in flight, while elite throwers use javelins with little flex, limiting the vibrations in flight. The reason for this is because more powerful throws will impart significant force on the javelin itself, increasing vibrations which in turn affects aerodynamics. The athletes in the current study observed that the spear replicas were much more like the higher distance rated javelins used by elite athletes in terms of stiffness. This could explain in part why many of the throws twisted and turned in flight, and fell either flat or with the proximal end first. It is interesting in light of previous discussions on wood selection to at least consider the possibility that hominins were aware of the flexibility of the wood chosen, making design choices optimising flight. Other design features of Olympic javelins that are important to consider include the centre of gravity. A redesign of the javelin in the 1980s aimed to make the sport safer, and most significantly included moving the centre of gravity 40 mm towards the distal end, and increasing volume behind the centre and limiting flight (Johnson 1987 p.17).

In ‘free-style’ events javelin athletes used to use a variety of throwing techniques, including holding the javelin at the rear and propelling it (Johnson 1987 p.6). Current rules are much more restrictive in terms of technique, but it is important to recognise that there are multiple throwing techniques that may maximise different aspects of flight or biomechanics. If these different throwing techniques utilise the shoulder in different manners, it will be important to view spear throwing in a more dynamic light, similar to the variability possible in spear thrusting techniques discussed in this and the next chapter.

7.3.4.4 Early spears as throwing weapons

The results presented in this trial confirm previous papers that demonstrated that Schöningen Spear II was capable of flight, of landing point first into a target, and of achieving significant KE. The results here expand upon the limited research available, providing further data on velocities, kinetic energy, effective distances, and flight trajectories. Differing designs will vary the results of this study, and this should be considered in interpretations of hand-thrown weaponry. Photographic and video footage confirm that the spears can be thrown with both flat and parabolic trajectories, depending upon the release angle and velocity, which the participants adjusted according to distance. Ethnographically, both light and heavy spears were thrown by hand (Noetling 1911; Spencer 1914), and the Schöningen spear II replica is only slightly heavier than the mean mass of wooden spears studied in museum collections(Table 6.5). The kinetic energy at impact would be relatively high, particularly for the higher velocities thrown at distance. Together the results demonstrate the efficacy of Schöningen Spear II, and by extension many of the other spears from Schöningen, as hand-thrown hunting weapons.

7.4 Summary of human performance trials of hand-delivered wooden spears

The primary purpose of these human performance trials was to evaluate previously reported data on hand-delivered weaponry utilised for replication experiments of these delivery systems. It was deemed essential to establish a better understanding of these relatively poorly-researched weapons in order to design the Phase 2 spear experiments presented in Chapter 8. Both trials resulted in the following general observations:

1. High variability when using humans, even when using trained participants, who have all received similar training in an activity.

2. The importance of using trained participants if launching by hand (vs. mechanically) in experimental research.

The results of the two trials can be summarised as the following statements:

1. Impact velocities in two-handed spear thrusting are faster than those proposed by Schmitt et al. (2003) but slower than those replicated by Wilkins et al. 2014a; Wilkins et al. 2014b). They correspond fairly well with knife stabbing.
2. Impact velocities and peak forces correlate poorly for two-handed spear thrusting, revealing the complexity of this weapon system, and the need to replicate the entire thrusting event, as peak forces occur after impact.
3. The effective distance of hand-thrown spears in the trial can be considered to be ca. 15-20 m on the basis of participants who are trained to throw, but not to hit targets. However what percentage is considered 'accurate' requires further study, including comparative studies with complex projectiles.
4. Overall, there is are slight increases in velocity from release to impact for hand-thrown spears, and they are capable of high impact velocities of over 30 m/s distances.
5. Impact velocities from two-handed spear thrusting and hand-thrown spears do not appear to overlap, potentially facilitating a distinction between these weapon systems. This hypothesis requires further testing. How energies compare remains poorly understood.
6. Adding years (rather than hours or even a few months) of experience clearly greatly improves performance of hand-delivered spears, and thus estimates based on inexperienced users - whether these are ethnographic groups mostly using other weapon delivery systems or untrained modern-day researchers - must be re-evaluated, and further trials should be undertaken.

The limitations in our understanding of MP hominins' physiological capacity for these two weapon systems remains a problem for those seeking to replicate the earliest weapon systems. Furthermore even trained participants to which experimenters have access today are only proxies for humans in the past who were designing, making and using weapons for survival, regardless of species. These limitations always need to be taken into consideration. With limited understanding of the biomechanical capabilities of earlier species of *Homo*, we have to make large assumptions that earlier species had broadly equal and similar physiological and cognitive capacities pertaining to weapon use. Continued research into these questions by palaeoanthropologists, both in relation to biomechanics and the fossil record are welcome and necessary. On the other hand, experimental archaeologists need to consider whether to account for human variability. Replicating a mean statistic, e.g. for impact velocity, superficially suppresses human variability, risks masking potential outcomes, and has the possibility of creating false taxonomies. A clear example of this is the overlap between velocities captured for hand-throwing spears with those from human performance studies on spearthrower use (e.g. Whittaker et al. 2017).

As per the model for the cycle of experimental research presented in Appendix 2 (Fig. A.2.1), the archaeological data led to testable research questions about hand-delivered weaponry, including those pertaining to performance parameters. Better demonstrating these facilitates experimental studies, such as those presented in Chapter 8, which are aimed at evaluating the archaeological record. The resulting data were evaluated and compared with previous studies, with some outcomes supporting and others rejecting estimates and hypotheses pertaining to performance. The results have generated further research questions that that are outside the scope of this PhD to directly test, and are outlined in Chapter 9. In conclusion, the results from these trials confirm the need for further human performance studies in prehistoric technologies in order to evaluate potential overlaps in parameters, in particular velocities. The results here form the basis to develop a robust approach to understanding the complex interaction between humans and the earliest weapon systems.

Chapter 8. Experimental approaches to wooden spears: lethality, equifinality, and the Pleistocene archaeological record

> *A fourth question is directed to any who would discount the very idea of large mammal hunting with wooden spears by Pleistocene Homo: How can science ever determine when this behavior actually began, if we allow our investigations to be guided by ideology rather than evidence and if we do not ask such provocative questions and then explore ways of answering them?*
>
> \- Bunn & Pickering 2010, p.403

8.1 Introduction

Evaluating lethality of the earliest weaponry, one of the primary objectives of this thesis, must take into account empirical data from experiments that are driven by questions about the archaeological record. This includes the archaeological wooden spears presented in Chapter 4 which were contextualised with ethnographic data in Chapter 6, and the potential hunting lesions presented in Chapter 5. After establishing performance parameters of a replica of a representative MP wooden spear (Chapter 7), this chapter directly addresses questions about the lethality of such spears. The experiments presented in this chapter broadly aim to address the question of lethality from three different viewpoints. Because questions of equifinality around potential hunting lesions from this period have not yet been addressed, and due to the large size and unclear nature of the curvilinear fractures on the Boxgrove and Swanscombe scapulae, an experiment exploring hammerstone percussion damage on scapulae is presented (8.2). A separate but relevant assessment of lethality relates to the design of the tip of the weapon, which is a key aspect of penetration of any sharp force weapon (Hughes 1998). To assess variation in tip design and relate this to the distal points of archaeological spears, schematic spear points were designed and 3D printed, and are used in free-fall impact drop tests to evaluate relative differences in penetration due to tip design (8.3). Section 8.4 makes use of data established in Chapter 7 experiments and uses replicas as thrusting and hand-thrown spears on horse carcasses. These final experiments investigate the terminal and wound ballistics of wooden spears, including Depth of Penetration (DoP), damage to spears (Appendix 1), and resulting hunting lesions. Section 8.5 makes meaningful links between the resulting bone damage from the experimental work (8.2, 8.4) with the proposed MP archaeological hunting lesions and a selection of previously published experimental and archaeological data on hunting lesions and carnivore damage. The final section (8.6) summarises and draws conclusions from all of Chapter 8.

8.2 Actualistic experiment: hammerstones and horse scapulae

8.2.1 Introduction: background and experiment questions

An actualistic study using hammerstones to impact horse scapulae was designed to address the potential for equifinality in determining the likely cause of curvilinear damage to the Boxgrove and Swanscombe scapulae. To briefly recap the evidence presented in Chapter 5, these two scapula represent the only potential lesions that have been identified from the entire MP, and thus their interpretation as such is key to evaluating hominin subsistence behaviours during the period. One issue that has been pointed out before (e.g. Gaudzinski-Windheuser 2016) is that of equifinality. There has been a single experimental study explicitly evaluating hunting lesions resulting from hand-delivered wooden spears (G. Smith 2003) and the possibility of alternative causes for damage to these two scapula is also understudied. While there is no direct evidence of weaponry at Boxgrove, there is direct evidence for the use of the hammerstones, including unmodified beach cobbles, cortical flint nodules with clear evidence of battering, anvils, and percussion impact notches on the large mammal remains (Austin et al. 1999; Parfitt & Roberts 1999). Stone tools, including both modified and unmodified hammerstones, used for percussion activities to open bone for marrow and/or grease extraction have been documented from the Early Pleistocene (e.g. Bunn 1981; de Heinzelin et al. 1999; Domínguez-Rodrigo et al. 2005) through to recent hunter-gatherer groups (e.g. Binford 1978; O'Connell et al. 1988). Most hammerstone percussion studies have focused on long bones which contain the highest quantities of marrow (Binford 1978; Blumenschine & Selvaggio 1988; Blumenschine & Madrigal 1993; Capaldo & Blumenschine 1994; Pickering & Egeland 2006; Galàn et al. 2009), while the characteristics of percussion damage to flat bones are less well understood.

Combining the evidence for the use of hammerstones to access within-bone nutrients with the large dimensions of the Boxgrove lesion, it is necessary to test whether hammerstone impacts could have led to the lesion on the Boxgrove horse scapula fragment. The study follows experimental protocols primarily developed in research concerned with hominin butchery patterns, aiming to distinguish human bone modifications from taphonomic damage (Blumenschine & Selvaggio 1988; Galàn et al. 2009).

The research questions informing the experiment design are:

1. Can impact from a lithic hammerstone on a horse scapula create curvilinear fractures?
2. Does such damage likely result from a single or from repeated impacts?
3. Are there any macroscopic or microscopic characteristics of hammerstone damage to flat bones that may distinguish it from weapon damage on flat bones?
4. Are there overlapping damage characteristics between hammerstone and weapon impacts?

5. What are sizes of any fractures and perforations?

8.2.2 Materials and Methods

8.2.2.1 Scapulae

The sample consists of six scapulae from adult horses that died a natural death. They were obtained from the Royal Veterinary College (Hatfield, Hert, UK), with no known health conditions affecting the bones and ethical clearance for research purposes. The scapulae were disarticulated with metal tools, with surrounding soft tissues including muscles and cartilage adhered. All bones were frozen immediately, and were thawed out over a period of 24 hours before the experiment within 6 weeks after freezing. Bones frozen for less than four weeks and then thawed retain a good ‘Freshness Fracture Index’ (Outram 2001; Outram 2002). Each scapula was assigned an event number (eg IMP 1 = Impact Event 1). Unretouched flint flakes were used to remove muscle mass but periosteum was not removed.

8.2.2.2 Stone tool materials

Flint hammerstones were collected from Sussex beaches and countryside, and consisted of two types: rolled beach cobbles and cortical nodules (Fig. 8.1, Table 8.1). An anvil was provided, consisting of a cortical flint nodule, measuring 273 mm x 175 mm x 162 mm. The anvil was used in every percussion impact event.

Figure 8.1. Two of the hammerstones selected in the study. Hammerstone 16 (Left) is a cortical flint nodule, Hammerstone 23 (Right) is a rolled flint beach cobble

8.2.2.3 Human Participant

A healthy adult male with no known shoulder or arm conditions was selected as the participant and wore gloves throughout to protect his hands from injury. He was selected according to stature (height: 1.83 m, mass: 90 kg) to replicate the estimated size of the Boxgrove hominin. Ethical approval was waived by UCL as the participant was not a vulnerable individual. The participant was verbally briefed, provided signed informed consent and was aware he could withdraw at any stage of the work without penalty.

Table 8.1. Measurements of hammerstones used in percussion impact events

IMP	Hammerstone number and type	mass (g)	length (mm)	width (mm)	thickness (mm)
1	023, rolled flint beach cobble	716	97	93	54
2	014, rolled flint beach cobble	909	140	73	69
3	024, rolled flint beach cobble	716	97	93	54
4, 5, 6	016, cortical flint nodule	481	93	70	61

8.2.2.4 Experimental setup and data collection

Each scapula was impacted with a hammerstone selected by the participant from the sample provided, with only one hammerstone permitted per impact event (Table 8.1). The anvil was used in all impact events. Scapulae were always impacted on the lateral side, with the medial side resting on the anvil (Fig. 8.2). The participant was requested to impact the blade of each scapula with the aim of exposing the inner cancellous bone, containing liquid grease and marrow. It was not the aim to pulverise bone but rather to investigate the possibility of curvilinear fractures and/or perforations resulting from intentional impact with hammerstones, and impact events ended when evidence for either appeared. In addition to hammerstone impacts the participant occasionally used wrenching motions to break apart sections of bone or cartilage, which is known ethnographically during both butchery and marrow access (Oliver 1993, p.208 and p.212).

Figure 8.2. Hammerstone study setup

Scapulae from IMP 1 through 5 were cleaned using gentle maceration using enzymatic detergent. Scapula 6 was buried for 14 months in calcareous soil at a depth of .5 m for comparative purposes. Each scapula was labeled by its impact event with an additional number per element/fragment (eg IMP 1/1 = Impact 1, fragment 1).

8.2.2.5 Data analysis

A DinoLite Pro HR (AM7000/AD7000) digital microscope with an internal camera was used to document and photograph microscopic damage. Microscopic analysis and imaging with a scanning electron microscope (Hitachi S-3400N VPSEM) was also undertaken. Methods for quantitative and descriptive analysis follow those described in Chapter 5.2.

8.2.3 Results

Of the six scapulae impacted by the participant, four bear perforations, either with a curvilinear fracture (IMP 1, Fig. 8.3) or complete perforations which are entirely or partly characterised by curvilinear fracture margins (IMPs 4, 5 and 6, Figs 8.4 - 8.6). Secondary damage includes crushing, hinging, cracking with radiating fractures, and flaking (Table 8.2). Flakes of cortical bone were separated from the scapula in several cases, particularly medially. No embedded stone was observed. All primary damage resulted from multiple impacts to the same site, suggesting that any such damage resulting from hammerstone percussion would likely be intentional. Primarily the rims were jagged, with the exception of part of IMP 6 (Table 8.2).

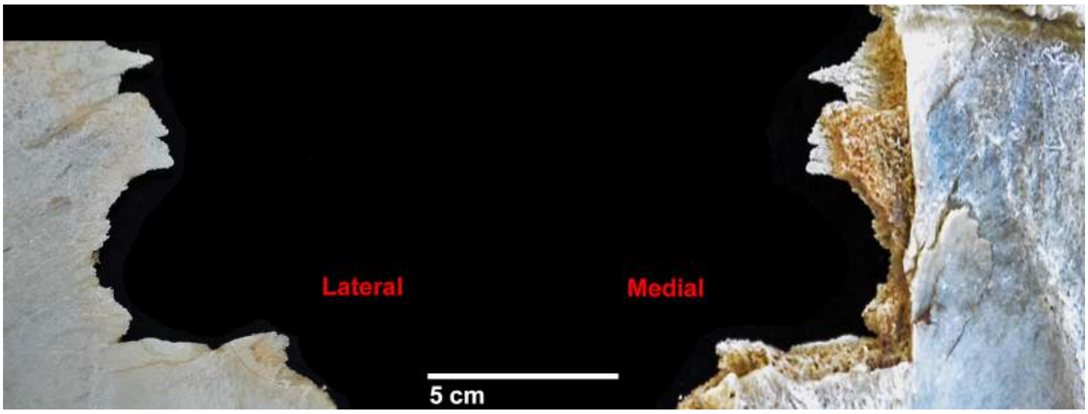

Figure 8.3. Impact 1. Left: lateral, right: medial

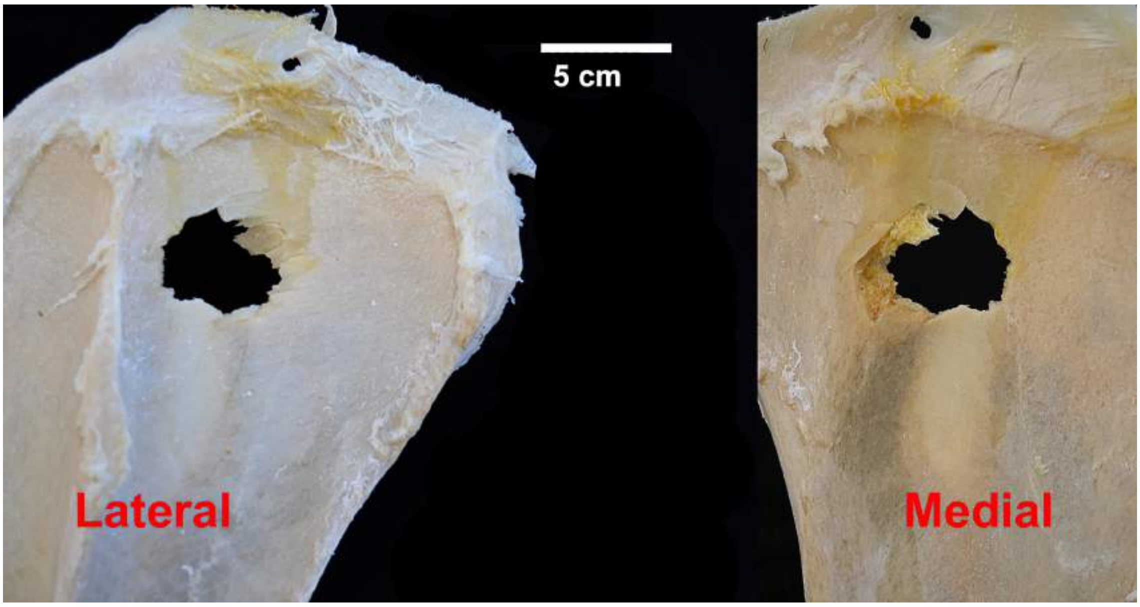

Figure 8.4. Impact 4. Left: lateral, right: medial

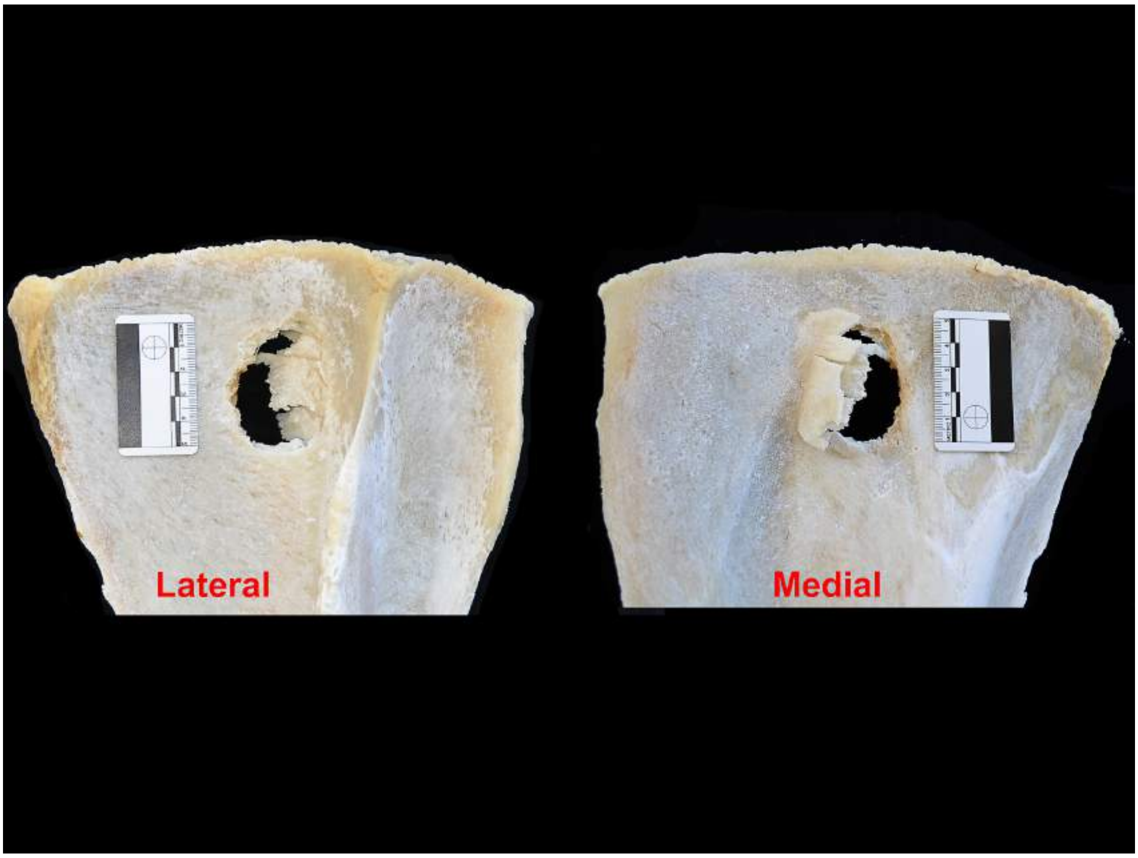

Figure 8.5. Impact 5. Left: lateral, right: medial

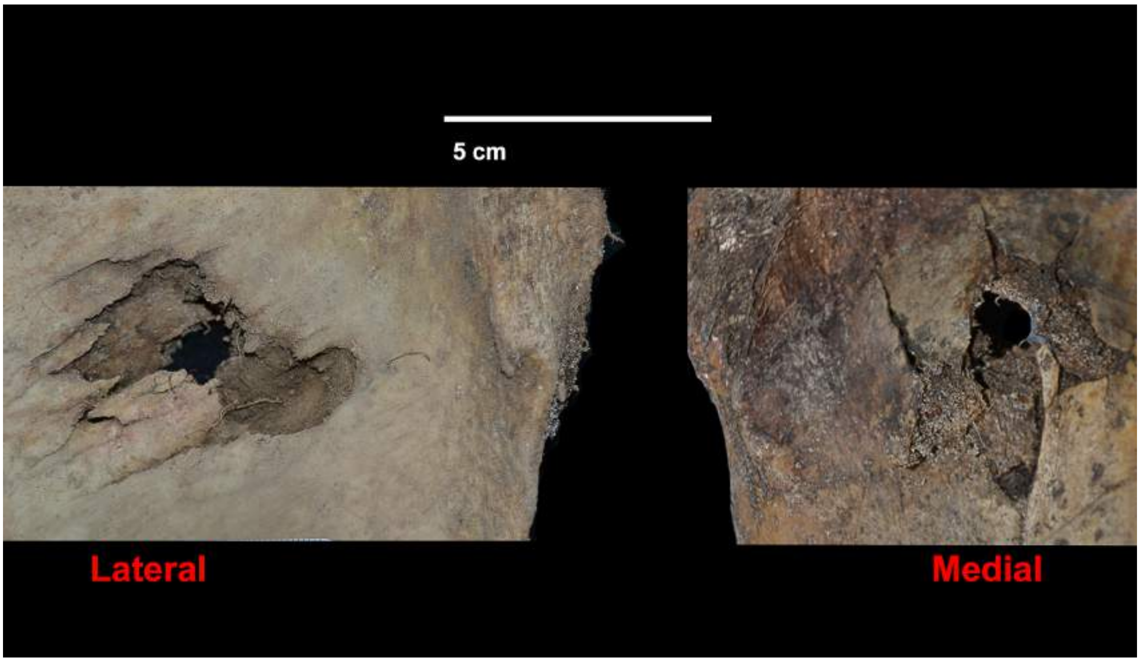

Figure 8.6. Impact 6. Left: lateral, right: medial

All experimental scapulae demonstrate internal bevelling, with impacts smaller on the entrance (lateral) side, and larger on the exit (medial) side, exposing cancellous bone medially. Dimensions of the damage, and bevelling ratios are presented in Table 8.3. Impacts 1, 4 and 5 have microscopic percussion marks around the impact areas (Figs. 8.7 - 8.9). Percussion marks of all three types were observed (Table 8.2), with marks observed primarily laterally and one example seen medially. No microscopic damage was observed on either side of Impact 6. It is possible that the alternative cleaning process used for Impact 6, which resulted in sediment adhering to the bone surface, affected the visibility of microscopic percussion marks. SEM analysis further illustrates some of the types of microscopic damage, including multiple overlapping microstriations around the edge margins of the impact sites which were less visible with the Dino-Lite (Figs. 8.10 - 8.14).

Table 8.2. Description of damage resulting from hammerstone experiment

Scapula	Primary Damage	Secondary Damage	Shape	Fracture Rim Characteristics	Microscopic Damage
Impact 1	**Lateral**: Curvilinear fracture **Medial**: Linear fracture	**Lateral**: cracking **Medial**: hinging, cracking (radiating), flaking	**Lateral**: curvilinear fracture **Medial**: linear fracture	**Lateral**: jagged **Medial**: jagged	**Lateral**: 1 pit with microstriations
Impact 4	Perforation	**Lateral**: Crushing, cracking (radiating) **Medial**: cracking, flaking	Circular but irregular	**Lateral**: primarily jagged **Medial**: primarily jagged	**Lateral**: 1 isolated pit
Impact 5	Perforation	**Lateral**: crushing, hinging, cracking **Medial**: hinging, flaking	Circular but irregular	**Lateral**: left side is sharp; top and bottom margins jagged; right margin jagged **Medial**: opposite pattern to lateral side	**Lateral**: 2 pits with microstriations; fields of isolated striations, focused around impact margin; 1 isolated pit
Impact 6	Perforation	**Lateral**: crushing, hinging, cracking (radiating), flaking, microflake **Medial**: hinging, cracking (radiating), flaking	**Lateral and medial**: Perforation circular, but surrounding damage irregular	**Lateral and medial**: jagged	None observed

Table 8.3. Measurement data and bevelling for hammerstone experimental sample

IMP	Length (longest axis, lateral side, mm)	Estimated Area (lateral, mm^2)	Estimated Area (medial, mm^2)	Bevelling	Bevelling Ratio
Impact 1	46	131.7	337.0	Internal	1 : 2.56
Impact 4	40	97.8	164.9	Internal	1 : 1.69
Impact 5	49	165.7	187.2	Internal	1 : 1.13
Impact 6	50	79.5	126.5	Internal	1 : 1.6

Figure 8.7. Pit with microstriations from Impact 1 at 50x magnification with the Dino-Lite

Figure 8.8. Isolated striae fields from Impact 5 at 50x magnification with the Dino-LIte

Figure 8.9. Isolated pit from Impact 4 at 50x magnification with the Dino-Lite

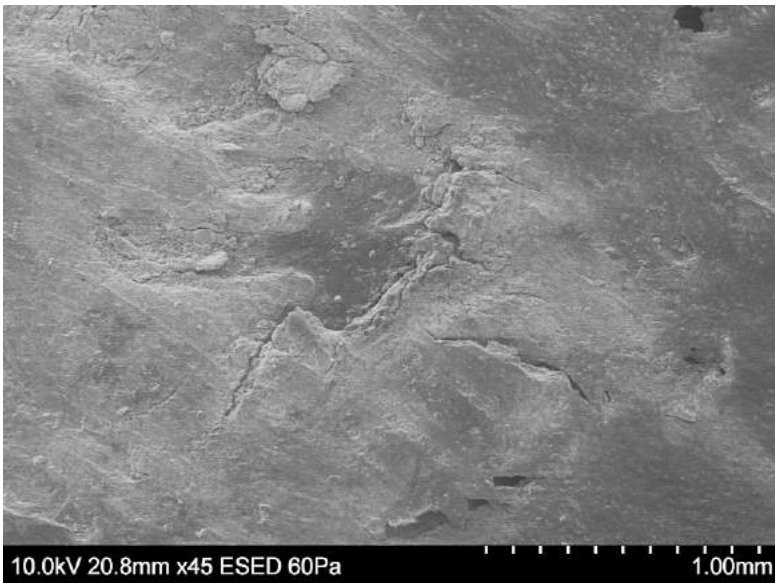

Figure 8.10. SEM image of Impact 5, showing an isolated pit. 45x magnification

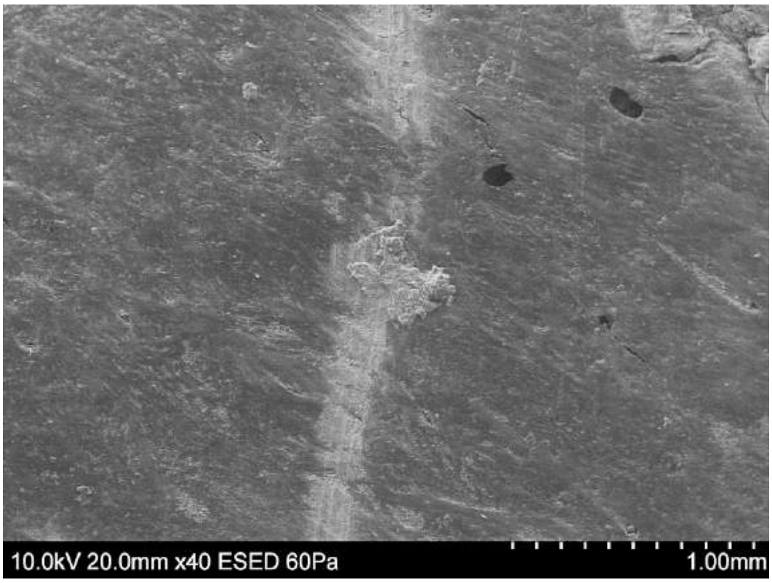

Figure 8.11. SEM image of Impact 5, showing a pit with microstriations, 40x magnification

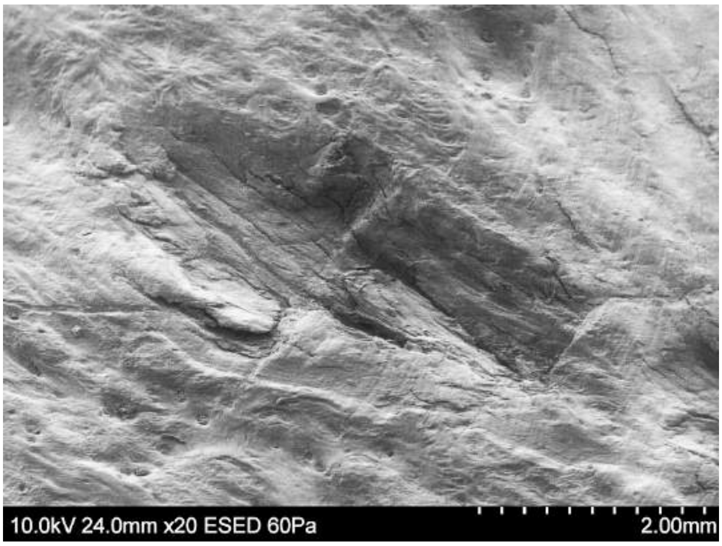

Figure 8.12. SEM image of Impact 4 pit, showing a particularly deep pit at 20x magnification

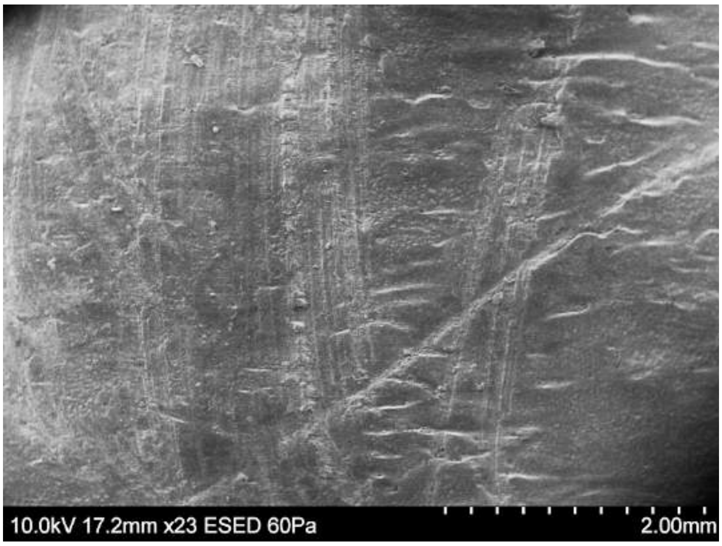

Figure 8.13. SEM image of Impact 5 showing Isolated striae fields at 23x magnification

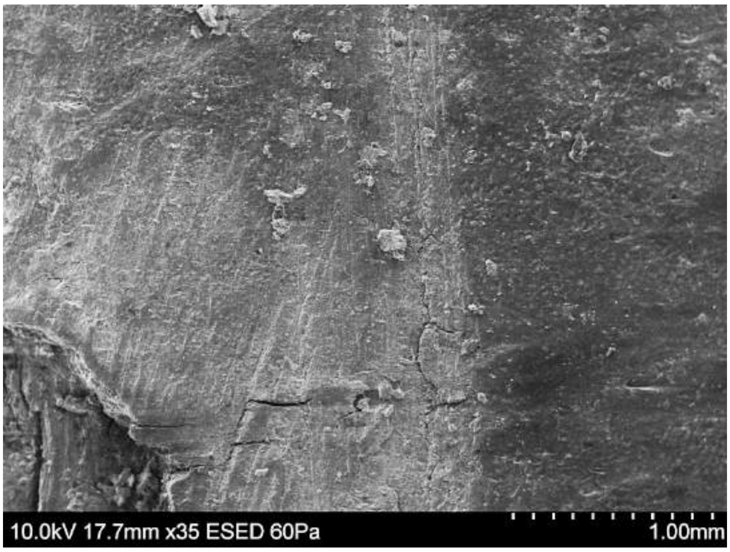

Figure 8.14. SEM Image of Impact 5 showing overlapping microstriations and sratches around the margin of impact site in the lower left corner

8.2.4 Discussion of hammerstone experiment

The data from this experiment demonstrated that there are areas of overlap between impacts from weaponry and hammerstones. Curvilinear fractures and perforations occurred on the blade where the pounding activties were focused and were the result of intentional and repeated impacts from cortical flint nodules and beach cobbles. The cortical nodule produced curvilinear fractures and perforations on all three scapulae impacted, whil the beach cobble only produced such damage in one out of three scapulae impacted. Cracking, crushing and hinging occurred on the impact side, while hinging, cracking and flaking occurred on the exit side. Margins were typically somewhat jagged, with some areas of sharp edge margins. Quantitatively the punctures and curvilinear fractures are relatively large, measuring from 40 mm to 50 mm on the longest axis. Microscopic impact damage occurred primarily on the side of impact and included isolated pits, pits with microstriations, and fields of isolated striations. This damage was easily observable for the scapulae cleaned with enzymatic maceration, but no damage was visible for the scapula cleaned in sediments; this tentatively suggests that taphonomic factors may obscure the visibility of such damage, but a larger sample size is necessary to better evaluate this. This possibility requires further experimentation with larger sample sizes. Internal bevelling was evident on each impact site as would be expected to generally occur from dynamic impacts. Overall this experiment confirms that perforations and curvilinear fractures with internal bevelling can result from repeated and intentional impacting of flat bones with hammerstones, a behaviour known ethnographically and inferred from sites throughout the Pleistocene. These behaviours tend to focus on long bones, which hold the largest marrow reserves, but are also known from flat bones, particularly when exploiting bones for grease as well as marrow (see 5.1.3.2). This is particularly possible in times of resource stress and/or when the animal exploited may be in poor condition with subcutaneous fat. While a single perforation to the middle of an otherwise complete or nearly complete scapula is unlikely to reflect hammerstone damage, as this would do little to expose available within-bone nutrients, when evaluating flat bone fragments with curvilinear fractures, such as the fragment from Boxgrove, this possibility should be considered. Section 8.5 will bring together the quantitative and qualitative analysis from Chapter 5, from this hammerstone experiment, and from the impact damage resulting from wooden spear impacts (8.4).

8.3 Spear Design: Controlled guided free-fall impact drop experiment

8.3.1 Experiment questions

Throughout the research of archaeological and ethnographic wooden spears in this thesis, morphometric analysis was undertaken, particularly focusing on the distal ends of the spears, in order to evaluate design. The design of the distal ends of wooden spears is significant for the research in this thesis because the ability of sharp-force weapons to penetrate a target at low velocities is reliant on the cross-sectional area and shape of the distal end of a weapon (Hughes 1998, p.350). Design of such weapons also balances the capacity to penetrate with the likelihood of breakage (Friis-Hansen 1990; Hughes 1998). A simple experiment was designed to test whether conical weapon points with small variations in distal diameter will have differing penetrating power.

The research question informing the experiment design is:

1. Leaving other variables such as point sharpness and mass constant, does penetration increase with a decrease in opening angle? (see Equation 4.2; Fig. 4.13)

The design of the experiment is a simplification of test procedures in stab and impact research (e.g. VPAM 2011) and was undertaken in consultation with Dr. Debra Carr at Cranfield University.

8.3.2 Materials and Methods

Using measurement data gathered from archaeological and ethnographic wooden spears, 3D schematic spear points were drawn using SketchUp 2016 (free version) (Fig. 8.15). Initially nine cones were designed with a height of 100 mm, and range of base radii, from 3.18 mm to 15.90 mm. The cones were initially printed on a EOSint P100 machine in nylon (PA2200 with a powder granule size of 40-50 μm). This material proved too elastic at the tip, and the cones were reprinted with a Formlabs Form 2 printer in resin which was stiffer but more brittle than the nylon (Fig. 8.16, left). Three cones with diameters falling within the observed archaeological and ethnographic range were selected, with slant angles ranging from 23° to 45° encompassing the range of slant angles calculated for archaeological wooden spears at 10 mm from the distal point, ranging from 27° to 41° (Tables 4.5, 6.6, and 8.4). Each cone was first weighed, then a metal bar was attached to the rear of each cone to ensure adequate mass, and Newplast™ plasticine was added to bring the total mass of each cone to exactly 180 g, ensuring that mass remained constant (Fig. 8.16, right).

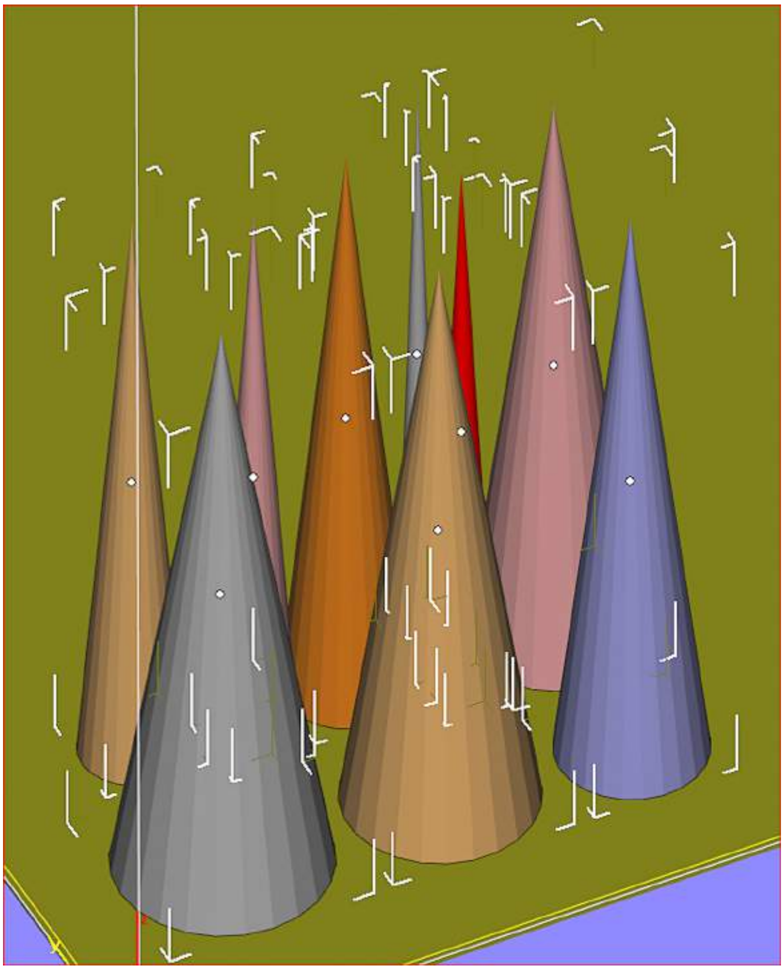

Figure 8.15. 3D cone drawings prior to printing

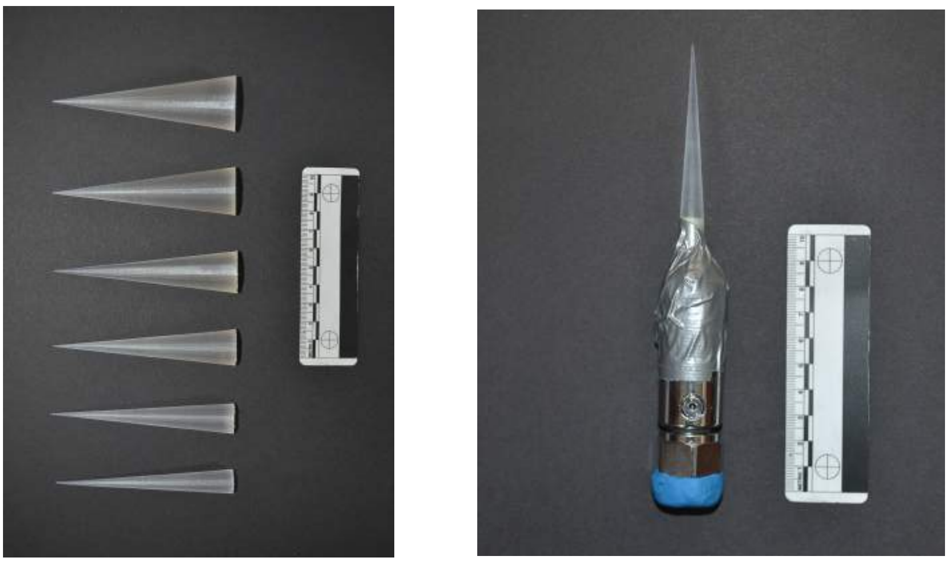

Figure 8.16. Left: A selection of the printed cones in resin. Right: A cone prepared for a drop, with added mass at the rear

Table 8.4 Measurement data for experimental spear cone prints

Print	radius at base (mm)	Slant height	Opening angle	mass*
3	6.4	100	7˚	5
6	11.1	101	13˚	15
7	12.7	101	15˚	20

***prior to adding mass with metal bar and plasiline. Final mass for all cones tested was 180 grams. Slant height and angles were calculated using the following website: Cleavebooks.co.uk/scol/calcone.htm**

A 2 m long plastic pipe with a 30 mm diameter opening was used to guide the drops, with holes drilled along the pipe to reduce air resistance and a plumb bob used to ensure verticality (Fig. 8.17). The total length of the drop was 2.1 m, to facilitate removal of the cones after each drop. Plastiline® (softness 40) was used as a homogenous target, with various clay mediums having a history of use in impact and armour research (National Research Council 2012). Cones were dropped 10 times each into Plastiline®, and for each drop, depth of penetration (DoP) into the Plastiline® was measured with a forensic scale.

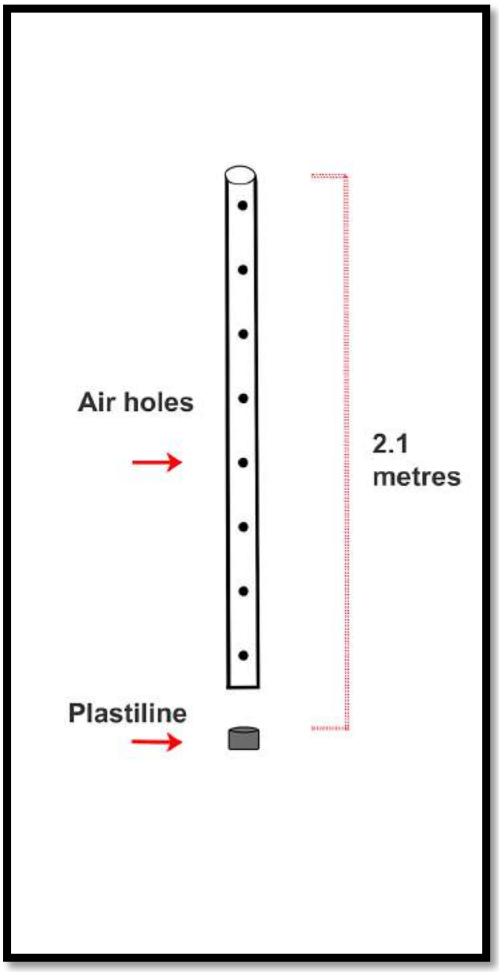

Figure 8.17. Schematic drawing of drop test setup

8.3.3 Results

The results indicate that there were differences in penetration into the Plastiline®. This supports the hypothesis that even small variation in the tip design of conically shaped wooden spears, and in particular its opening angle, affects the ability of a conical point to penetrate. The wider the angle, the less effective the point is at penetration. The spread between minimum and maximum DoP (2 mm) was the same for the three replicates (Table 8.5), and the means all fall in the middle of each spread (Fig. 8.18). There are no overlaps in DoP among the three cones. CV for cones 3 and 6 were both 1.8% while for cone 7 it was 2.5%, showing slight differences, but in all cases variation is low.

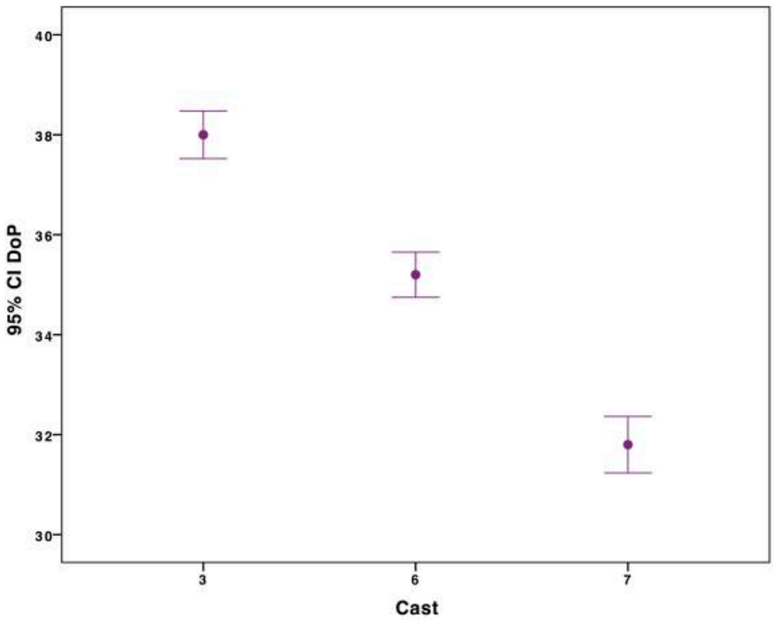

Figure 8.18. 95% confidence interval of DoP for each series of drops by cast

The thinnest cone slightly blunted upon its first impact with the Plastiline®, though this appears not to have affected the results of further drops, while the other two cones did not blunt at all. This suggests that blunting may have only a small effect on penetration, and that the diameter of a spear at the distal end may be a bigger factor than sharpness.

Table 8.5. Descriptive statistics of guided free-fall impact test

Cone	Mean DoP (mm)	Min DoP (mm)	Max DoP (mm)	CV	n
3	38.0	37	39	1.8%	10
6	35.2	34	36	1.8%	10
7	31.8	31	33	2.5%	10

8.3.4 Discussion

The results of this experiment confirm suggestions that point design is an important factor in penetration, even for a simple shape such as a conical point. Narrower tips facilitate penetration, resulting in more effective penetration. On the other hand, narrower tips are also likely to incur more damage, both from blunting and breaking, potentially inhibiting further use until the tip undergoes resharpening (see further exploration of this phenomenon in 8.4). The design of a given point could reflect design choices that are matched to prey. Two possible factors include matching the diameters to the rib spacing, alongside matching robusticity to a prey's hide, muscle and fat thickness. As Hughes (1998, p.347) stated, 'Trade-offs in performance characteristics lead to variability in artifact design'. Thus, although others have suggested that the robusticity of wooden spears from the archaeological record reflect delivery methods, this design feature could also relate to the prey that the weapon was designed to target whether for hunting or self-defence. The different effects of conical weapon tip designs on breakage and penetration in hunting contexts could be tested using a series of controlled experiments, including testing breakage of varying wood species and condition, and the effects of variables such as hide, muscle and fat thickness on penetration at varying energies.

8.4 Experiments using wooden spears on horse carcasses

8.4.1 Introduction

8.4.1.1 Background and experiment questions

As has been discussed throughout the thesis, a fundamental goal is to explore the performance of wooden spears, with a particular focus on addressing whether the weapons are viable for large mammal hunting. Research trends discounting this viability have been strong, but as argued in previous chapters this characterisation has not been underpinned with objective datasets. The experiments here explicitly use results from Chapter 7 rather than often-used estimates of hand-delivered spears in their design, and any resulting damage will be compared with the actualistic study of hammerstone use. Bringing the various research approaches together in this way greatly improves the confidence of interpretation of MP wooden spear usage and any potential bone damage.

A few experiments have been undertaken to address the hypothesis that stone or osseous tipped weapons have functional advantages over plain wooden or hafted wooden-tipped weaponry. Guthrie (1984) experimented with a variety of organic projectile points including wood, bone and antler (ca. 500 g), firing them at unknown velocities on a moose carcass. The wooden spears penetrated the moose, with a mean DoP of 142.5 mm (n = 32). Comparing breakage of the wooden weapons combined with 'lethality', Guthrie concludes that wood is less effective than the other organic weapon materials tested. Waguespack et al. (2009) tested wooden arrows vs. lithic-tipped arrows on ballistic gelatine (concentration unreported) at bow/arrow velocities, concluding that lithic-tipped arrows penetrate slightly farther than wooden arrows. Wilkins et al. (2014a) built upon this by testing untipped wooden spears vs. lithic-tipped spears at hand-delivered velocities (though see Chapter 7), also on ballistic gelatine, and measured inner wound cavities as well as DoP. That study, testing spears at velocities that fall between thrusting velocities and hand-throwing velocities, concluded that while wooden spears penetrate further than lithic-tipped spears, the permanent damage tracts created by lithic spears were more substantial; the authors suggest this supports the hypothesis that the innovation of hafting provides a functional advantage. However, the lithic points used in that study are wider than the wooden points they used, and this morphometric difference is not accounted for in the study. Wide-bladed wooden spears are also known from ethnographic collections (pers. obs.), with a possible archaeological example of a wooden tanged point (Gaspari et al. 2011). The hypothesis that it is related to hafted material rather than shape of weapon point therefore requires further testing. Of the three studies, Wilkins et al. (2014a) provide important data for comparing their use of of ballistic gelatine (~11% concentration by mass) with the animal carcasses used in the present study, although it is necessary to take into account the difference in firing velocities to the experiments presented below (7.8 m/s - 10.3 m/s). Their results had a mean DoP of 220 mm for untipped wooden spears when fired at the above velocities into unmodified gelatine, but unfortunately the replicated velocities are faster than those captured in the human performance thrusting trial (Chapter 7), and do not account for energy of the entire thrusting motion. Finally, Salem and Churchill (2016) conducted an experiment testing lithic-tipped vs. wooden tipped arrows at bow/arrow velocities, again into unmodified ballistic gelatine (10% concentration by mass). They measured DoP as well as volume of gelatine affected. Similar to Wilkins et al's (2014a) study, their conclusions are that there is a functional advantage of tipping a weapon with a lithic point, as they produce greater permanent damage tracts and therefore may produce larger wounds, with the study having similar limitations for evaluating hand-delivered wooden spears, in particular impact velocities which do not relate well, differences in morphology of weapons, and the lack of modification of gelatine. Rieder (2001) conducted an experiment using a male javelin athlete to hand-throw a replica of Schöningen spear II (500 g) into unmodified ballistic gelatine, resulting in penetration depths of 225 mm - 250 mm (mean = 238 mm; n = 10). As was discussed previously (3.2.4.2), there are both advantages and limitations to using ballistic gelatine as a target, and it should not be used to represent likely DoP into an animal, particularly in an unmodified state. If gelatine is to be used, 10% concentration by mass has been demonstrated to more closely replicate animal tissue than 20% gelatine (Mabbott et al. 2016).

Research pertaining specifically to hunting lesions caused by wooden spears is more limited than the experiments above investigating ‘lethality’. Two experiments have provided some relevant reference material for the Boxgrove scapula. There are references to and a film of analytical/experimental work by members of the Boxgrove team but results are not quantified, making comparison with the Boxgrove scapula problematic (Pitts & Roberts 1997; Roberts 1999c). Another small-scale experiment was conducted in which a female javelin thrower threw a 2 m long wooden spear from a distance of 6 m at a 15.5 kg lamb carcass (size class 1), resulting in damage described in the publication as cracking, splintering, saw-toothed fractures and complete removal of portions of the scapulae (Smith 2003). The same experiment involved spear thrusting, which resulted not only in what was described as splintering, cracking and bone deformation, but also in perforations (Smith 2003). Resulting lesions from that experiment are not quantified.

The research questions informing the experiment design for this section are:

1. What is the wounding capacity of a wooden spear on a size class 4 mammal (horse) when used as a thrusting spear?
2. What is the wounding capacity of a wooden spear on a size class 4 mammal (horse) when used at hand-thrown spear velocities?
3. Is there any visible impact damage to adult large mammal bones from wooden spears, and what are resulting damage characteristics and morphometrics?

Secondary aims of the experiment are:

1. To record damage to the spears from thrusting and hand-throwing. These data will facilitate future experimental research into damage to wooden spears, as well as expand understanding of use-life including repair and re-use.
2. To note the morphometrics of external wounds from wooden spear impacts on a large mammal carcass.

8.4.1.2 General experiment design

Adult horse torso parts with hide but without viscera and organswere chosen for the lethality experiments. The targets are further detailed in 8.4.2.3, but an explanation for choice of target follows here. Smith's (2003) experiment using wooden spears on a juvenile sheep carcass indicated the ability of these weapons to penetrate an animal target and damage bone. However, the experiment used a juvenile sheep weighing 15.5 kg for the target, a size class 1 animal (Table 2.1), whereas MP sites like Boxgrove and Schöningen show hominin modification of larger prey, up to size class 6 (Table 2.1), with both of these sites in particular known for exploitation of equids. The larger the size class, the thicker the soft tissues and larger the bones, affecting penetration (Frison 1974; Frison 1989; Badenhorst 2012), with higher energy necessary to penetrate equal distances. Taking into consideration additional differences including most notably hide thickness and bone mineral density between adult and juvenile and size 1 vs. size 3 and 4 animals (Badenhorst 2012), it is clear that an experiment with a target representative of animals from MP sites such as Schöningen and Boxgrove is necessary to continue to build a relevant dataset enabling an evaluation of hypotheses pertaining to both spears and hunting lesions from the period.

As discussed in Chapter 3, 'lethality' is a somewhat arbitrary measure, as a dynamic hunting situation would be affected by many different variables that are not relevant in testing on dead animal carcasses, let alone simulants such as PermaGel™ or ballistic gelatine. Even when inserting bones and hide into ballistic gelatine targets (e.g. Kieser et al. 2013; Iovita et al. 2014), the connective tissues are not adequately modeled, and bone surfaces may be altered prior to inclusion. While a dead animal carcass also imperfectly simulates live animals (Badenhorst 2012) testing on an animal carcass is the most ethical, realistic target available for lethality studies, and facilitates an understanding of a weapon's ability to penetrate and damage hide, muscle tissue, bone and organs. Testing on a live animal would possibly improve penetration, due to differences in tautness of skin and *rigor mortis* (Badenhorst 2012). Experimental design always requires choices to be made, many of which are necessarily guided by practical concerns such as cost, ethics, and health and safety concerns (Eren et al. 2016).

For the reasons discussed in 2.3.1.4, thoracic sections, including hide but excluding viscera and organs, of semi-feral horses were selected for the targets. Ethical approval was waived by UCL, and was obtained for both experiments from the Cranfield University Ethics Committee, Shrivenham, UK (Reference CURES/746/2016). Risk assessments were submitted to both UCL Institute of Archaeology and Cranfield University. Thrusting events are labeled TE and throwing impacts are labeled IE to minimise confusion in the text.

8.4.2 Materials and Methods

8.4.2.1 Experimental setup and data collection

Both experiments took place at the Defence Academy of the United Kingdom (Shrivenham, Oxon, UK) to make use of specialist equipment and technicians. The thrusting experiment took place in an indoor ballistic testing laboratory on February 10, 2016, and the throwing experiment took place at an outdoor firing range on July 20, 2016. For both experiments, experiment recording sheets were used to manually record each impact. For the thrusting experiment, the entire experiment was filmed with a standard digital video camera, and high speed video of a sample of spear thrusts were recorded with a Phantom V7 high-speed video camera (Fig. 8.19) enabling velocity to be calculated using Phantom 675.2, software. Resolution was set to 640 x 480 pixels. After difficulties capturing the relatively slow and long thrusting events, the exposure rate was adjusted to 300 μs and the sample frame rate to 500 fps. For the spear throwing setup, a Phantom V1212 high-speed video camera was used (Fig. 8.20). The resolution was set to 1280 x 800 pixels, exposure time at 4 microseconds, and data was collected at a sample rate of 1000 fps. For spear thrusting and throwing, spears were left in the target and the DoP marked on the spear in order to measure with a calibrated ruler the depth the spear penetrated into the target. Spears were photographed in the target, then after removal, the external wound was photographed with a scale, and the distal ends of the spears were photographed.

Figure 8.19. Experimental setup for the spear thrusting experiment, showing high speed video and target (covered)

Figure 8.20. Experimental setup for the spear throwing experiment, showing placement of high speed video and target

8.4.2.2 Spear replicas

Replicas for the spears for both experiments were manufactured from Norwegian spruce (*Picea abies*), culled in the New Forest. Trees were selected from natural stands planted in the early 1960s that were later thinned to one m distances. The trees grow in natural forested conditions, and those chosen for spear making grew as seedlings near the older and larger trees. The trees selected are between 20 and 30 years old, with diameters of around 70-90 mm, and up to ca. 150 mm at the base, in order to avoid the use of softer outer wood. The small trees selected were growing next to and under the shade of larger trees (Fig. 8.21), which results in slower growing conditions and denser wood (Tsoumis 1991, p.120). A few examples of cross-sections can be seen in Fig. 8.22.

For both experiments in this chapter, replicas were crafted manually with metal tools and then finished with a fine sandpaper in order to produce a toolmark-free surface. This facilitated investigation of use traces. Some sample surfaces were moulded with a high quality silicone moulding agent (Prevest DenPro® Hiflex Putty) to capture these original surfaces for future comparisons with damaged and reworked spear surfaces during use. Tip measurements (Table 8.6) followed as closely as possible diameters calculated from a scaled photograph of the tip of spear II using Photoshop C6 (Thieme 1999a, p.391). As for the replicas in the Chapter 7 experiments, the distal ends of the spears were created from base of the trees, which provides the hardest wood and tips were offset from the soft pith. During the thrusting experiment on the carcass, it was sometimes necessary to resharpen blunted and split tips as cost and time constraints prohibited the use of one spear per impact.

For the experiment using replicas at hand-delivered velocities, the spear replicas needed to be crafted to work with an air cannon. Therefore, they were made differently to the replicas for previous experimental work in this thesis. Seven replicas were made to the length of 1050 mm to fit in the barrel of the air cannon. To make mass equal for all replicas, lead sheeting was tacked towards the rear of the replicas to make each weigh exactly 750 g (Fig. 8.23), which is near the mean mass of 764 g of 10 complete experimental replicas (Tables 7.6, 7.12 and 8.7), excluding replica 3B, which was significantly heavier than other replicas and not used. Foam discs were cut to the inner diameter of the air cannon and placed in front of the sheeting, creating a seal that forces the spear replica out of the barrel due to applied air pressure.

Figure 8.21. Felling a small tree for replicas. Note the proximity of the tree to a larger, faster-growing tree. The trees were selected in this way to replicate higher density of wood through slow growing conditions

Figure 8.22. Cross-sections of trees used to make replicas for the spear thrusting carcass experiment. Cross sections match replica 1C, 2C and 3C, from left to right

Table 8.6. Measurements for spear replicas from spear thrusting/carcass experiment

Replica	Length	DIA at 10 mm	DIA at 50 mm	DIA at 800 mm	DIA at 1150 mm (midpoint)	DIA at 1530 mm	Mass	Point of balance*
Schöningen Spear II†	2300	5 ‡	15 ‡	37	35	34	‡	‡
Replica 1C	2300	5	15	35	34	34	749	1155 (50%)
Replica 2C	2295	5	16	37	34	34	597	1120 (49%)
Replica 3C	2295	5	15	35	35	34	813	1145 (50%)
Replica 4C	2295	5	15	37	35	34	677	1150 (50%)

All measurements are in mm except mass, in grams. * Measurements are distances measured from distal end. † Measurement data from Thieme 1999a: 389. ‡ Data not published, where data are provided, they were estimated from published scaled photographs (Thieme 1997)

Table 8.7. Measurements of spear replicas for spear throwing/carcass experiment

Replica	Length	DIA at 10 mm	DIA at 50 mm	DIA at 800 mm	Mass (g)*
Schöningen Spear II†	2300	5 ‡	15 ‡	37	‡
Replica 1D	1050	6	16	37	422
Replica 2D	1050	6	14	37	400
Replica 3D	1050	5	16	36	389
Replica 4D	1050	7	16	36	356
Replica 5D	1050	6	14	36	338
Replica 6D	1050	6	15	37	403
Replica 7D	1050	6	13	35	446

All measurements are in mm except mass, in grams. † Measurement data from Thieme 1999a: 389. ‡ Data not published; where data are provided, they have been estimated from published scaled photographs. * Before lead sheeting was added to equalize mass. P.O.B. measurement provided for other spear replicas in this thesis is not relevant for these shortened throwing spears.

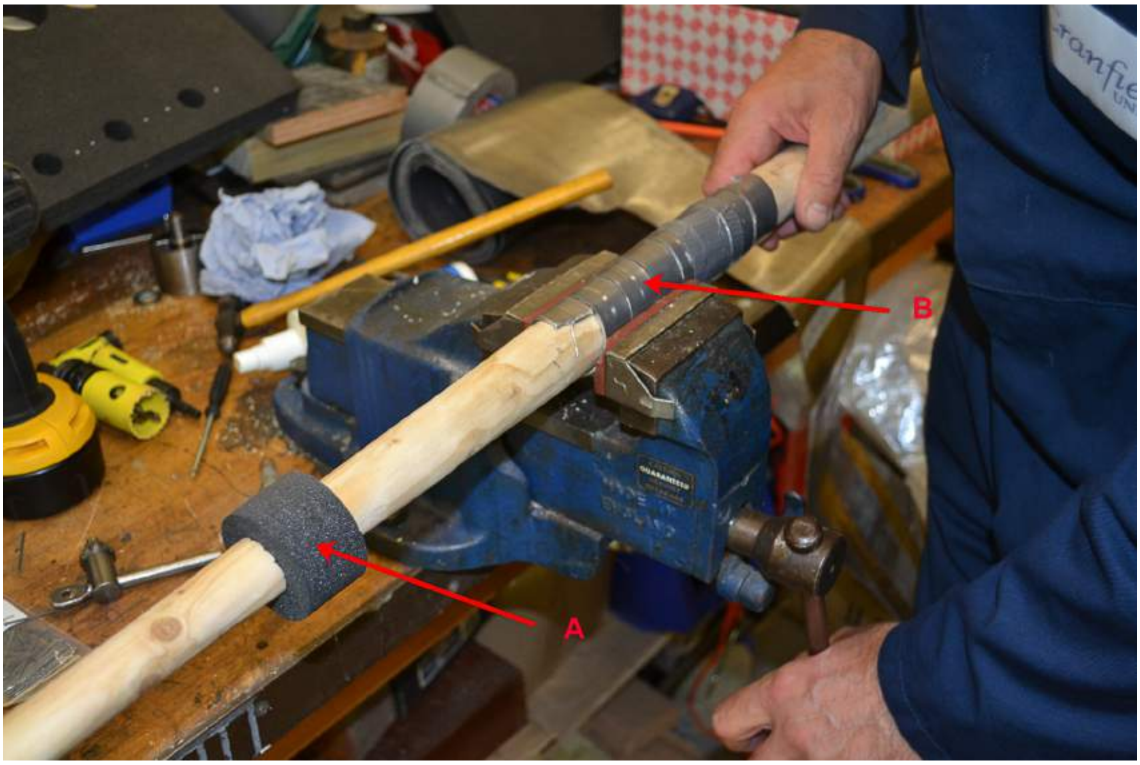

Figure 8.23. Spear replica being prepared for use in the air cannon. A shows a foam disc and B is the lead sheeting

8.4.2.3 Target

The horses were culled using ethical procedures at an abattoir, and were food-grade and thus fit for human consumption, eliminating any ethical concerns in testing and disposal. Thoracic sections (Fig. 8.24) are estimated to have weighed ca. 140 kg, and came from adult semi-feral horses weighing approximately 450 kg, (size class 4). As Fig. 8.25 shows, the thorax of a horse contains vital organs including the lungs, heart, and arteries. The ribs cover many of these vital organs, and while a horse is in locomotion, the front leg movement allows the opening up of the ribs and tightening of hide, facilitating penetration (Friis-Hansen 1990). A hit in this target area could result in immediate organ failure and/or bleeding, making this the prime target area for hunters.

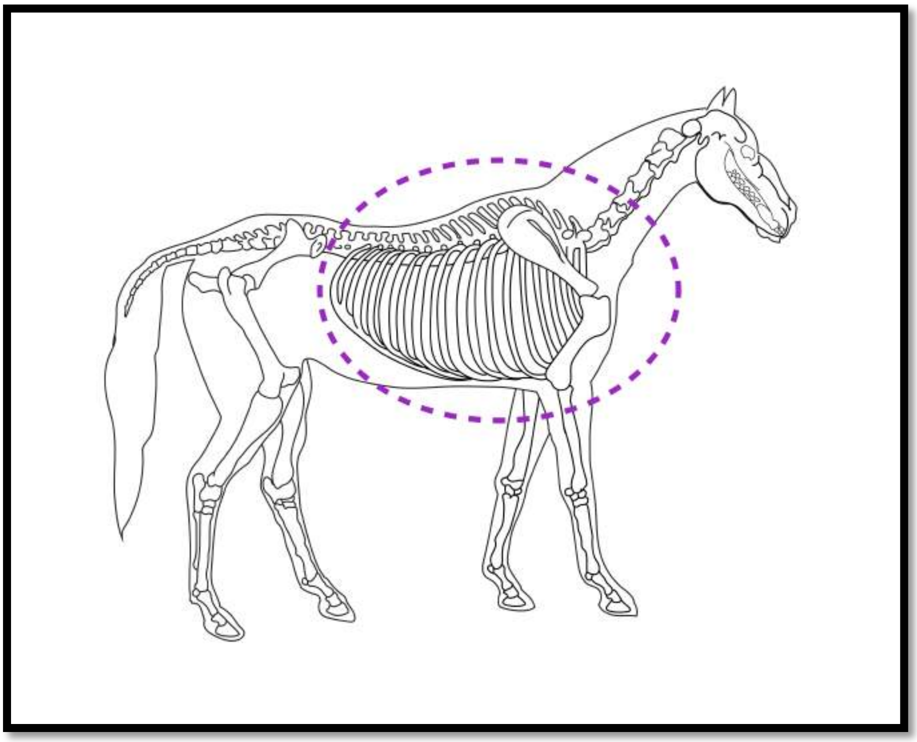

Figure 8.24. Drawing of horse skeleton. Purple circle gives approximation of the section selected for testing in both experiments

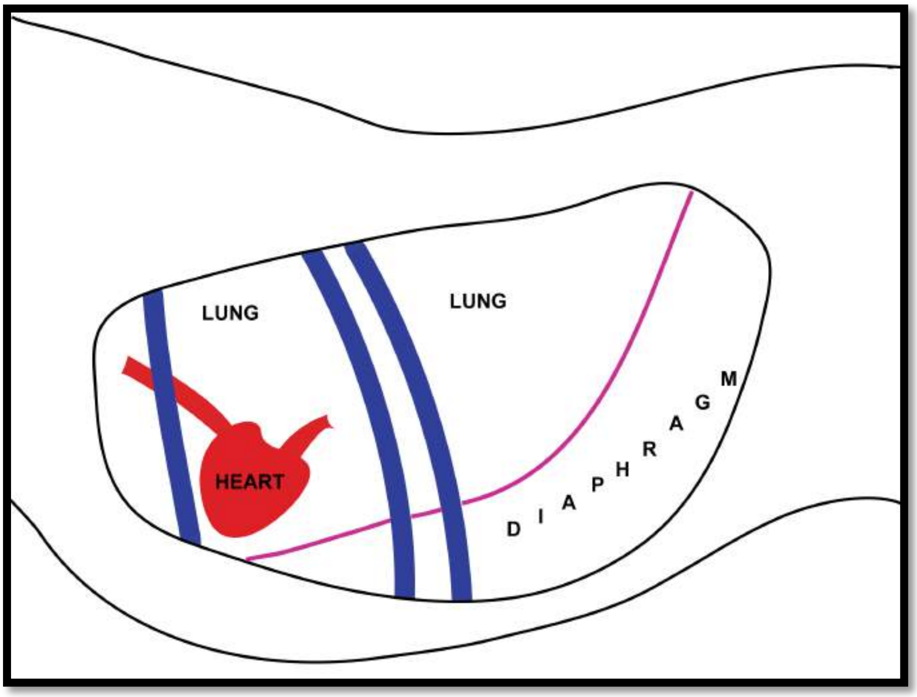

Figure 8.25. Schematic drawing of left side of horse torso, showing approximate locations of major organs and arteries. (Drawn by A. Milks, after dissection slides)

Hide was left on for experimental purposes but viscera and organs were removed to comply with on-site licence requirements. The time elapsed between death and experimentation was ca. 24 hours, and horse carcasses were tested at room temperature, with previous studies demonstrating no difference in penetration when testing on animal tissue that had been previously frozen or refridgerated compared with fresh tissue, provided it is tested at room temperature (Breeze et al. 2015). Both of these factors should counteract the effects of rigor mortis, which should have passed by ca. 24 hours in warm conditions. Although in this condition, the horse part does not replicate a live animal, the use of an eviscerated animal was necessary due to licensing restrictions on site. The absence of organs is considered to have a relatively limited influence on the ability to penetrate the horse thorax, as the density of lung tissue is considerably less than that of bone and muscle (Demuth 1968). To confirm this a few test stabs were done into 37 kg blocks of ballistic gelatine, as well as one stab through the horse carcass into a block of ballistic gelatine (both 10% by mass concentration, conditioned at 4° C) placed inside the cavity, through which the spears impacted with ease as reported by both participants. The results of these test thrusts are excluded from the larger data set of results unless otherwise stated.

For the thrusting experiment the torso measured ca. 820 mm from stomach to withers, and 960 mm across. It was initially placed 560 mm off the ground on a scissor lift (Fig. 8.26, left), but the torso was moved throughout the experiment to accommodate the use of different thrusting techniques. This included placing the torso into a position lying on the floor (Fig. 8.26, right), simulating an animal that was already down on the ground.

Figure 8.26. Setup of horse torso for spear thrusting experiment. Left is on scissor lift, for thrust events one through nine. Right is on the ground, for thrust events 10 through 13

For the throwing on carcass experiment, as it took place outdoors in high temperatures it was necessary to segment the torso into four sections to keep them at 18º celcius until use. There was no rain and the air temperature on the experiment day had a mean of 21ºC and maximum of 27º C (weather data accessed from www.wunderground.com, access date: 1/15/2017), and thus the samples may have warmed slightly between initial and final shots. The segmenting facilitated moving the target for shot placement. Each thorax segment was arranged on top of wooden pallets, topped with sandbags, which ensured minimal movement of the target during impact (Fig. 8.27). A piece of strawboard was placed behind the sample to minimise damage to the spear from impacting with the supporting wooden pallet behind.

Figure 8.27. Target setup for the spear throwing on carcass experiment

8.4.2.4 Firing

The results of the human performance trials from Phase 1 of the research programme, presented in Chapter 7, informed Phase 2 experimental design. This was particularly important for choosing how to replicate hand-delivered spears, both thrust and hand-thrown. The results of the spear thrusting trial clearly indicated that spear thrusting, which is complex mechanically and variable biomechanically, even amongst a cohort with similar training and thus skill sets, is best replicated by trained humans. The significance of training was emphasised, as the velocity results suggested an increase in performance over untrained spear users. For this purpose it was deemed necessary to forgo experimental control of this variable, as the alternative mechanical setups 'firing' thrusting spears have not yet been adequately compared with using human participants (Iovita et al. 2016). The dynamism of this process is part of understanding 'effectiveness', and though for purposes of, for example, use-wear, the experimental control of that variable might be deemed most important, for this experiment it was necessary to best replicate the action in order to assess lethality. Based upon conclusions from Chapters 6 and 7 on the importance of skill and training, two male participants were chosen for spear thrusting, both highly trained in spear use, and in particular in Filipino martial arts. Participant 1 (P1) is a professional martial arts practitioner, and the other (P2) is a military personnel whose experience includes bayonet training, military combat experience, and regular training in Filipino martial arts. P1 was paid, while P2 was a volunteer. Comparisons of velocities captured in this study with those from Chapter 7 (7.2) make further contributions to the understanding of the effects of training on performance. Neither participant has any known conditions that would adversely affect performance. For health and safety purposes, participants were provided with safety glasses and grip gloves (Fig. 8.28). Participants were given free choice about thrusting techniques used (discussed in Chapter 7), with hand orientation, gestures and footwork recorded for each Thrusting Event (TE).

Figure. 8.28. Grip gloves used in the thrusting experiment

Hand-thrown spears, which are projectile weapons and can be fired as such, were fired mechanically using an air cannon (also called air guns), which have been used to replicate hand-thrown spear velocities in previous work (e.g. Milks 2010; Iovita et al. 2014; Iovita et al.

2016). Air cannons are capable of firing projectiles at varying velocities, and work by using stored up compressed gas from a cylinder to accelerate the projectile out of a barrel (see also Chapter 7.2.4). Previous work using the air cannon provided data regarding the pressure values (bar; 1 bar – 100 kPa) needed to achieve the desired range of velocities (Milks 2010). The velocity range selected for the testing reported in Chapter 8 was based upon results in Chapter 7. Although impact velocities from aimed throws in the human performance throwing trial ranged from 13.5 m/s - 21.7 m/s, a few from distance throws reached velocities of over 30 m/s. Furthermore, Rieder's (2001) study recorded impact velocities with a mean of 23.8 m/s and a maximum of 25.5 m/s throwing a 500 g replica of Spear II at a 5 m distance. Elite javelin athletes regularly throw javelins of a similar mass at velocities > 25 m/s (Table 7.3). Therefore, it was necessary to test up to 25 m/s in order to assess the effectiveness of these spears in a representative range of spear throwing velocities. The air cannon setup is pictured in Fig. 8.29. The length of the barrel is 1 m, and the internal diameter measured 50.8 mm. The distance between the end of the barrel and the carcass was 1090 mm, while the height of the barrel was adjusted during the experiment to facilitate shot placement.

Figure 8.29. Air cannon setup. A indicates the foam discs used to create a seal between the projectile and the inner surface of the barrel. B is the controller, C is the barrel of the cannon, and D is the point of a spear

8.4.2.5 Data analysis

Analysis of the video footage used the software package Phantom Cine Viewer v2.5.744.0. For the spear thrusting on carcass, impact was defined as the video frame in which the spear first interacted with the horse carcass and was designated as frame = 0. Impact velocity then was defined as the mean velocity calculated from frames -2 to -22 before impact. For the spear throwing, defining impact followed the same basic criteria. However, as the throwing experiment was able to film at a higher frame rate due to the use of a better high speed video camera there are more frames per video. The longer the distance over which velocity is calculated, the more reliable the velocity measurements. Therefore, to make the distance over which velocity is calculated similar to those in the thrusting on carcass experiment, impact velocity for the spear throwing experiment was defined as the mean velocity calculated from frames -2 to -92 before impact.

Qualitative analysis of any resulting damage follows methods described in Chapter 5. Bones were examined with a hand lens, and a DinoLite Pro HR AM7000/AD7000 digital microscope was used to document and photograph relevant microscopic damage. Measurements of bone damage were taken using calipers. In the case of curvilinear damage, a scaled photograph was digitaly analysed using the same method as outlined in Chapter 5. Spear damage was photographed digitally and with the Dino-Lite microscope, and described according to terminology set out in Chapter 3.3.

8.4.3 Results

11 Thrusting Events (TEs) took place in the thrusting experiment, with Participant 1 (P1) executing six and P2 executing five of these. The spear throwing experiment resulted in 13 Impact Events (IEs) being fired at the target, all within the range of spear throwing velocities. Tables 8.8 and 8.9 present selected results of the two experiments (full results are in the data files on the accompanying CD). Figs. 8.30 and 8.31 show the approximate locations of impacts on the horse torso from the spear thrusting experiment.

Table 8.8. Results of the thrusting/carcass experiment

Thrusting Event ‡	Participant	Spear Replica	Resharpened	Hand orientation, placement and gestures †	Footwork †	Velocity	DoP
3	1	3C	N	Double, reverse	standing over	5.78	270
4	1	1C	N	Single	rooting	*	160
5	2	1C	N	Double, forward	rooting, drop step	*	63
6	1	4C	N	Double, combination	rooting	6.46	59
7	2	1C	N	Double, forward, ‘pool cue’	2 steps in	7.55	0
8	1	3C	N	Double, reverse	1 step in	*	323
9	2	3C	N	Double, forward, ‘corkscrew’	2 steps in	6.13	324
10	1	2C	N	Double, reverse	rooting	4.59	0
11	2	3C	N	Double, reverse	standing over	5.02	120
12	1	1C	Y	Double, reverse	standing over	*	62
13	2	3C	N	Double, reverse	1 step in	3.52	326

‡ Table does not include TE 1 and 2, which were tests into gelatine only for comparative purposes. TE 3 is the test with horse carcass and gelatine, and TEs 4 – 13 are horse carcass only. † Definitions and descriptions can be found in section 7.1.3

Table 8.9. Selected results from the spear throwing/carcass experiment. Full results can be found as a data file on the accompanying CD

Impact Event	Spear Replica	Resharpened	Velocity (m/s)	Kinetic energy (J)	DoP (mm)	Impact Angle
1	4D	N	23.26	203	284	0
2	1D	N	24.89	232	195	0.004
3	5D	N	18.07	122	80	0
4	2D	N	17.33	113	103	0.0057
5	3D	N	17.63	117	154	-0.0212
6	3D	N	15.03	85	181	-0.0632
7	3D	Y	12.25	56	72	-0.078
8	7D	N	23.04	199	152	-0.008
9	2D	Y	17.57	116	49	-0.0172
10	5D	Y	24.82	231	254	0
11	7D	Y	16.26	99	109	-0.038
12	6D	N	20.15	152	190	0
13	7D	Y	19.03	136	218	-0.0289

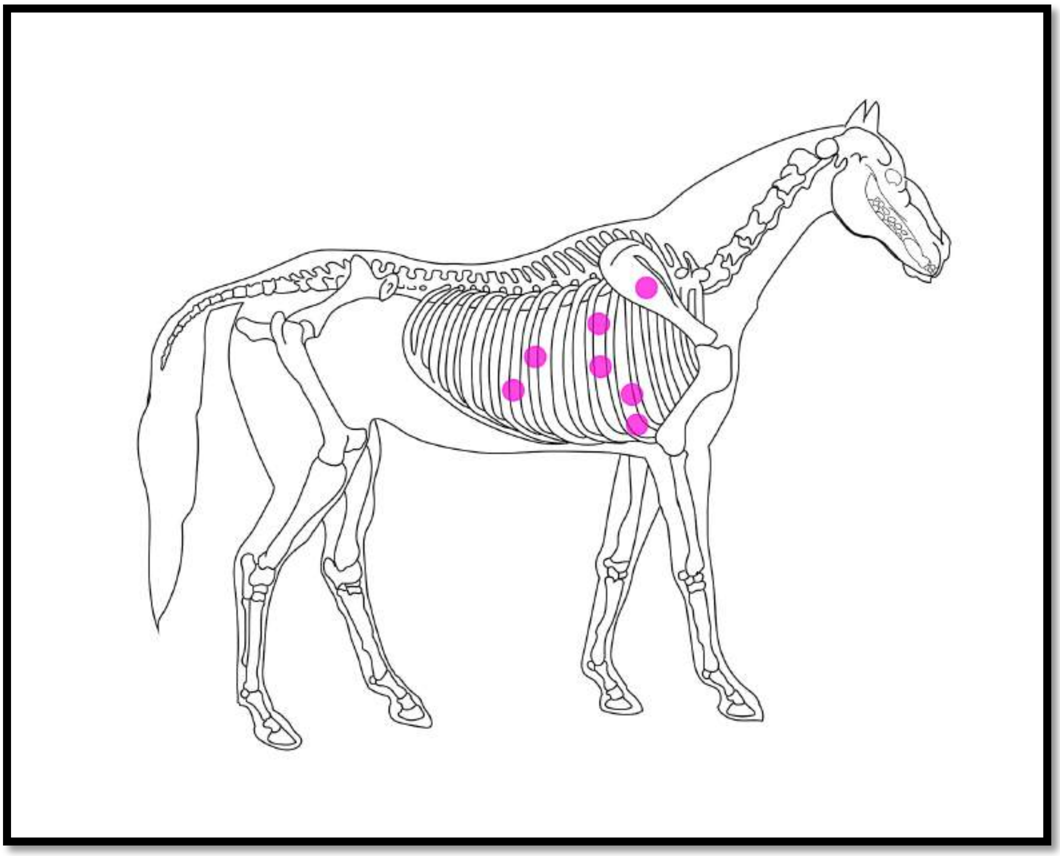

Figure 8.30. Approximate location of spear thrusts into right side of carcass. Drawn by A. Milks

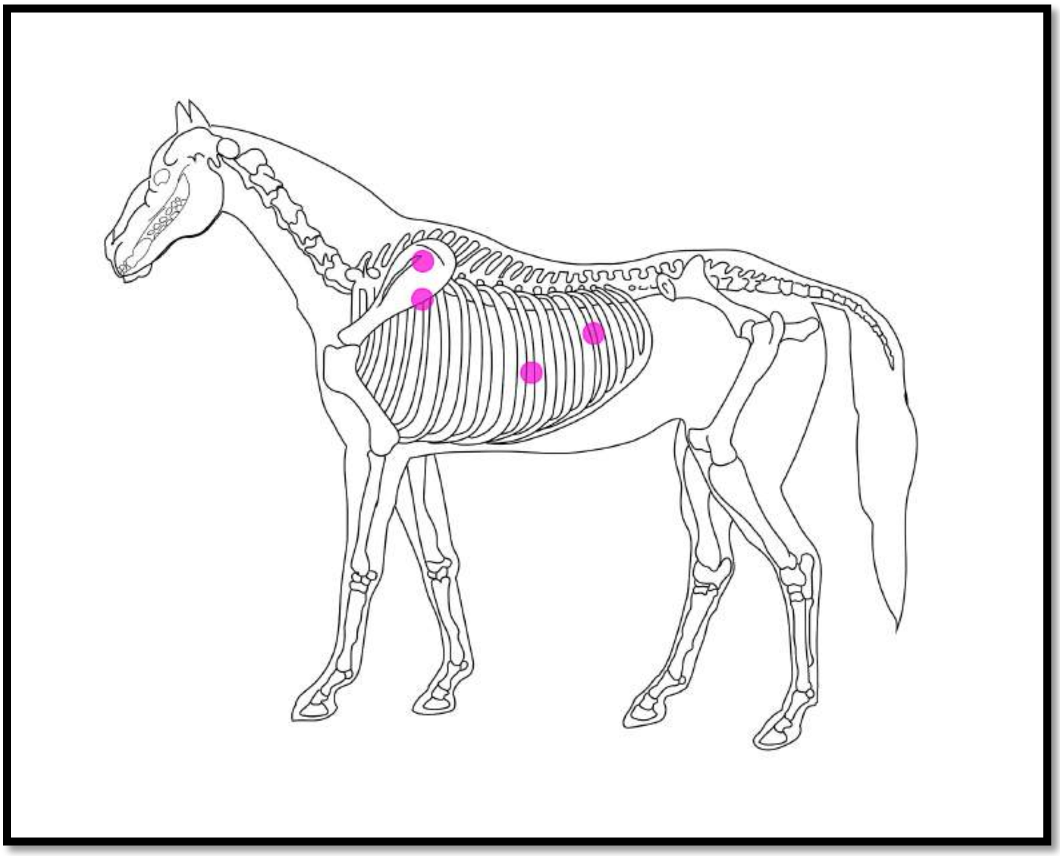

Figure 8.31. Approximate location of spear thrusts into left side of carcass. Drawn by A. Milks

8.4.3.1 Velocities

Table 8.10. Descriptive statistics for thrusting impact velocities (m/s)

Mean	SD	Min	Max	n
5.579	1.3251	3.52	7.55	7

Out of the 13 TEs, eight were captured with high speed video[1]. One video had neither enough frames nor were the marks on the spear used for calibration visible, rendering this video unsuitable, leaving seven for analysis of impact velocity (Table 8.10). The velocity results make an useful comparison with the human performance trial in Chapter 7. Minimum, maximum and mean velocities all exceeded the results from the human performance trial by around 1 m/s. The two highest impact velocities from TE 6 and TE 7 were executed by P1 and P2 respectively, showing that both participants, who have extensive training in spear use, executed higher velocities than sample of 11 military personnel from the human performance trial, all of whom received training in bayonet use as part of basic training. This result may be due to the increase in skills of the participants, but equally it may support the hypothesis that decreases in mass lead to increases in impact velocity (Horsfall et al. 1999), as the spear replicas used in this experiment lacked the relatively heavy force transducer, reducing overall mass by over 50% of the mean of 709 g (n = 4) from this experiment. The highest velocity, 7.55 m/s, resulted from an approach of two steps in, though P2 was not running at the target. The second highest velocity resulted from a 'rooting' approach, in other words with P1 in a standing position with no steps in. Therefore the increase in velocities cannot be solely down to the allowance of a moving approach (as opposed to a static stance in the human performance trial). The means broken down by participant are 5.61 m/s for P1 (n = 3) and 5.55 m/s for P2 (n = 4), showing similar performance in velocity between the two participants. Importantly for making comparisons with hand-thrown spears, the maximum impact velocity still does not approach the minimum impact velocity (12.7 m/s) in the human performance throwing trial. This 'cushion' of separation between the two weapon systems further suggests that their impact velocities do not overlap, though it remains poorly understood how total energies compare.

Table 8.11. Descriptive statistics for throwing impact velocities (m/s)

Mean	SD	Min	Max	n
19.179	3.8767	12.25	24.89	13

[1] Pressure bars associated with each velocity can be found in the 'Spear Throwing Carcass' dataset on the accompanying CD.

In the throwing experiment, IEs were fired at velocities between 12.25 m/s and 24.89 m/s (Table 8.11). The range fits well with observations of hand-thrown spear velocities discussed in Chapter 7. The mean is slightly higher than that captured during the human performance trial, but lower than those from other sources (Table 7.3), and is similar to previous estimates (e.g. Hughes 1998).

8.4.3.2 Kinetic energy

Kinetic energy (KE) calculated from the impact velocity and mass of the experiment firing hand-thrown spears on the carcass resulted in a range of 56 J - 232 J (Table 8.12). The maximum KE tested was lower than that from the human performance trial (Table 7.16), which had a range of 65 J - 444 J. The difference is because the highest velocities captured in the human performance trial (>25 m/s) were not tested. The maximum KE in this experiment exceeds estimates for hand-delivered spears in archaeologically-oriented experimentation on both humanly and mechanically projected hand-thrown spears (Tables 7.3 and 7.4), primarily due to the heavier mass of spear replicas in this experiment compared with previous experiments undertaken (e.g. Howard 1974; Van Buren 1974; Rieder 2001; Milks 2010; Hutchings 2011; Sano & Oba 2015).

Table 8.12. Descriptive statistics for kinetic energy in spear throwing experiment

Mean	SD	Min	Max	n
143.1	56.44	56	232	13

8.4.3.3 Depth of Penetration

The DoP's achieved in the spear thrusting on a carcass represented a relatively wide range. Two TE's failed to penetrate the target causing no damage (DoP = 0), while the maximum DoP easily exceeded 150 mm in five TE's, and three of these achieved a DoP >300 mm. The mean DoP for thrusting was 155.2 (Table 8.13), with a high SD (132.2). These results are similar to the high variability seen in the human performance spear thrusting trial. One thrust that failed to penetrate at all (TE 7) was aiming for the ribs, while the other (TE 10) was aiming for the scapula. Relevant to interpretations of the Boxgrove and Swanscombe scapulae, none of the thrusts aiming for the scapula (n = 3) achieved a DoP >150 mm while five of the eight thrusts at the ribs penetrated >150 mm. Relating impact velocity and DoP in spear thrusting, the highest impact velocity failed to penetrate the target at all, while the lowest impact velocity (TE 13) achieved the highest DoP (Fig. 8.32).

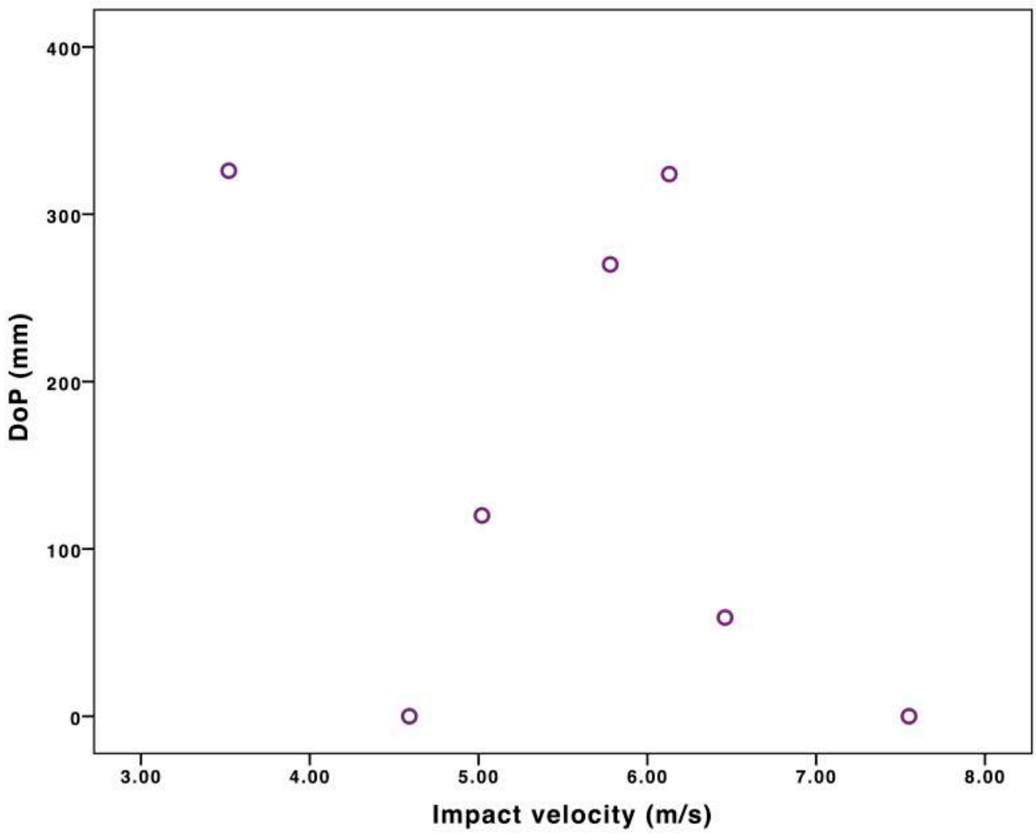

Figure 8.32. Scatterplot of Depth of Penetration and impact velocity in spear thrusting on carcass, representing TE's for which velocity was captured

Table 8.13. Descriptive statistics for DoP from spear thrusting experiment

Mean	SD	Min	Max	n
155.18	132.242	0	326	11

For the spear throwing experiment, DoP ranged from 49 mm to 284 mm (Table 8.14). The mean of 157.00 mm is very similar to the spear thrusting experiment, but with a lower SD (72.134). However, unlike in the spear thrusting trial, all of the spears penetrated the carcass. One spear bounced back out (IE 7) after penetration, but it was possible to calculate a DoP of this impact event by reviewing the high speed video footage. A scatterplot of impact velocities and DoP (Fig. 8.33) shows a general trend that increasing velocity will increase the DoP in spear throwing.

Table 8.14. Descriptive statistics for DoP from spear throwing experiment

Mean	SD	Min	Max	n
157.00	72.134	49	284	13

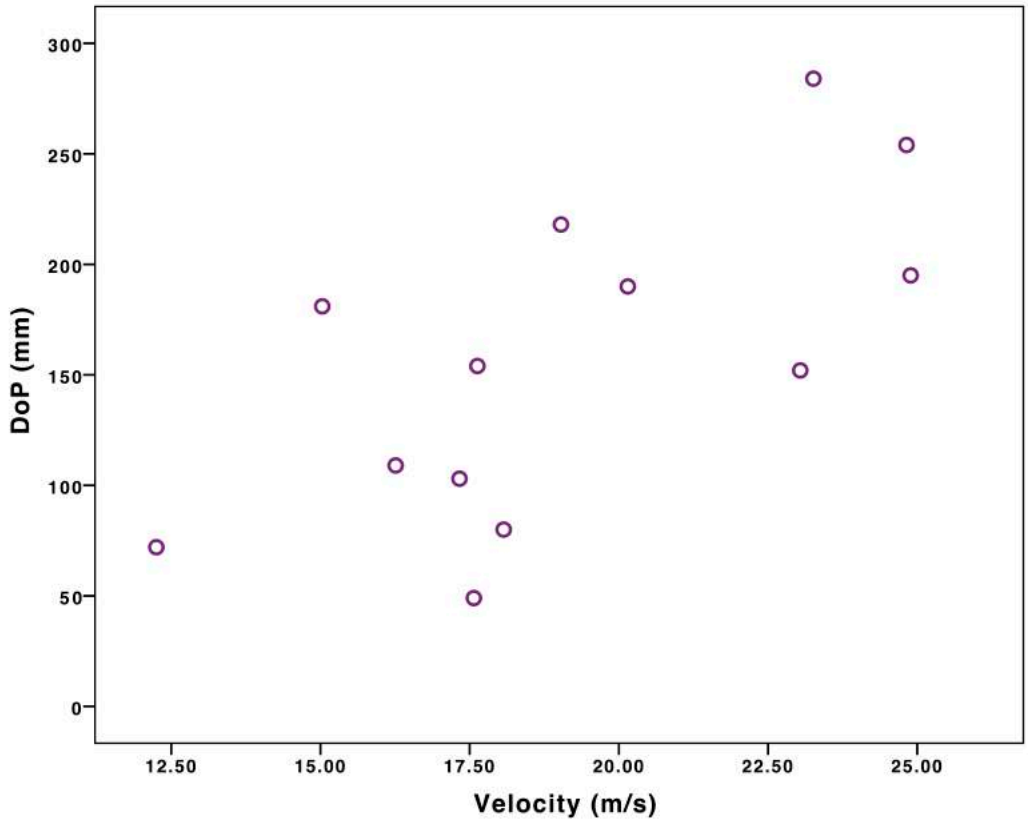

Figure 8.33. Scatterplot of Depth of Penetration and impact velocity in spear throwing on carcass

8.4.3.4 Technique: (thrusting only)

Participants chose to wear grip gloves in all but two of the thrust events (TE4, TE6).
Both participants used the 'middle grip' (Fig. 7.6) for hand placement throughout the experiment. Hand orientation varied throughout, and included a single hand hold (n = 1), and double hand holds with forward grip (n = 3), combination grip (n = 1), and reverse grip (n = 6). Footwork involved rooting (n = 4), stepping in (n = 3) and static positions (n = 4).

8.4.3.5 Wound ballistics: wound profiles and hunting lesions

External wounds from both experiments resemble those described in Wood & Fitzhugh (2015) caused by bone point projectiles. They are lenticular, and measure approximately 20-30 mm in length (Figs. 8.34 -8.36). This is similar to diameter of spear at the point that the spear penetrated, around 20 mm, which matches the diameter of the spear at this depth (Tables 8.7 and 8.8). Wood & Fitzhugh (2015) suggest that these wounds would not have bled profusely, particularly when compared with lacerated or incised wounds that they found resulted from lithic-tipped weaponry. Interestingly, the intercostal spacing where the wounds were measured, and the diameter of the spears at the DoP (between 200 and 300 mm) both measure between 20 and 30 mm, with external and internal wound measurements also being similar in size (Fig. 8.35). It is logical that the spear diameters match the external wound cavity, but for the dimensions to also match rib spacing is intriguing, and merits further investigation and comparisons with rib spacing of other large ungulates thought to have been potentially hunted with wooden spears. It is possible that the spear point design reflected the balance between the need for robusticity against spear breakage, and ease of penetration into the thoracic cavity.

Figure 8.34. External wound from spear thrusting on horse carcass

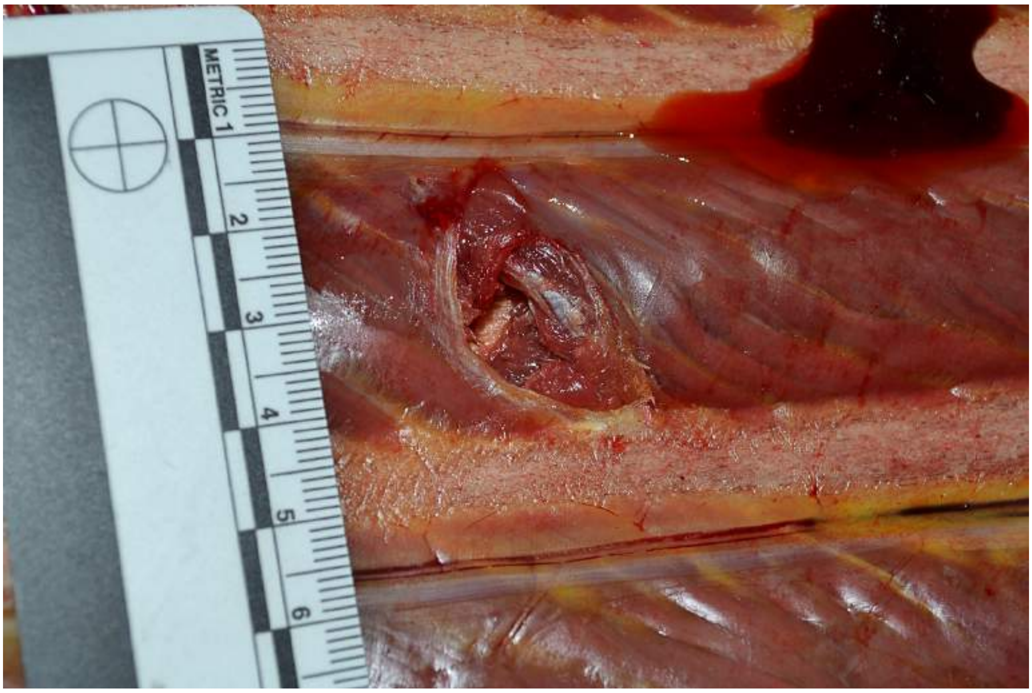

Figure 8.35. Internal wound from spear thrusting on horse carcass between ribs

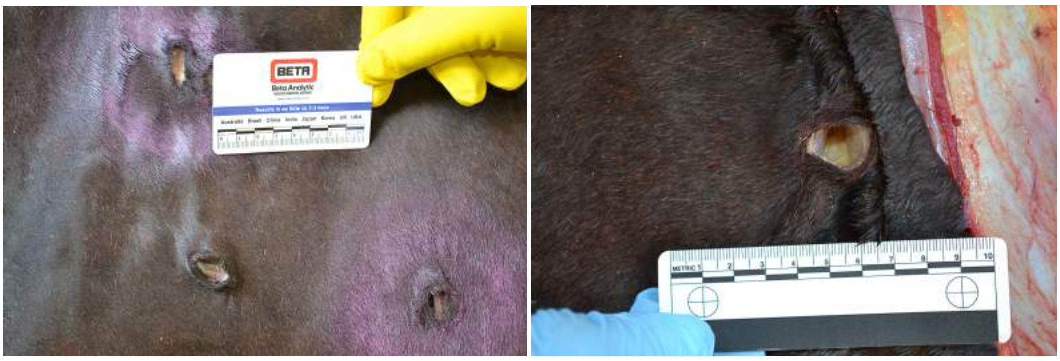

Figure 8.36. Left and right: external wounds from spear throwing on horse carcass

In at least two cases in the throwing experiment, spear points were broken off leaving wood fragments in the muscle tissue (Figs. 8.37 and 8.38). This would potentially lead to infection if the animal had survived the hunting event, though animals have been known to survive and heal from embedded lithic points (e.g. Noe-Nygaard 1974; Oakley et al. 1977).

Figure 8.37. Example of a broken spear point from throwing experiment, embedded in muscle tissue overlaying the scapula

Figure 8.38. Example of a broken spear point from throwing experiment. IE 4 with spear replica 2D impacted the scapula at 17 m/s. This failed to puncture or perforate the scapula blade, breaking the spear point

Bones from the spear thrusting/carcass experiment did not demonstrate any damage from spear impacts. This is in spite of several thrusts that would be classified as 'lethal' on the basis of DoP. The participants observed that upon impacting the rib area (n = 8), the spear would often be felt to slip around the edge of a rib allowing it to be pushed through the muscle tissue and into the thoracic cavity. Impacts with the scapula also left no visible damage. The participants noted that attempts to impact the scapula (n = 3) caused a lot of physical resistance to their own bodies, and that although they could penetrate through the hide and relatively thick muscle tissue they were unable to thrust into or through the scapula. In one case it is thought that the participant first impacted the scapula, and that the spear slipped off that bone and into the thoracic cavity through the ribs. This is in contrast with results from Smith (2003), where participants were able to puncture through the scapula of the juvenile sheep carcass using wooden spears as thrusting weapons.

It is important to reiterate that hunting impacts to scapulae would likely be considered a 'miss' by a hunter, as even if the weapon penetrates through the bone, this would involve a significant loss of KE (Friis-Hansen 1990). However, scapulae were targeted in these experiments in order to assess the ability of hand-delivered wooden weapons to damage these bones to make comparisons with potential MP hunting lesions (Chapter 5), as well as with damage to scapulae from other weapon types and delivery systems.

For the throwing experiment, two IE's resulted in macroscopically identifiable damage. Replica 1D impacted the fifth rib on the left side (IE 2) at a velocity of 25 m/s and KE of 232 J. This impact just missed the scapula, and penetrated to a depth of 195 mm after shattering the rib. The rib fractured into multiple pieces, (Figs. 8.39 - 8.41) with one bone fragment lost during carcass processing. This shot would have been likely to be a fatal impact, as the spear ruptured the thoracic cavity, which would have caused air to rush in, resulting in collapsing of the lungs. Primary damage includes multiple fractures, which can be best described as a butterfly fracture (Fig. 8.41) (Pechnikova 2013; Kieser et al. 2014). The fracture has an impact point with a microflake attached (Fig 8.40). Further cracking in the form of radiating cracks are evident on both sides of the rib. The fracture angles are obtuse or acute, and some fracture margins are sharp while others have a jagged outline.

Figure 8.39. Rib damaged from spear impact in throwing experiment. Left: fragments separated, right: fragments refitted

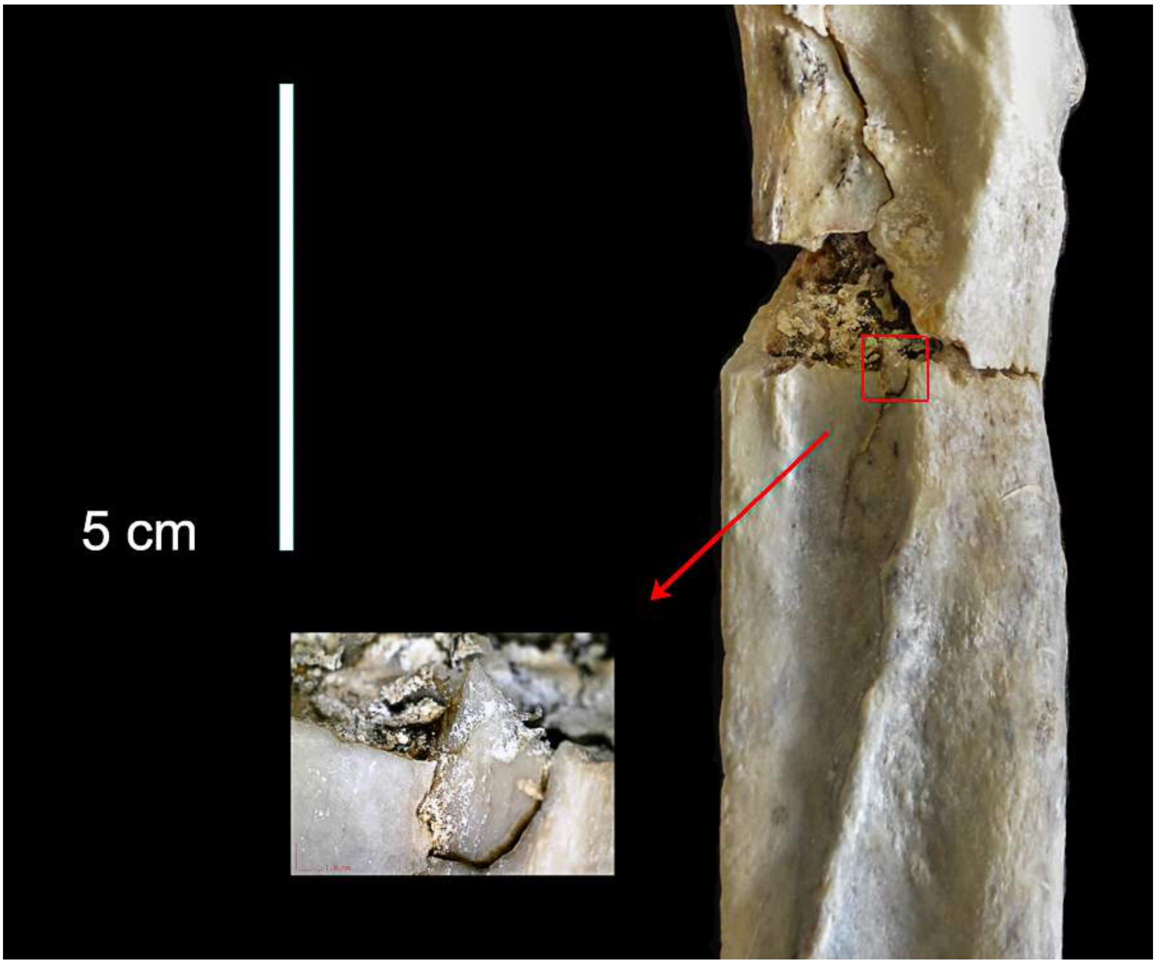

Figure 8.40. Close up of damage to rib. Red box shows detail of microflake at the point of impact from the spear

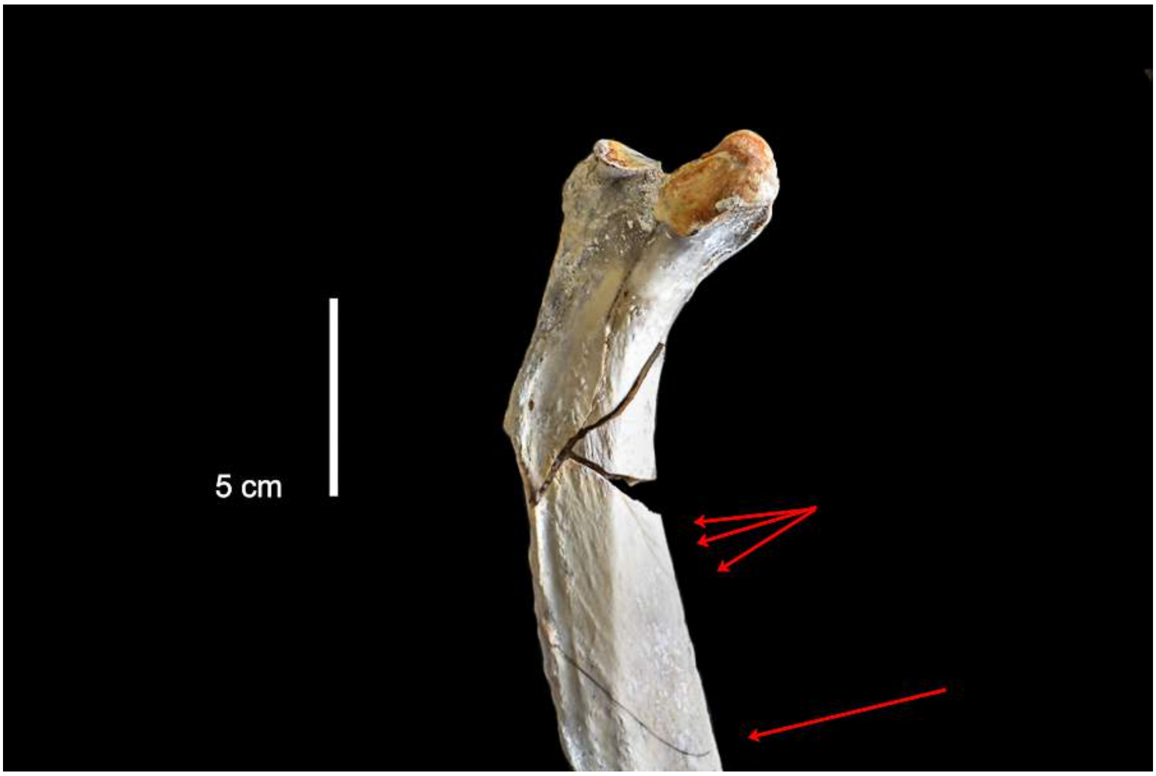

Figure 8.41. Medial side of damaged rib, refitted. Red arrows point to radiating spiral fractures

The left scapula bears a small amount of damage. IE 3 impacted the ridge of the scapula at 18.1 m/s, resulting in a DoP of 80 mm. This impact did not cause any visible damage to the scapula. The following impact (IE 4) hit the same scapula at 17.3 m/s, with only slightly more penetration (103 mm) than IE 3. This hit resulted in a damaged spear (Fig. A.1.14 in Appendix 1), and the wound would have been unlikely to be fatal. The area of impact shows light 'bruising' to the scapula blade (Fig. 8.43), which was more evident prior to cleaning and is similar to that illustrated elsewhere (Parsons & Badenhorst 2004). There is also a very small puncture (Figs. 8.42 - 8.44) which microscopically shows displacement of cortical bone, and which macroscopically could easily be mistaken for a natural feature of the bone or a carnivore tooth mark. This area correlates roughly with scan site 4 (see Table 3.2 and Fig. 3.4), which is a relatively dense area of bone.

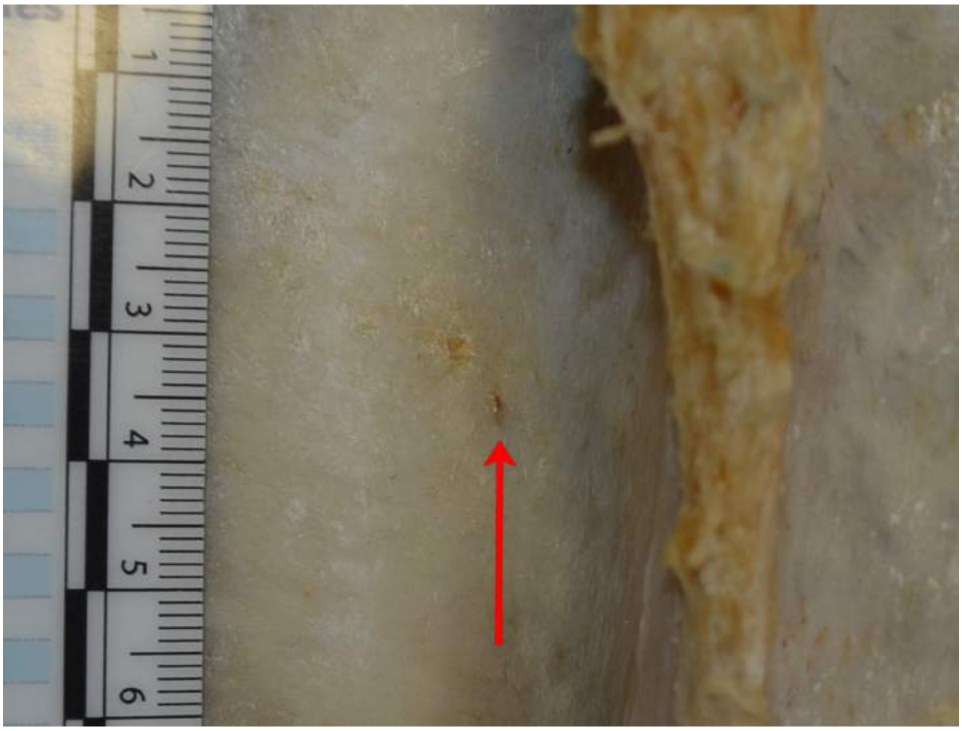

Figure 8.42. Scapula damage from IE 4, red arrow pointing to impact point

Figure 8.43. Left: Puncture in scapula blade from IE 4 at 50x magnification, right: red circle shows area of bruising around puncture

Figure 8.44. Bottom, puncture at 250x magnification, showing some displacement of cortical bone

An impact to the right scapula (IE 9) at 17.57 m/s resulted in a perforation on the edge of the supraspinous fossa (Fig. 8.45). Laterally there is a curvilinear fracture, with a piece of bone attached only by fibrous connective tissue that runs along the edge of the blade, and which would be unlikely to preserve intact in archaeological contexts. Secondary damage laterally includes crushing and cracking, and the rim is primarily jagged. Medially, the damage includes hinging, flaking and cracking, with a primarily sharp rim (Fig. 8.46). Two small flakes of cortical bone from the medial side measuring 23 mm and 7.5 mm in length were recovered. Bevelling is also present, and will be further discussed in 8.5. The area of impact correlates roughly with scan site SP3 (Table 3.2, Fig. 3.4), with a mean BMD1 of .55 for equids, and therefore this area has a lower density than IE 4. The similarity in thinness of bone at this part of a scapula (as shown in Fig. 3.5) for both IE 4 and IE 9, as well as similar impact velocities underscores the signficance of BMD in terms of damage signatures.

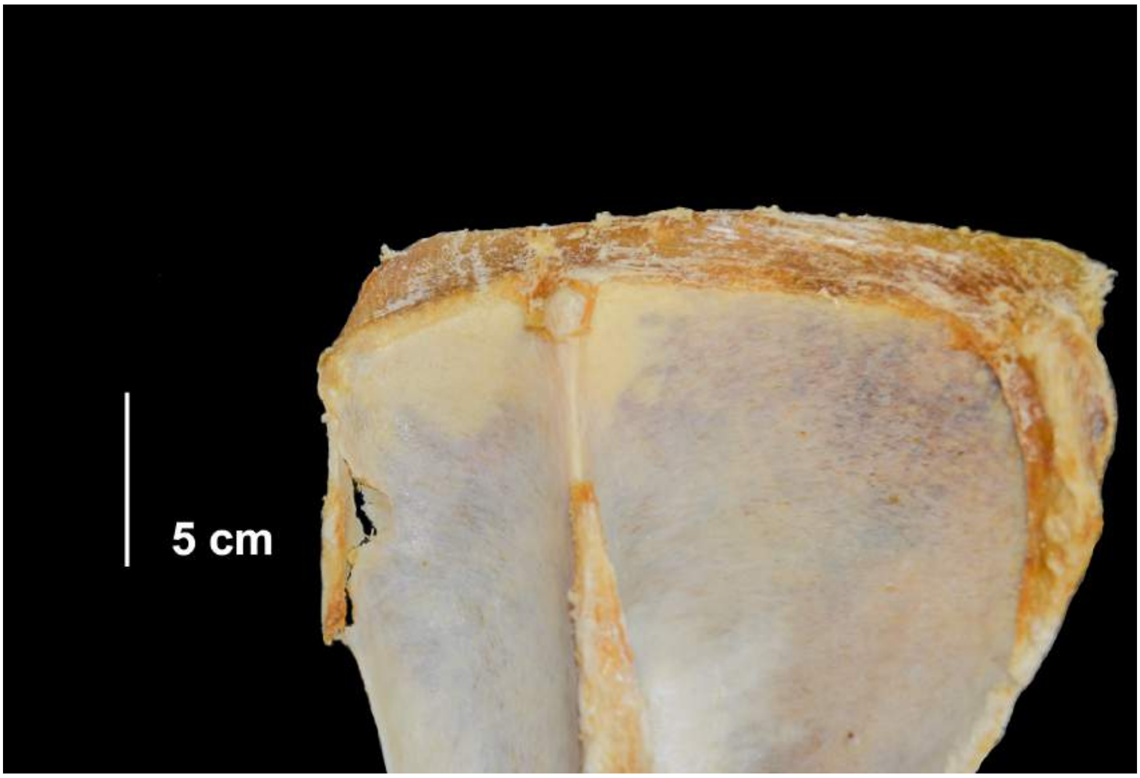

Figure 8.45. Lateral view of right scapula from spear throwing experiment, with damage to the edge of the supraspinous fossa

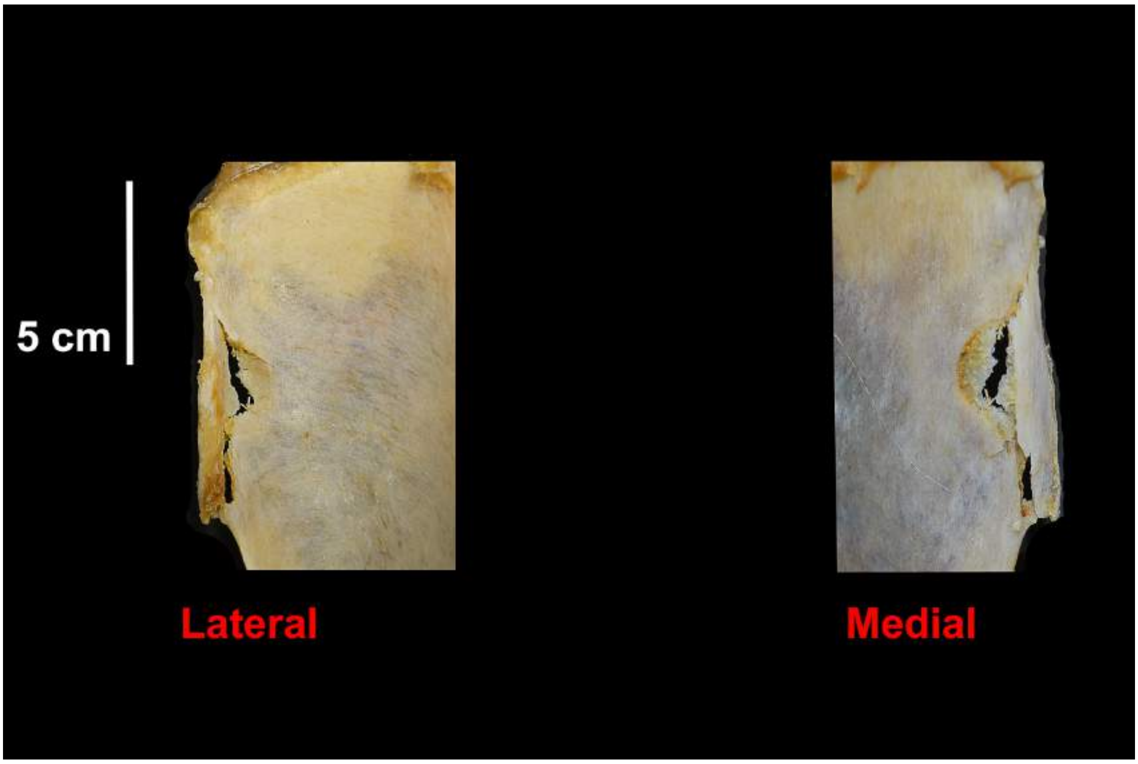

Figure 8.46. Lateral and medial views of damage to right scapula from spear throwing experiment

8.4.4 Discussion

The results of these experiments reject hypotheses that wooden spears function poorly as hunting weapons, and demonstrate that they are capable of lethally wounding a large adult horse. The KE of MP wooden spears as hand-thrown weapons at least matches if not exceeds those of spearthrowers and exceeds estimates of energies from bow/arrow impacts (Table 7.5). When used as thrusting spears DoP ranged from 0 mm to 326 mm, with 45% of the thrusts penetrating >150 mm. As hand-thrown weapons, DoP ranged from 49 to 284 mm and was >150 mm in 62% of the impacts. Therefore, although mean DoP's for both delivery methods were similar (thrusting = 155 mm; throwing = 157 mm), throwing penetrated beyond 150 mm more frequently. The possibility that this may reflect that the throws were mechanically projected while the thrusts were by human participants cannot be ruled out and would need further testing to determine whether this difference in DoP stands up in a statistically significant sample. Impacts were therefore frequently deep enough to prove lethal to the animal, either penetrating into the area containing the heart or lung, or more generally into the thoracic cavity which would have resulted in the collapse of pressure and near-instant death. The mean DoPs from the two experiments are only slightly smaller than the mean DoP from an experiment using lithic-tipped spearthrower darts on a pig carcass (mass between 84.2 g and 225 g, velocities between 21 m/s and 27 m/s) with a mean DoP of 175 mm (range 46 mm - 320 mm, n = 27) (Whittaker et al. 2017). Preliminarily this suggests that lithic-tipped spearthrowers may only result in slightly greater DoP than hand-delivered wooden spears, with further studies systematically examining KE vs. point material necessary.

Results of this terminal ballistic study shows both similarities and differences in results between the two weapon systems. The morphology of the external wounds are similar for both delivery methods, with a simple conical cross-section; the spears do not create large, gaping wounds but rather relatively small, lenticular wounds. This suggests that DoP and location would be the most significant factors in determining lethality of these weapons, making both aim and energy behind impacts all the more significant.

Used as thrusting spears in the thoracic region of a large adult horse, wooden spears left no visible damage to bone. While the spears penetrated between the ribs, fitting comfortably between rib spacings, they failed, as thrusting weapons, to damage the scapulae. These results have not replicated the damage produced in Smith's (2003) experiment using wooden spears as thrusting weapons on a juvenile sheep carcass, which is probably because juvenile animals are not readily comparable to adult mammals due to differences in hide thickness, muscle tissue, and bone mineral density. Penetration through an adult horse scapula with wooden spears as thrusting weapons at this stage appears unlikely. Damage to spears was primarily limited to relatively minor tip damage, apart from the broken spear (replica 4C, see Appendix 1).

However, as throwing weapons, readily visible and identifiable damage occurred to both bones and spears (Appendix 1). In most cases, damage to the spears was more likely than visible damage to the bone. One hunting lesion, located on the thin edge of one of the scapula blades would have been unlikely to prove lethal, and may have healed (see Noe-Nygaard 1974). However, a direct impact to a rib at 25 m/s, resulting in a DoP of 195 mm cracked the rib into multiple fragments, and would have greatly injured if not quickly killed the animal. The resulting damage to both scapula and rib will be compared in section 8.5 with damage resulting from hammerstone and other weaponry impacts.

8.5 Comparing dynamic impacts from wooden spears and flint hammerstones

8.5.1 Introduction

Empirically evaluating potential hunting lesions proposed to have occurred from impact with wooden spears (see Chapter 5) necessitates comparisons with results from sections 8.2 and 8.4 of this thesis. Further complementing these data are a small body of studies on hunting lesions, including both published and unpublished experimental and archaeological examples. Morphometric characteristics of these datasets are brought together in this section in order to have a wider sample with which to evaluate the MP artefacts.

8.5.2 Materials and methods

The scapulae included in this comparative analysis are the two MP archaeological examples, experimental hammerstone and untipped wooden spear bone damage presented in sections 8.2 and 8.4, and additional published and unpublished datasets (8.5.2.1, 8.5.2.2).

8.5.2.1 Materials: Knight experiment scapulae

Two experimental scapulae from unpublished experimental work undertaken by Bernard Knight were made available for study by the Natural History Museum (Figs. 8.47 and 8.48). The Knight experiment involved impacting horse scapulae, without meat or hide attached, with wooden spear points using an impact machine (*The Butchers of Boxgrove*, 1996).

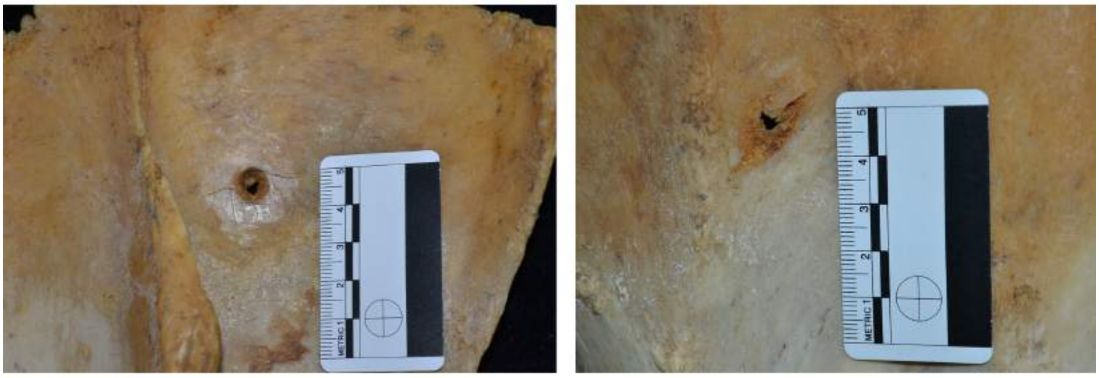

Figure 8.47. Left scapula from Knight experiments. Left: lateral view, Right: medial view (Photos by A. Milks)

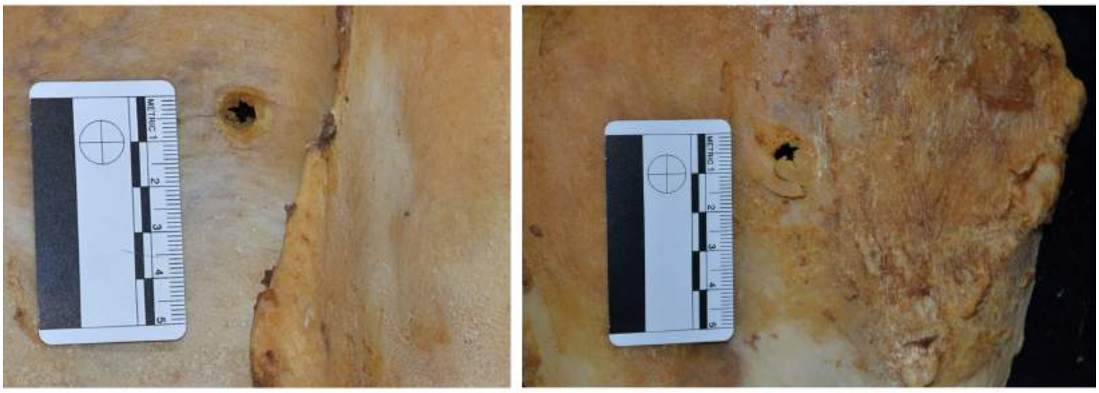

Figure 8.48. Right scapula from Knight experiments. Left: lateral view, Right: medial view. (Photos by A. Milks)

8.5.2.2 Materials: published images of hunting lesions, experimental and archaeological

Publications with scaled images showing unhealed archaeological or experimental damage to ungulate scapulae were also included for comparative purposes. Sources for the images used and resulting quantitative data are available in the 'Scapula Damage Dataset' on the accompanying CD. Although Figs. 4, 5 and 20 from Noe-Nygaard (1974) are drawings, the length of the blade is provided in the figure caption, providing scale. For the analysis of bevelling, images of both lateral and medial sides were necessary and so the sample for this measurement only included those scapulae for which both sides were photographed, making it a smaller sample than that for length and area comparisons.

8.5.2.3 Methods

The descriptive and quantitative analyses follow those described in Chapter 5. Microscopic analysis on the Knight scapulae was conducted using a Dino-Lite USB microscope. Additional measurements presented regarding carnivore tooth pits from publication data tables are discussed but are not included in the scatterplots, as the materials either come from studies pertaining to long bones (e.g. Selvaggio & Wilder 2001), or elements are unreported in relation to tooth pit size (e.g. Domínguez-Rodrigo & Piqueras 2003) which would impact upon the quantitative analysis.

If the Boxgrove fracture represents a hunting lesion, due to its location on the blade it is likely to only represent a section of closed perforation. Therefore, for the quantitative analysis comparing areas of hunting lesions and hammerstone impact damage, the areas of complete perforations were halved in order to broadly compare them with curvilinear fractures. The measurements for areas of perforations and curvilinear damage presented in Fig. 8.49 therefore represent different measurements to the complete areas presented elsewhere (e.g. Hammerstone impacts 4, 5 and 6 in Table 8.3). Complete measurement data are available in the data files on the accompanying CD.

8.5.3 Results

Impacts from experimental use of wooden spears (group 1) are similar in area and length to experimentally produced lesions from lithic and osseous weapons (group 2) (Figs. 8.49 and 8.50). Areas and lengths of these two (groups 1 and 2) are small in comparison with experimentally produced hammerstone lesions (group 3). The areas of the Boxgrove and Swanscombe scapulae are larger and do not overlap with the experimental weapon perforations, and the Boxgrove damage compares well with hammerstone damage. Areas of potential hunting lesions from the Late Pleistocene (group 5) also appear relatively small compared with Boxgrove and Swanscombe, but there is overlap between proposed hunting lesions from the Holocene (group 6) - some of which were suggested by Noe-Nygaard (1974) to represent spear damage - and those from the Middle Pleistocene, as well as with the experimental hammerstone impacts (group 3). Looking at length, Swanscombe overlaps with experimental and archaeological hunting lesions, but not with hammerstone damage. The 95% confidence intervals of areas calculated by Selvaggio & Wilder (2001, Table 1) on experimental carnivore tooth pits ranged from 0.04 mm^2 to 31.4 mm^2, with spotted hyaenas producing the largest pits. The largest areas were concentrated on areas of thick cancellous bone. Lions also produced pits with relatively large areas. The carnivore tooth pits therefore overlap with weapon damage of all types, as well as the smaller hammerstone impacts, but are smaller than the area of the Boxgrove damage (Fig. 8.49). Carnivore tooth pit mark analysis from published experimental samples, excluding tooth scores, provides 95% confidence intervals for lengths (longest axis) of between 0.23 mm and 20.80 mm from canids, felids, bears, and primates, with the smallest pits caused by babboons and the largest by hyenas (Domínguez-Rodrigo & Piqueras 2003, Table 1). The lengths show a potential overlap between carnivore tooth pits, particularly to areas of cortical bone with weapon impacts, though again, the length of the Boxgrove fracture exceeds this (Fig. 8.50). This pattern does not hold true for hammerstone damage, which is much larger in length. The Swanscombe scapula overlaps in length with the largest carnivore damage reported so this cannot be entirely ruled out, though it is unlikely. The length of the Boxgrove damage is considerably greater than pits from carnivores, making this an unlikely cause for the damage.

Overall this confirms that the size of perforations and punctures to ungulate scapula using wooden spears compare fairly well with experimentally produced lithic and osseous projectile impact marks, though intriguingly some of the potential archaeological hunting lesions from the Holocene (group 6) appear particularly large compared with other weapon impacts. However, the experiments presented in 8.4 demonstrate that it would probably take substantially higher energy impacts to perforate an adult equid scapula in any but the thinnest areas of the blade with a wooden spear, as no perforations occurred experimentally through thick areas of the blade using wooden spears, in spite of repeated attempts in both thrusting and throwing. This contrasts with experimental and unhealed archaeological examples of scapula perforations from lithic/osseous weaponry, which frequently perforate thick middle sections of adult ungulate scapulae.

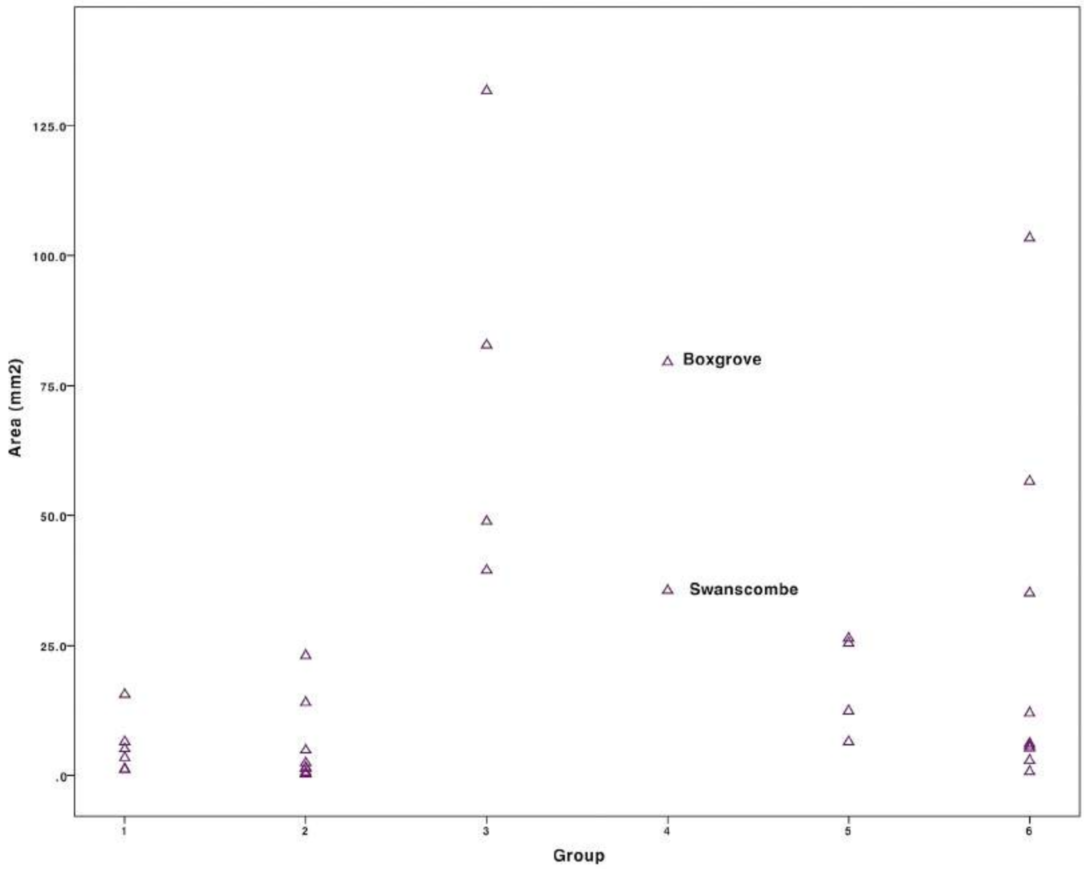

Figure 8.49. Scatterplot comparing estimated areas (mm^2) of experimental and archaeological scapulae bearing either curivilinear fractures or perforations. Areas of complete perforations were halved in order to compare with curvilinear fractures. Groups are as follows. 1: Wooden spear experiments. 2: Lithic/Osseous-tipped projectile experiments. 3: Hammerstone experiment presented in section 8.2 of this thesis. 4: Potential Middle Pleistocene scapulae with hunting lesions (Boxgrove and Swanscombe, labelled). 5. Potential Late Pleistocene scapulae with hunting lesions. 6. Potential Holocene scapulae with hunting lesions. Sources: Group 1. One scapula from the spear throwing on horse carcass experiment, presented in section 8.4 of this thesis. Two scapulae from unpublished experiment by B. Knight, courtesy of the NHM; Smith 2003, Figs. 4 and 5. Group 2. Castel 2008, Plate 2, Photo 5; Letourneux & Pétillon 2008, Fig 5 (n = 3 perforations); Parsons & Badenhorst 2004, Fig. 1 (n = 4 perforations); Smith et al. 2007, Fig. 3 (a); Group 5: Letourneux & Pétillon 2008, Fig 10; Nikolskiy & Pitulko 2013, Figs. 3 (B,D) and 4 (D). Group 6. Leduc 2012 Figs. 3 (b) and 9 (a,b); Noe-Nygaard 1974 Figs. 4, 5 and 20, plates 1c, 1d, and 3a

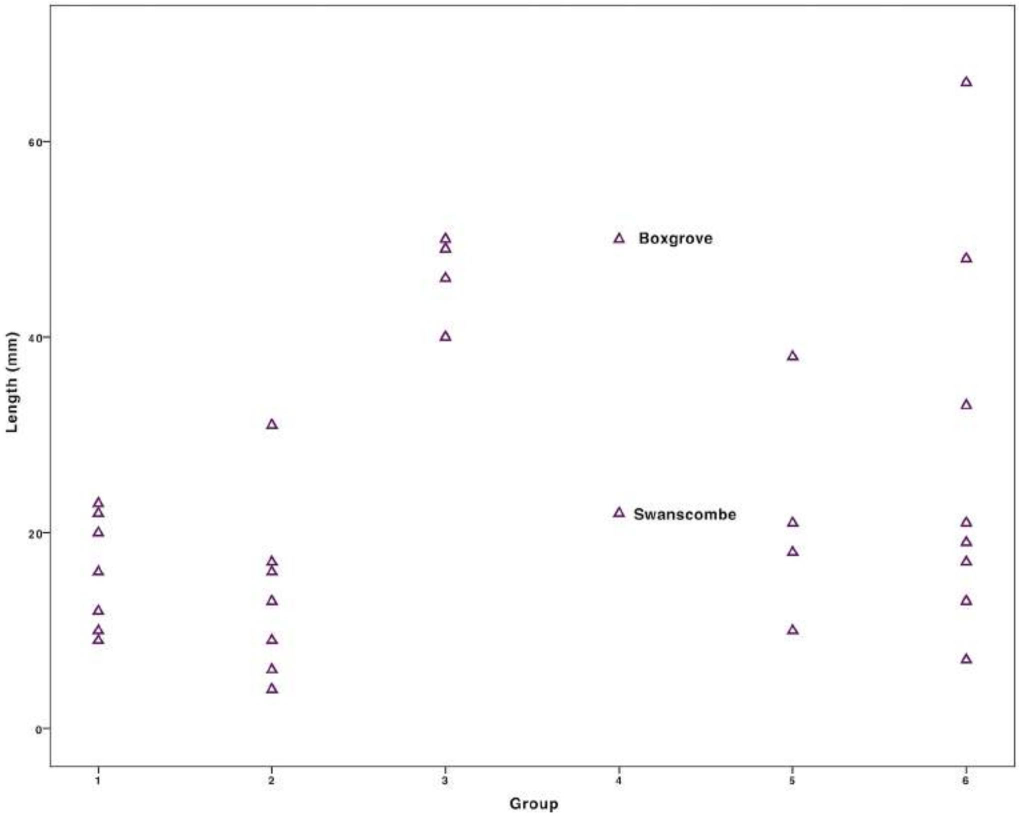

Figure 8.50. Scatterplot of length (mm) of longest axis of scapulae perforations. Groups and sources same as Fig. 8.64

In comparison with experimental samples and published examples together (Table 8.15), the bevelling ratios for both the Boxgrove and Swanscombe scapulae are very small. While most bevelling from impacts is ‘internal’, the Knight scapula shows that external bevelling can also occur from wooden spear impact. Therefore internal bevelling is not a diagnostic feature of a sharp-force weapon impact as it can also occur from blunt force, including hammerstone impacts, and external bevelling is also possible, making identification of direction of impact difficult as well.

Table 8.15. Bevelling data for scapula perforations including Middle Pleistocene archaeological examples, experimental sample, compared with data from published scaled photographs where lateral and medial views were both reproduced. * Presented in this thesis, section 8.4

Scapula	Estimated Area (lateral, mm^2)	Estimated Area (medial, mm^2)	Bevelling	Bevelling Ratio (lateral to medial)
Boxgrove	49.9, present state (79.5, lateral, *in situ* photograph)	48.3, present state	External	1.03 : 1
Swanscombe	35.6	39.3	Internal	1 : 1.1
Hammerstone Impact 1	131.7	337.0	Internal	1: 2.56
Hammerstone Impact 4	97.8	164.9	Internal	1: 1.69
Hammerstone Impact 5	165.7	187.2	Internal	1: 1.13
Hammerstone Impact 6	79.5	126.5	Internal	1: 1.6
Knight experiment, Left	6.9	11.7	Internal	1: 1.69
Knight experiment, Right	13	10	External	1.3 : 1
Milks spear throwing/carcass experiment, Right *	15.6	28.4	Internal	1: 1.82
Letourneux & Pétillon 2008, fig 10	13	22	Internal	1: 1.69
Noe-Nygaard 1974 plate 1c	113.2	77.6	External	1: 1.46

Scapula	Primary Damage	Secondary Damage	Shape	Fracture Rim Characteristics	Microscopic Damage
Boxgrove	**Lateral and medial**: curvilinear fracture. Possibly resulting from a perforation	None visible	Curvilinear fracture	**Lateral and Medial**: sharp	None
Swanscombe	**Lateral and medial**: curvilinear fracture. Possibly resulting from a perforation	**Lateral**: flaking **Medial**: flaking	Curvilinear fracture	**Lateral and Medial**: sharp	None - heavily weathered surface
Hammerstone Impact 1	**Lateral**: Curvilinear fracture **Medial**: Linear fracture	**Lateral**: cracking **Medial**: hinging, cracking (radiating), flaking	**Lateral**: curvilinear fracture **Medial**: linear fracture	**Lateral**: jagged **Medial**: jagged	**Lateral**: 1 pit with microstriations
Hammerstone Impact 4	Perforation	**Lateral**: Crushing, cracking (radiating) **Medial**: cracking, flaking	Circular but irregular	**Lateral**: primarily jagged **Medial**: primarily jagged	**Lateral**: 1 isolated pit
Hammerstone Impact 5	Perforation	**Lateral**: crushing, hinging, cracking **Medial**: hinging, flaking	Circular but irregular	**Lateral**: left side is sharp; top and bottom margins jagged; right margin jagged **Medial**: opposite pattern to lateral side	**Lateral**: 2 pits with microstriations; fields of isolated striations, focused around impact margin; 1 isolated pit
Hammerstone Impact 6	Perforation	**Lateral**: crushing, hinging, cracking (radiating), flaking, microflake **Medial**: hinging, cracking (radiating), flaking	**Lateral and medial**: Perforation circular, but surrounding damage irregular	**Lateral and medial**: jagged	None observed
Knight experiment, Right	Perforation	**Lateral**: crushing, cracking (radiating) **Medial**: hinging, flaking	Circular	Jagged	None
Knight experiment, Left	Perforation, circular	**Lateral**: crushing, cracking (radiating) **Medial**: hinging, flaking	Circular	Jagged	None
Milks spear throwing carcass experiment, Right *	Perforation, curvilinear fracture	**Lateral**: crushing, hinging, cracking **Medial**: hinging, flaking	Curvilinear	Jagged	None
Milks spear throwing carcass experiment, Left *	Puncture	**Lateral**: some crushing, visible with magnification	Ovoid	Jagged	None

Table 8.16. Description of damage to scapulae from Middle Pleistocene examples, compared with hammerstone study impacts and * indicates impacts from wooden spears in throwing experiment presented in 8.4

Table 8.17. Checklist of damage characteristics comparing MP archaeological hunting lesions with experimental hammerstone and wooden spear impacts

Characteristic	Boxgrove scapula	Swanscombe cervid scapula	Experimental hammerstone Impacts to scapulae	Experimental wooden spear impacts to scapulae
Microscopic Percussion Marks	X	Couldn't assess	✓	X
Puncture	X	X	X	✓
Perforation	✓	✓	✓	✓
Curvilinear fracture	✓	✓	✓	✓
Drag marks	X	X	X	X
Embedded stone or wood Fragments	X	X	X	X
Crushing	X	X	✓	✓
Microflakes	X	X	✓	✓
Hinging	X	X	✓	✓
Cracking	X	X	✓	✓
Feathering	X	X	X	X
Flaking	X	✓	✓	✓
Bevelling	✓	✓	✓	✓
Sharp fracture edge	✓	✓	✓	✓
Jagged fracture edge	X	X	✓	✓

Tables 8.16 and 8.17 compare the characteristics of experimental damage with the two MP scapulae studied. Features not shared between experimental hammerstone and wooden spear impact damage include microscopic percussion marks, limited to hammerstone damage, and puncture marks which are limited to spear impacts. Curvilinear fractures on flat bones occur from both means of impact, and therefore this morphological feature cannot be relied upon to be diagnostic of weapon impact. Unlike impacts from lithic-tipped weaponry, no drag marks or embedded weapon fragments were evident from the experimental work using wooden spears. This is in contrast to macroscopic and microscopic identification of such marks from the use of lithic-tipped and osseous projectile weapons (Smith et al. 2007; Castel 2008; Letourneux & Pétillon 2008; O'Driscoll & Thompson 2014). Further studies are needed to examine whether these these differences will hold up with larger samples, and to examine whether the differences are due to higher impact velocities or to differences in weapon tip material.

Summarising this section comparing bone damage from varying impacts with archaeological examples, the hammerstone impact experiment demonstrated that:

1. Impacts to scapula blades using hammerstones can result in both curvilinear fractures and perforations, as a result of *repeated, intentional* impacts.

2. Experimental hammerstone impacts on scapula often - but not always - results in microscopic percussion marks.
3. Experimental hammerstone damage to scapulae overlaps metrically with the fracture on the Boxgrove GTP 17 horse scapula fragment.

In assessing the Boxgrove scapula fragment the following three points are significant.

1. When archaeological evidence of perforations retaining the *entire* rim are located in the centre of a scapula, without any other signs of carnivore or hammerstone impact damage, these most likely represent impact from a weapon. Although it has been demonstrated in this chapter that such perforations *can* occur experimentally from hammerstones (e.g. Figs. 8.8 - 8.10), it is difficult to imagine a scenario where creating a hole in the middle of a scapula with a hammerstone would be the desired outcome, and hammerstone damage for marrow or grease access would likely result in the fragmentation of scapula blades. Although reconstructions of the Boxgrove scapula sometimes depict the artefact as representing a fragmented section of what was originally a circular perforation (e.g. Gaudzinski-Windheuser 2016) the artefact is only a fragment of a scapula blade from a highly fragmented individual horse, bearing a relatively large curvilinear fracture with minimal external bevelling. Furthermore, other bones both at GTP17 as well as at other sites at Boxgrove show traces of hammerstone impact and in some cases of the use of an anvil, presumably for access to marrow and grease locked within the bones.
2. The experimental evidence from using wooden spears as hand-delivered hunting weapons on adult horse carcasses has demonstrated that punctures and perforations are unlikely to occur on any but the thinnest areas of a horse scapula. Although the thickness measurements have indicated that the fracture was in a relatively thin area, the schematic drawing placing unhealed hunting lesions on a scapula (Fig. 3.3) showed that unhealed fractures to Mesolithic scapulae were concentrated in a thinner area slightly below and towards the spine. Taking these lines of evidence together, for the Boxgrove fragment to represent a perforation from a wooden spear, the energy involved would probably have needed to be greater than those replicated in these experiments.
3. Morphometrically the fracture on the Boxgrove scapula is a better match, both in terms of length as well as area, to experimental hammerstone damage than it is to experimental weapon impacts including both from untipped wooden spears as well as lithic and osseous weaponry. It is a poor match to carnvore tooth pits.
4. Bevelling on the Boxgrove fragment is almost nonexistent, with external direction. This, in combination with the fact that bevelling can occur from hammerstone impact as well as weapon impact, negates the use of this feature for diagnosing wooden spear use.

Given these three lines of evidence, the most parsimonious explanation is that the Boxgrove fracture was caused by a dynamic hammerstone impact for marrow access. Further evidence of microscopic percussion marks at Boxgrove, including on scapulae, will be a welcome addition to this interpretation.

The Swanscombe scapula is more difficult to assess. With no other indications of human modification, the pitted surface of the bone, the poor context for the artefact, and evidence of fluvial activity at the site, taphonomic or even excavation damage cannot be ruled out. Morphometrically, it overlaps with weapon damage and not with the experimental hammerstone damage, and internal bevelling suggests that an impact may have occurred from the lateral side. Some flaking is evident on both sides of the fracture, but this occurs during both experimental spear and hammerstone impacts so is not diagnostic. In contrast with the Boxgrove scapula fragment, the Swanscombe scapula is nearly complete; the location of the damage in the centre of the scapula blade, while the edges on either side remain primarily intact makes hammerstone impact damage seem unlikely. Carnivore damage is possible, though it is on the large side of tooth pits, and whether carnivores create large perforations in scapulae is unclear as most studies relate to long bones. Unfortunately because of its poor condition, interpreting this scapula as being humanly modified at all is problematic.

This analysis confirms that there are problems of equifinality applying morphometric analysis to potential hunting lesions, and assessments on this basis must be treated with caution, with descriptive and comparative analyses such as that presented here a necessary additional tool. Even with the analysis presented here, significant methodological advances in research into hunting lesions will be necessary before any features - apart from embedded weapon tips - can be considered ‘diagnostic’ of weapon use. The word ‘diagnostic’ must be used with caution when looking at damage features, and alternatives must be discussed, if not experimentally ruled out.

8.6 Summary and conclusions of experimental research

The results of the experiments in Chapter 8 demonstrate that concerns over equifinality (e.g. Gaudzinski-Windheuser 2016) in recognising hunting lesions during the Middle Pleistocene were well-founded. Leaving aside potential issues with taphonomic factors including carnivore damage - which was not directly studied in this thesis but is certainly a relevant issue - there are overlaps in nearly all of the characteristics defined for dynamic impacts. It is not possible to rule out projectile impact from a wooden spear as being the cause of the curvilinear damage on the Boxgrove and Swanscombe scapulae, but given the failure of multiple thrusts into horse scapulae to even mark the bone let alone perforate it, spear thrusting appears unlikely, unless the hominins were significantly stronger than those humans used in the experimental work here.

An experimental examination of hammerstone use on scapulae for marrow access has confirmed that this type of dynamic impact damage can mimic weapon impacts, and highlights the true complexities of zooarchaeological assemblages, analyses of which need to account for multiple agents, not all of which are self-evident.

Most significantly, the experiments presented in 8.4 have clearly demonstrated that, making biomechanical assumptions of similarity - if not superiority - with contemporary trained modern human participants, hominins using wooden spears as hand-delivered weapons on large prey were armed with the capacity to kill. However, a big caveat regarding the lethality of wooden spears is their apparent inability to easily perforate through scapulae of large adult mammals, which is in contrast to evidence on perforations through scapulae from other organic and lithic-tipped weaponry. Presumably this would apply to other bones and/or areas of bone of similar or greater thickness and BMD. Although previous research testing wooden weapons against lithic-tipped weapons found similarities in terms of DoP (Waguespack et al. 2009; Salem & Churchill 2016), these experiments used unmodified gelatine blocks, and do not therefore apply to potential differences in the ability of wood vs. lithic or bone weaponry to penetrate through hide and bone. Although the experiments presented in this thesis have not directly compared wood and lithic/bone weaponry on animal carcasses, it is probable that a limitation of wooden weaponry relates to bone penetration. Although the wooden spears were capable of lethal wounds in the rib area, these lethality measures (DoP) do not necessarily apply where weaponry would need to penetrate through large or dense bones, and when the wooden spears did impact the scapula with high energy it tended to damage the spear and not the bone (compare section 8.4 and Appendix 1). Therefore, limitations of wooden spears in comparison with subsequent weapons do not appear to relate to solely to energy of impact, or their ability to penetrate hide, but rather their ability to cut through bone. Whether this is due to the sharp edges of typical lithic weapon points, or more connected with differences in material properties would be worth exploring in future experimentation. An implication of this finding is that aim becomes all the more important in use of wooden spears, as they are most likely to be lethal when aimed directly at the rib cage or other areas such as the front of the thoracic cavity in order to be effective.

While lethal and effective as hunting weapons against large mammals, the spears only damaged the bone during throwing about a quarter of the time (23% of throw impacts), and left no visible damage during thrusting. The above assessment of effectiveness suggests that most damage to bone would be visible on ribs, which preserve poorly. Combining this infrequency of bone damage with potential overlaps from other agents, the results help to make sense of the MP European zooarchaeological record. This record indicates that while hominins were systematically butchering and consuming large sized adult prey there is a curious lack of archaeologically visible damage from the use of weaponry (Gaudzinski-Windheuser 2016). Even at sites such as Schöningen, with excellent preservation there is little or no recognisable zooarchaeological evidence of the use of weaponry (T. Van Kolfschoten pers. comm.; B. Starkovich pers. comm.) although there are examples of healed lesions to equid ribs interpreted as resulting from intraspecific aggression (Van Kolfschoten, Burhs & Verheijen 2015). This is in contrast to the Late Pleistocene and Holocene records, where although hunting lesions are still relatively rare, there are recognisable perforations as well as embedded lithic and osseous weapon points. Although the results here may undermine suggestions that the Boxgrove scapula fragment represents impact from a wooden spear implicating the use of weaponry in hunting the horse from GTP 17, it seems more judicious at this point to emphasise the limited zooarchaeological signature that would have resulted from the use of wooden weaponry. The implications of the performance and design of untipped wooden spears, traces to the spears themselves during use, and what this might indicate about hunting strategies and social group structures are further explored in the final chapter.

Chapter 9. Implications: Integrating wooden spears into hominin behavioural shifts during the Middle Pleistocene and beyond

… we must refine our hypotheses about the links between weapons and adaptation to a particular environment, the ability to colonize new realms, as well as the cognition and skills that made these achievements possible…it will perhaps be necessary to re-examine some of our most basic assumptions about performance and quality.

- Iovita & Sano 2016a, p.294

This final chapter brings together the results and discussions of the wide-ranging interdisciplinary research from Chapters 2 through 8 in order to integrate the findings with each other, and then uses these findings as an exercise in inference building by contextualising them within the behavioural shifts of the European Middle Pleistocene. Chapter 9 begins by restating the research aims and objectives set out in the first chapter (9.1), and then discusses how these were met, including any limitations (section 9.2), followed by suggestions for future research (9.3). It then proceeds by sumarising the key results from the thesis to discuss wooden spear performance in detail, including those that pertain to hand-delivered spears as a group, as well as those relating specifically to the use of wooden spears (9.4). Building on the findings regarding spear performance, 9.5 briefly discusses current methodological problems in identifying the use of wooden spears in the archaeological record. Section 9.6 explores the implications of the results of the thesis for MP hominin behaviours, with a final discussion on how this fits with wider models of human evolution.

9.1 Restatement of research aims and objectives

This thesis had as its aim to improve understanding of some of the most basic assumptions made about the performance of hand-delivered wooden spears, the earliest and longest-serving weapons. It was able to replace a number of estimates in the literature with evidence-based data on key features of spear performance including:

- Their design, energy at impact, and ability to penetrate large mammals for the purpose of hunting
- Their effective distance as hand-thrown spears
- How their use corresponds to prey and environments
- Archaeologically visible signatures their use may leave

The objectives that were set to meet the above aims are:

1. To establish the mechanics of hand-delivered untipped wooden spears, used as thrusting and hand-thrown spears with a particular focus on mechanics, encompassing impact velocities (thrusting and hand-thrown spears), force (thrusting spears), kinetic energy (thrusting and hand-thrown spears), and effective distances (hand-thrown spears).
2. To analyse the morphometrics of archaeological and ethnographic hand-delivered wooden spears, with a particular focus on the penetrating tips of the spears. To determine how the archaeological examples compare with one another, as well as with ethnographic examples, and whether any of the features are indicative of function.
3. To further illuminate the performance parameters as well as the environments, prey, hunting strategies, and the global spread of wooden spears in recent contexts through a review of the ethnographic literature.
4. To determine whether hand-delivered untipped wooden spears are capable of lethally wounding a large adult mammal.
5. To establish through an analysis of potential Middle Pleistocene hunting lesions and experimentally-produced bone damage the characteristics of any resulting lesions from wooden spears, and to initiate an investigation of whether these characteristics are diagnostic of wooden spear use or whether they may overlap with other human or taphonomic processes, obscuring their recognition.
6. To compare all of the resulting data for implications about the hunting behaviours, social organisation, and cognitive capacities of Middle Pleistocene *Homo*.

9.2 Evaluating the research aims and limitations

9.2.1 Meeting the aims and objectives

Results from this thesis have revised previous estimates of both the broader category of thrust and hand-thrown wooden spears. How each objective was met will now be reviewed in turn.

1. The thesis met the first objective primarily through experimental approaches. Participants in the human performance trials were trained in thrusting and throwing spears. These trials replace previous estimates of the impact velocities of both delivery systems with datasets providing velocity brackets for further testing of hand-delivered spears. The spear thrusting trial also captured force profiles and peak forces of wooden spears during use, and facilitate our understanding of the human variability in this delivery method, and strengthening the view that replicating thrusting spears as projectile weapons is inappropriate. The throwing trial not only provided the first data on the relationship between release and impact velocities for these weapons, but also gives an indication that in the hands of skilled users, they are effective at distances >10 m. Both trials indicate that in comparison with any available previous studies, training

improves performance, and that untrained participants do not therefore paint a clear picture of the effectiveness of prehistoric weaponry. This thesis was not able to evaluate what difference adding a stone or osseous point would make to all of these variables, and these would need to be tested separately. It was outside the scope of this study to evaluate the differences that variation in mass makes on performance, and so the results should be treated as mean values.

2. The second objective was met through original research on the morphometrics of distal parts of archaeological wooden spears, and of further features of ethnographic wooden spears (Chapter 6) with larger samples than have been presented to date. The objective was met in part through a better understanding of the design of the penetrating tips of archaeological wooden spears, and an experiment helped to highlight that even small differences in tip diameter may affect penetration. The morphometric study of ethnographic examples highlighted the difficulties in assigning delivery methods to these spears, and thus inferring function or creating clear taxonomies from morphometrics. Both studies clearly indicate that archaeological wooden spears were robust in comparison with those of recent pre-industrial societies, and also that attention was paid to the penetrating part of the spear. Overall the analysis of their design supports their function as penetrating weapons, intended for hunting.
3. The ethnographic review proved fruitful in highlighting that the recent use of wooden spears was globally spread, they were used in a variety of environments against small, medium and large prey, and with a wider variety of hunting strategies than are often suggested. The review met this third objective even though it was not intended to be comprehensive, although a clear differentiation in delivery method was frequently not met and there are many ambiguities in the literature.
4. The objective of evaluating the capacity of hand-delivered untipped wooden spears to lethally wound a large adult mammal was met via the experimental work in Chapter 8. The result was clear that as both thrusting and throwing spears, they are capable of lethally wounding an adult horse in the main target area containing vital organs, with hand-thrown spears slightly more reliable than thrusting spears. Spears could break catastrophically during use, indicating the use of multiple spears for a successful hunting episode. A limitation of the spears may be their inability to cut through bone, including through dense areas of a scapula, making aim a significant factor in the successful use of such a weapon. This work is supported by the ethnographic evdence showing that wooden spears were used recently to hunt both smaller and larger terrestrial game, as well as marine-based prey.
5. The aim to quantitatively and qualitatively evaluate potential Middle Pleistocene hunting lesions from wooden spears was met through the analysis in Chapter 4 and experimental work recreating the use of both hammerstones and wooden spears. The results suggest that the Boxgrove scapula best matches impact from a hammerstone,

with the Swanscombe scapula more difficult to assess due to lack of surety of human modification. Use as thrusting spears left no visible bone damage, while throwing spear damage may overlap with hammerstone damage. The experiments demonstrate areas of overlap for anthropogenic and carnivore assemblage modification in relation to flat bones. It was outside the scope of the thesis to evaluate further potential causes of overlap in damage characteristics, but damage from fluvial activities, trampling, post-depositional movement and excavation damage must be investigated further. Although the results make the search for diagnostic criteria pertaining to wooden spear use problematic, it does make sense of the absense of visible and identifiable weapon damage in the MP archaeological record, a period of time that has direct evidence of wooden spears alongside butchered animals.

6. The last objective was met in the discussions of several of the chapters, and will be further discussed in this chapter. The spears have been demonstrated to be suitable against a wide range of prey in a variety of environments, and to be effective against large mammals. They impact with significant force as thrusting weapons and very high KE as thrown spears, easily penetrating through thick hide and muscle. This demonstrates that although they may have limitations relating to ability to cut through bone, it is too simplistic to characterise them as ineffective. This last point is underscored by their persistence through the Late Pleistocene and until recent times. If MP hominins were selecting large rather than small prey in hunting, it is unlikely to be due to limitations of their weaponry. The damage the spears incur during use does strongly suggest the use of multiple spears, and against larger game cooperative hunting of at least two, if not more, individuals. The deliberate shaping and relative standardisation of spear tips demonstrates a sophisticated awareness of both terminal and wound ballistics. With this last objective the broadest in scope, it will therefore inevitably continue to be addressed through future research.

9.2.2 Limitations of the research

There are obvious limitations to the research in this thesis, many of which are shared with most approaches to archaeological evidence from the period. First, both modern human participants and primates represent imperfect referential models due to differences in cognition, physiology and behaviour. Therefore, results here, including from the human performance trials, acknowledge this in interpreting experimental results in the performance of wooden spears.

There was a limit to the amount of experimental work that it was possible to undertake in the scope of the PhD thesis. Whilst the focus could have been solely on replicating spears on animals on the basis of the estimates that are so often used, it was strongly felt that such estimates were inadequate, necessitating the human performance trials prior to setting experimental protocols replicating the spears on an animal. The work has provided a foundational understanding, but there is clearly further work to be done.

The ethnographic literature rarely provided clear data regarding delivery methods or performance of wooden spears, and there was a limit to the amount of time that could be dedicated to such a review. Therefore it is not comprehensive, and further research could help elucidate specifically which types of environments might be best suited to wooden spear use, and perhaps help clarify why groups with alternative technologies chose to continue making and using simpler wooden spears alongside more complex forms.

9.3 Future research

With such a wide-ranging and holistically oriented research programme, this thesis has resulted in a long list of further questions for future research. The most important and pressing of these will be covered here.

Regarding the performance of hand-delivered weaponry, the following questions have resulted from conducting experimental research:

1. What effect would introducing an animal target have on peak forces for two-handed spear thrusting?
2. What effect does introducing a lithic or osseous point have on peak forces and force profiles for two-handed spear thrusting?
3. Is homogeneity of variance in human performance similar regardless of training? Similarly, does variability decrease with training, or is ability in a certain measure, e.g. velocity, simply raised?
4. What effect does change in mass have on hand-delivered spears in terms of velocity? Similarly, what effect would differences in mass have on accuracy?
5. Is fitness or technique more significant for the effectiveness of hand-delivered weaponry?
6. What effect would target training have on the results of effective distances of hand-thrown spears?

Regarding the terminal and wound ballistics of wooden spears in particular:

1. What effect does wood density have on tip and shaft damage, particularly catastrophic damage?
2. Would lighter wooden spears be capable of equal DoP, or is a heavier mass key for force and energy of these weapons? Similarly, does the larger diameter of archaeological examples in comparison with ethnographic spears reflect their intended use on large mammals, requiring them to have more energy at impact?
3. Is a limitation of wooden spears in comparison with osseous- and lithic-tipped spears that wood struggles to cut through bone, with the latter two better at perforating scapulae due to durability and/or sharpness?

Another fruitful research topic for the future that could be met with a variety of methods would involve investigating macroscopic and microscopic damage to wooden spears from use, comparing such marks and traces with manufacturing traces and post-depositional damage. Such work would be primarily experimental in nature, and breaks and damage incurred during experimental use (Appendix 1) can form the basis of a reference collection to compare with all of the archaeological examples. Further evaluating the morphometrics of wooden spears, and specifically of the Schöningen collection would help elucidate their function and variability. In particular a clearer understanding of the location of maximum diameter, point of balance, and estimates of mass may help in determining delivery method, which has ramifications for debates on hominin thrusting vs. throwing and associated hunting strategies.

9.4 The performance of wooden spears

9.4.1 Summary of results of research on ethnographic and archaeological experimental studies

This section brings together in table form a summary of the key results from Chapters 4 to 8.

Table 9.1. Summary of selection of ethnographic data on wooden spears

Measurement	Results	Reference Section
Effective Distance ethnographic hand-thrown spears	20-40 m	6.3.4
Prey size class hunted	sizes 1 through 4	6.3.3
Mass	150 g - 2246 g (mean = 701 g, n =58)	6.7.1
Length	1375 mm - 4385 mm (mean = 2804, n = 58)	6.7.1
Maximum Diameter	13 mm - 32 mm (mean = 21 mm, n = 58)	6.7.1
Location of Maximum Diameter (% from distal tip)	4% - 66% (mean = 35%, n = 58)	6.7.1
Diameter at 100 mm	6 mm - 22 mm (mean = 12, n = 57)	6.7.1
Diameter at 150 mm	8 mm - 23 mm (mean = 13.4, n = 57)	6.7.1
opening angle (to 100 mm)	4° - 13° (mean = 7°, n = 57)	6.7.1
Point of Balance (% from distal tip)	34% - 56% (mean = 47%, n = 58)	6.7.1

Table 9.2. Summary of archaeological data on wooden spears

Measurement	Results	Reference Section
Length	mean = 2002 mm, n = 8	4.3.4
Maximum Diameter	42 mm, n = 8	4.3.4
Location of Maximum Diameter (% from distal tip)	16% - 88% (mean = 43%, n = 4)	4.3.4
Diameter at 100 mm	15 mm - 26 mm (mean = 18.5, n = 6)	4.3.4
Diameter at 150 mm	16 mm - 29 mm (mean = 21 mm, n = 6)	4.3.4
opening angle (at 100 mm)	9° - 15° (mean = 10°, n = 7)	4.3.4

Table 9.3 Summary of experimental data using wooden spears

Measurement	Results	Reference Section
Distance of thrown spears	up to 31 m for distance throws	7.3.3.2
Impact Velocities thrown spears	12.7 m/s - 33.3 m/s (mean = 17.26 m/s, n = 31)	7.3.3.1
Change from release velocity to impact velocity thrown spears	-1.51 m/s - 5.4 m/s (mean = 0.57 m/s, n = 18)	7.3.3.1
Hit/miss rates thrown spears	5 m: 58% hit rate 10 m: 25% hit rate 15 m: 25% hit rate 20 m: 17% hit rate 25 m: 0% hit rate	7.3.3.2
KE thrown spears	65 J - 444 J (mean = 122.5 J, n = 31)	7.3.3.1
Impact Velocities thrust spears*	2.8 m/s - 7.6 m/s (mean = 4.79, n = 45)	7.2.3.4, 8.4.3.1
Peak Force thrust spears	362 N - 1120 N (mean = 661.4, n = 39)	7.2.3.5
Depth of Penetration on horse carcass using thrust spears	0 mm - 326 mm (mean = 155.2, n = 11)	8.4.3.3
Depth of Penetration on horse carcass using thrown Spears	49 mm - 284 mm (mean = 157.0 mm, n = 13)	8.4.3.3

*** combines data from two thrusting experiments**

9.4.2 Attributes of wooden spears: new models

The results of the archaeological, ethnographic and experimental approaches presented in this thesis have demonstrated that robust MP hominins inhabiting Europe using wooden spears as hand-delivered weapons were armed with the *capacity* to hunt small, medium and large prey in a variety of environments. I specify capacity here rather than the practice, on the basis that ethnographic groups used wooden spears to hunt size class 1 through 4 animals (Table 6.2). Therefore the fact that MP and early LP hominins focused on medium to large prey (size classes 2-6, Table 2.1), suggests that choice of prey was not necessarily due to a limitation inherent in the weapons themselves. In Chapter 3 (3.1.2) a list of attributes that are used to compare the performance of prehistoric hunting weapons was proposed based on previous research. Some attributes relate more to delivery method, while others relate more to the form and materials of a particular weapon. Fig. 9.1 is a model of how each attribute connects with others, with the size of each attribute reflecting how many connections can be inferred. This is not intended to imply that the attributes with the most connections have the most influence on lethality but rather to highlight their interdependence. What is immediately striking about the model is the importance of design. Every other attribute has a relationship with this central aspect of spear performance. In contrast, the focus on limitations of hand-delivered spears and/or wooden spears has often been on ‘effective distance’, ‘safety to user’, ‘suitability to prey and environment' and/or 'ease of manufacture' (e.g. McNabb 1989; Veil 1991; Churchill 1993; Shea 2006; Haidle 2009; Shea & Sisk 2010a).

This thesis investigated many of these attributes through its interdisciplinary research, including on the morphometrics of wooden spears. Although limited access to archaeological wooden spears meant that a complete analysis of morphometrics was not possible, the aspects that were addressed have highlighted the importance of continuing to analyse the design features that are evident in both fragmented and complete examples, which will also contribute to analysis of the design of osseous and lithic-tipped hand-delivered spears. Each of the attributes is now discussed in turn in relation to hand-delivered wooden spears, on the basis of the outcomes of research in this thesis as well as previously published work.

9.4.3 Design

As can be seen in Fig. 9.1, the design of weapons influences all the other attributes used to evaluate performance. For example, the mass, point of balance, and wood selected all affect velocity, flight trajectory, and stability in flight (see Chapters 4, 6 and 7). By extension, these properties also affect how easy the spear is to throw at distance and the time invested in learning to use it. The material, shape, and sharpness of the tip of a weapon influences how easily the weapon penetrates through hide, muscle tissue, and bone, which ultimately determines the DoP along with KE or force (depending on whether projected or thrust). These same features will also affect the durability of a weapon, so the maker of a spear needs to balance the benefits of each (decisions that are presumably at least partly made through experience). The design of both archaeological and ethnographic examples can be analysed, the results of which aid in evaluating the other attributes relating to performance.

9.4.3.1 Tip design

The design of the distal tips of archaeological and ethnographic wooden spears is standardised in comparison with other design variables such as length and mass (Chapter 4, Chapter 6), reflecting an understanding that tip design is crucial for penetration. The drop-test experiment in Chapter 8 (8.3) demonstrated that even small differences in slant angle of the tip of a spear could affect penetration. Replicas of Schöningen Spear II were shown (section 8.4) to be capable of penetrating through relatively thick horsehide and muscle tissue.

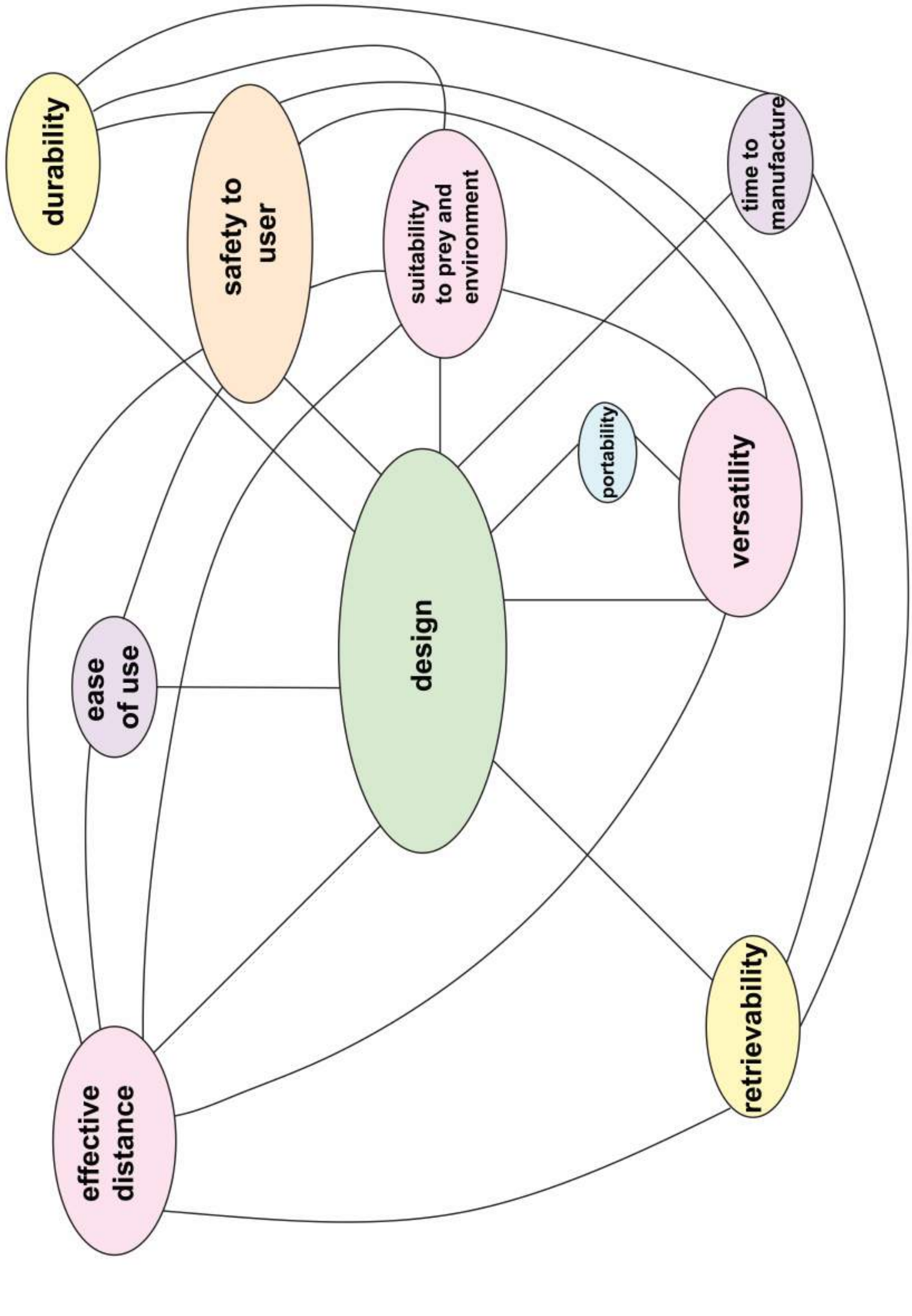

Figure 9.1. Visualisation of the attributes for evaluating spear performance. The larger the oval, the more direct connections it has with other attributes

Diameters of the Clacton, Schöningen and Lehringen spears measure between 16 and 29 mm at 150 mm from the tip (Table 9.2), which may facilitate penetration between the ribs of large mammals as this appears to bear a relationship to intercostal rib spacing (see sections 6.7.1

and 8.4.3.5). Distal tips are consistent with an intended design suitable for intercostal penetration, and were unlikely to have been solely designed as weapons for self-defence or power scavenging, though their use in these latter activities was likely important (section 4.4.4). However, they would be extremely useful for both of these as well and therefore they were likely to be multi-purpose weapons. Tip diameter is likely balanced against spear tip damage, with distal points both breaking and/or incurring major or minor damage during experimental use (Appendix 1). Although the experiments were not designed to examine breakage, they have provided preliminary data for comparative purposes. Experimental work aimed at comparing breakage of wood in relation to other materials would facilitate an assessment of the durability of different species of wood in relation to Late Pleistocene innovations in weapon materials.

9.4.3.2 Overall design

The morphometric study of ethnographic spears in this thesis broadened the previously published ranges (Oakley et al. 1977), particularly of mass and length of hand-delivered spears, demonstrating that there is variability in overall design, and particularly for mass. Correlations with the ethnographic literature confirm that a range of masses of spears were thrown at distance including spears signficantly heavier than the replicas used in the experimental work for this thesis, and therefore their mass does not preclude them from being thrown at a distance. Point of balance was found to be fairly constrained in ethnographic wooden spears (section 6.7.1), and is likely to be an important feature of design, warranting further study in the archaeological examples; experimental work on this feature would prove useful in determining more precise correlations between location and functionality.

9.4.3.3 Mechanics of hand-delivered spears

The results of the human performance throwing trial showed that impact velocities of a replica of Schöningen Spear II ranged from 12.7 m/s - 33.3 m/s (mean = 17.26) for all throws, and a range of 13.5 m/s - 21.7 m/s (mean = 16.6) for aimed throws (Table 9.3, section 7.3.3.1). The impact velocities were fairly constant at 10 m to 15 m distances, and were higher for throws 20 m and greater. This last finding has significance for hunting strategies: imagine a scenario where a group of hominins throws a volley of spears at a herd of animals from a distance of 25-30 m resulting in impact velocities reaching over 30 m/s; this is far greater than the velocities tested on a horse carcass in Chapter 8. This strategy would be an effective first line of attack, with hominins subsequently moving closer in for aimed throws and/or thrusts at the main target area of any wounded or stunned animals. The KE involved in throwing ranged from 65 J - 444 J (mean = 122.5), which exceeds estimates for complex projectiles (Tables 7.3, 7.4, 7.5, 7.16, 9.3). This directly contradicts the statement that 'mechanically projected missiles typically hit with more force (sic) than hand thrown or thrusting weapons' (Clarkson 2016, p.203). The ability of a projected weapon to penetrate is highly dependent on the KE (not force) at impact, while the human performance thrusting trial in this thesis has demonstrated that the mechanics of spear thrusting differ from those of projectiles.

The morphometric study of ethnographic spears showed a relatively strong relationship between the maximum diameter of a spear and its mass (section 6.7.1). There is a clear difference between maximum diameters of archaeological examples in comparison with recent ethnographic examples, regardless of delivery method (Tables 9.1, 9.2 and section 6.7.2), which therefore likely shows a reduction in mass of spears over time. KE is the most reliable means of directly comparing the ability of the different projectiles weapons to penetrate an animal; assuming that tip design and material were kept constant, this is clearly not a limitation of hand-thrown spears in comparison with complex projectiles. A key finding of this thesis that has ramifications for future experimental research is the likelihood that overlaps in velocities of hand-thrown spears and spearthrower spears are evident. This finding complicates the quest for identification of velocity-dependent impact fractures (e.g. Hutchings 2011), as well as evaluations of the wound ballistics of different weapon types because discrete performance brackets may not exist.

The mechanics of spear thrusting are different from projectiles in motion (section 7.2.4), making both controlled replication and direct comparison between delivery methods challenging, and the forces in this study are not directly comparable to KE from studies on projectile weapons (contra Schoville et al. 2017). The experimental work in this thesis demonstrated that wooden spears used as thrusting weapons by trained participants (Chapters 7 and 8) have impact velocities significantly slower than hand-thrown spears, ranging from 2.8 m/s - 7.55 m/s (Table 9.3). Peak forces ranged from 362 N - 1120 N, (mean = 661.0 N), and as this is a key component of DoP in thrusting, these forces need to be replicated in experimental work. A direct study comparing different tip materials and forces in thrusting would help clarify whether adding a stone point would facilitate penetration, which may result in lower peak force. While KE could not be calculated for thrusting using the measurements taken in the experimental work, the loads involved are clearly high, and proved more than sufficient to penetrate the horse carcass. Directly comparing the energy of thrusting spears to projectile weapons will require further data collection, for example by integrating measurements of force with distance. It is hypothesised that increases in spear mass may slightly lower velocity at impact, but at the same time may also help increase DoP, something that could be experimentally tested.

9.4.3.4 Wound ballistics of hand-delivered wooden spears

Depth of penetration for hand-delivered spears were high enough for both thrusting and throwing to be considered lethal to a horse, with a mean of 155.2 mm for thrusting and 157.0 mm for throwing (Table 9.3). Interestingly all of the throwing impacts on the carcass penetrated to some degree, while this was not the case for spear thrusting (section 8.4.3.3). Similarly, thrown spears impacted >150 mm more often (62%) than thrust spears (45%). Although relatively small sample sizes, these results indicate that spear thrusting and throwing with wooden spears can result in DoPs capable of seriously wounding and killing a large animal, but that hand-thrown spears are potentially more likely to wound an animal with a single impact. It has been suggested elsewhere that wooden spears differ from lithic-tipped weaponry in the types of wound profiles, which would also make DoP and therefore KE and a sharp tip important (Salem & Churchill 2016). Bleeding of wound cavities would probably be less profuse, and the potential for the animal to escape and heal may be greater (Salem & Churchill 2016). However, as discussed elsewhere in the thesis (8.4.1.1), these studies include testing variable shapes at the same time as variable materials, and therefore the results should be considered preliminary.

The examples discussed here illustrate that design strongly influences lethality, the evaluation of which is a key objective of this thesis. Wooden spears did not make any visible damage to bone when used as thrusting spears; conversely, when used as hand-thrown spears they created visible hunting lesions on both ribs and scapulae and these lesions overlap in size and damage characteristics with those made by experimentally-produced lithic and osseous-tipped weapons. A limitation of these earliest weapons appears to be that they do not easily penetrate through dense bone, with the wood points often fragmenting in the muscle tissue, or the spear shafts breaking (section 8.4, Appendix 1). This result implies that aim when using wooden weaponry is significantly more important than it would be for lithic or osseous-tipped weapons with sharper cutting edges and/or more durable points, as these are able to cut through bone (e.g. O'Driscoll & Thompson 2014) and therefore a major limitation relates to the material properties of wood rather than the mass of the spear, or the velocity or distance from which it is thrown. This in turn suggests that the innovation of hafting, evidently in use by Neanderthals by 200,000 BP with the probability of lithic-tipped spears in use during the early Late Pleistocene, as early as MIS 7 or 6 (Mazza et al. 2006; Villa et al. 2009), and may have been significantly more influential on hunting success than mechanically-projected weaponry, thought to have been an innovation of *H. sapiens*. This point has significant ramifications for those who continue to seek causation for the replacement of Neanderthal populations by *H. sapiens* on the basis of technological superiority and hunting strategies.

9.4.4 Effective distance of hand-thrown spears

The effective distance of hand-thrown spears has been discussed multiple times in this thesis (e.g. sections 6.1.2, 6.3.4, 7.1.1, 7.3.4.2). This measure is irrelevant for thrusting spears, which are contact weapons. While many have somewhat blithely dismissed wooden spears' (or humans'!) ability to 'reliably' hit a target when thrown, direct references to what percentage of throws resulting in a hit would be considered 'reliable' are not typically suggested (but see Churchill 2014). Therefore this thesis is unable to directly support or reject ambiguous statements on accuracy in comparison with complex weapons, but it does provide data with which to compare future accuracy studies of other launching systems. The results addressing the ability of trained humans using hand-thrown spears to hit a target (Chapter 7) provide a baseline for future comparisons. The athletes were able to hit a target on the ground at distances up to 20 m, with a decrease in percentage of hits at each distance and interestingly, possibly a slight increase when the target was placed vertically higher. Participants also threw the replica spears in distance throws of over 30 m. The javelin athletes in the trial were neither the most elite throwers, nor were they inexperienced throwers. A limitation of the throwing participants used for the present study (Chapter 7) is that they do not regularly practice to hit a target, and therefore it can be expected that training for aim would greatly increase their ability to hit a target. Adding to the experimental data, the review of the ethnographic literature on throwing distance places conservative estimates considerably higher, from 20 m - 40 m. It is not appropriate in this case to rely upon statistical measures in terms of limitations of weapons because there are too many variables that confound our ability to make parallels between groups, as well as between MP hominins and recent hunter-gatherers. Instead, the ethnographic review highlighted the need to consider whether we can establish ranges for performance of different delivery systems which encompass the upper limits of distance and velocities when used by highly skilled hunters. Together, the findings in this thesis do not support estimates of a limit of 5-10 m effective distance for hand-thrown spears. The model for innovations in weaponry that was proposed in Chapter 3 (Fig. 3.2) is replicated here with the addition of a conservative estimate of 15 to 20 m distance for hand-thrown spears (Fig. 9.2). This has considerable implications not only for assumptions on the prey and hunting strategies suitable for hand-thrown spears, but also for safety of the users. Although hand-thrown wooden spears are still likely to achieve smaller distances than mechanically aided projectiles, the differences when used by skilled throwers are not nearly as great as have been suggested. Iovita & Sano (2016a) discuss issues for simple linear models of weaponry through time, mentioning that the ability to identify launching mechanisms has proven to be elusive, and also that linking development in technology with biology has significant challenges. I would add that the continuance of hand-delivered technologies alongside mechanically-aided weaponry further obscures signatures that might relate to delivery method. The reworked model (Fig. 9.2), which will surely continue to evolve in response to further research, reflects that hand-thrown spears (including wooden spears) were not retired as outdated models (Spears 2.0!), but rather continued to be in use after subsequent innovations, not only by groups who only used wooden spears such as the Tasmanians, but also by groups who used hafted weapons and complex projectiles alongside wooden spears. This increasing diversity in weaponry over time therefore must be taken into account for Late Pleistocene archaeological contexts.

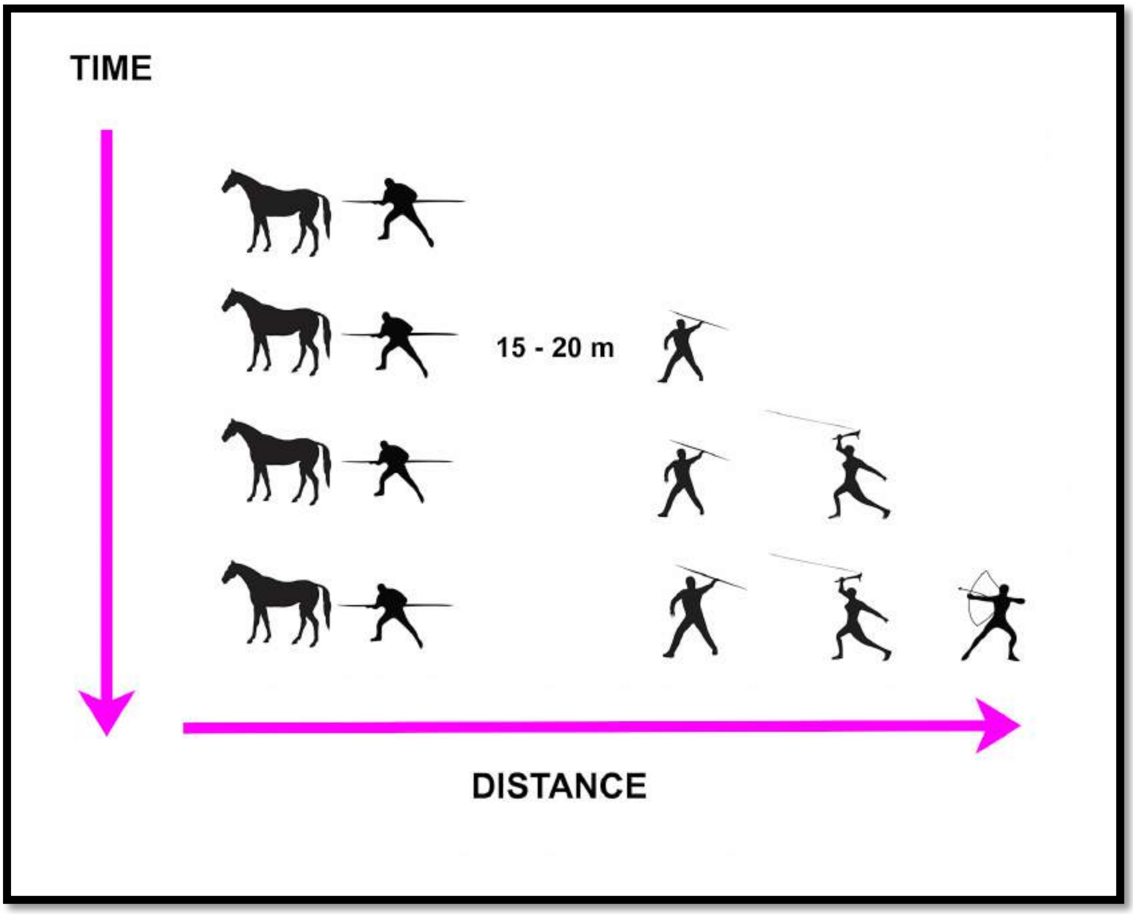

Figure 9.2. Model of changes in weaponry delivery systems through time, with a revised estimate of 'effective distance'

9.4.5 Suitability to prey and environment

The ethnographic study (Chapter 6) demonstrated that a wide range of prey sizes, with variable behaviours and in a wide variety of environments and climates, were targeted with untipped wooden spears, even when other weapon systems were regularly used for hunting. The evidence from Schöningen and Lehringen, where wooden spears have been found in direct association with butchered remains of large mammals strongly supports the capability of larger prey (≥ size class 4) to be killed with these earliest known weapons. The experimental work (section 8.4) confirmed the ability of wooden spears to penetrate an adult horse carcass sufficiently to wound and kill such a large animal, and this is the first experiment of its kind using these wooden spears on such a large animal. However the ethnographic evidence showing the targeting of smaller prey using hand-delivered wooden spears (size classes 1-3) has significance for understanding shifts towards a broader spectrum diet, perhaps as early as MIS 9 (Blasco & Peris 2012) although possible throwing sticks such as those suggested at Schöningen and Florisbad Peat 1 from MIS 5e (Thieme 1997; Schoch et al. 2015, Appendix 1 Table A.1) must also be considered for those rarer examples of weapons used in the predation of small game. Thus, wooden spears should be considered as weapons suitable to a wide range of prey, both in terms of size and behaviours, inhabiting diverse habitats including both closed forested and open grassland environments (section 6.3.3).

9.4.6 Versatility

Hand-delivered wooden spears are known from the ethnographic review to have functioned as effective weapons not only in hunting terrestrial animals of a variety of prey sizes and types, but also for fishing, interpersonal violence, and self-defence against both humans and animals, making them versatile weapons (Tables 6.1 and 6.2). In addition, several of the MP examples could have functioned as either thrusting or throwing spears, as demonstrated for Schöningen Spear II (Chapters 7 and 8). This versatility helps to evaluate the economic benefits of a weapon that was used by multiple species of *Homo* over hundreds of thousands of years. Hypotheses that hand-delivered and/or wooden spears were limited to a small selection of hunting strategies have not been supported by this research. The experimental work has demonstrated that the spears are capable of distance throws, which allows a variety of possible hunting strategies including approach hunting. The ethnographic review clarified not only that both heavy and light wooden spears were regularly thrown at distance for hunting, but also that associated hunting strategies included approach, ambush, pursuit and disadvantage hunting executed by single individuals up to large-scale cooperative groups that sometimes involved women and children in game drives (section 6.3.3). Hand-delivered wooden spears can thus be thought of as functionally flexible and versatile weapons, and when thrown were 'true' projectiles, i.e. those thrown at distances comparable to spearthrower distances with greater KE than complex projectiles (contra Churchill 1993; Shea 2006).

9.4.7 Portability

Portability was not experimentally tested, but ethnographic accounts contribute to evaluating this attribute. The ethnographic evidence demonstrated that multiple wooden spears were often carried, sometimes for multifunctional purposes with one or more used for throwing, reserving a last spear for thrusting (section 6.3.3). This means that the collection of spears found at Schöningen, which may also reflect discard over time as evidenced by the differing season of deaths of the horses (Julien, Rivals, et al. 2015), could represent both multiple users and/or multiple spears per individual. Although carrying multiple spears would be possible for hominins, the length and mass of early spears must be taken into consideration. Carrying one or more spears as well as flint tools and/or raw material for flint for a distance would potentially require additional means for carrying such as clothing or containers, which has implications for coordinate technologies. At both Boxgrove and Schöningen the raw material used for lithics was local and therefore in some senses expedient (Pope & Roberts 2005; Serangeli & Conard 2015). Spears however, were likely brought into the site at Schöningen, reflecting planning and mobility of weaponry (Conard et al. 2015), with curation suggesting relatively long use lives. If the Boxgrove fauna were killed using weapons, these were almost certainly also brought to the area from further afield due to the nature of the landscape. In comparison with shorter and lighter bow/arrow technologies, there is almost certainly a limitation in terms of how many of these large hand-delivered spears could be comfortably carried long distances in comparison with a set of arrows. Therefore, large hand-delivered wooden spears are logically less portable than Upper Palaeolithic inventions including bow/arrows or slingshots.

9.4.8 Durability

Damage to spears occurred experimentally, particularly during throwing at the carcass (Appendix 1). Such damage would necessitate rapid repair and/or the use of multiple weapons. This supports hypotheses that the hominins engaged in cooperative hunting. An awareness of the properties of wood in the MP is reflected in the choice by hominins not only to use wood with both density and elasticity, but also in the offsetting of the tips of the Schöningen and Lehringen spears from the softest inner part of the tree (Thieme & Veil 1985; Veil 1991; Schoch et al. 2015). Their durability compared with stone or osseous weapons cannot be directly compared in this thesis, apart from remarking that they do break during use and that Guthrie (1984) noted that wood breaks more frequently than osseous points. Much of the tip damage incurred during experimentation was repairable (Appendix 1), and at least one spear at Schöningen shows signs of curation (Schoch et al. 2015), while possible damage to tips is visible on the scans of some of the Schöningen spears (section 4.3.2).

9.4.9 Retrievability

Retrievability was not directly tested in the experimental research of this thesis, but some hypotheses can be formed on the basis of effective distance findings. Retrievability of hand-delivered wooden spears is possible, given the distances involved and the size of the weapons making them visible in the landscape, though if throwing at animals trapped in muddy water such as has been argued for Schöningen (Voormolen 2008b; but see Stahlschmidt et al. 2015a), this could be slightly compromised. Overall, their retrievability would logically be rated as high in comparison with smaller- and greater-distance weapons, but landscape surely plays an important role.

9.4.10 Safety to the user

The effective distances involved with thrown wooden spears demonstrate that strategies for spear throwing would not be as dangerous as have been characterised, though spear thrusting, a technique used amongst recent hunter-gatherers in hunting is dangerous due to proximity to prey (Chapter 6 this thesis; Churchill 1993). Given the likelihood for damage to the tips of wooden spears to occur during use, the implication is that in order to successfully hunt with minimum risk of injury, cooperative hunting with a group of hominins carrying potentially two spears or more is probable. Therefore hunting large herd animals such as horses, as well as power scavenging from dangerous carnivores would not have been a solitary activity. However, hunting of smaller flight animals could be executed by small groups or solitary hunters without much risk of injury. Use as a thrusting spear facilitates repeated use of the weapon, and although this could be much more dangerous, the repeated use provides safety to the user. With spear throwing, one spear is one shot, which is a clear limitation in comparison with bow/arrow hunting. Berger & Trinkaus (1995) discounted spear throwing by Neanderthals on the basis of the mass of spears - which has been disproven in this thesis - and on the physiological capacity for throwing, which is still under debate (e.g. Churchill & Rhodes 2009; Roach & Richmond 2015a). The strong possibility that MP hominins were capable of hand-throwing spears leaves the cause of trauma on Neanderthal remains, and by extension dangerous hunting strategies, up for debate (Trinkaus 2012).

9.4.11 Investment in manufacture

Manufacture of spears was not directly researched in this thesis, but other studies have demonstrated that a spear made with Lower and/or Middle Palaeolithic lithic tools requires about 4.5 to 5.5 hours of manufacture, though the entire process of raw material procurement can be considered significantly longer (Veil 1991; Haidle 2009). With a significant time investment, these spears may also have been personal pieces of kit, as representative of the identity of the maker and user as a handaxe may have been, matched to a user's physique much as modern day javelin athletes select javelins with differing properties to match their stature, strength, and skill (Johnson 1987). The attention to design that is clear from the earliest examples of these weapons (Chapter 4) highlights that they were carefully shaped, probably with a variety of tools and methods, with consideration for the distal parts of the spears (Chapter 4; Schoch et al. 2015; Veil 1991). No clear evidence yet exists for the use of fire in manufacturing MP wooden spears (Oakley et al. 1977; Schoch et al. 2015; Stahlschmidt et al. 2015b; pers. obs.), though this possibility could be further explored given recent methodological advances and given the possible use of fire in the manufacture of the Lehringen spear (Thieme & Veil 1991) and ethnographic spears (Appendix 1; pers. obs.).

9.4.12 Ease of use and investment in learning

This final measure is perhaps one of the most interesting findings from both the experimental research and ethnographic review in this thesis. Untipped wooden spears make for lethal weapons, both at close contact as well as at a distance, but there is a caveat. The experiments (Chapters 7 and 8) demonstrated that training positively impacts on velocity, force, and ability to hit a target. Some (e.g. Cundy 1989) have suggested that perhaps the disadvantage of hand-delivered weapons in comparison with complex projectiles lies not in their inability to hit a target at a distance or penetrate a hide, but rather in the time investment it takes to master thrusting and throwing. It is hypothesised here on the basis of comparing the results of Chapter 7 with Churchill's (2014) informal throwing experiment, that throwers regularly trained in target practice would show significant increases in effectively hitting a target compared with the javelin athletes in this study. Ethnographers have written of the training of children and young men in weapon use being one of the primary focuses of 'education' (section 6.3.4). Javelin athletes similarly practice many hours per day to be able to throw at distance. The surety of certain weapon researchers that they or their participants are capable of matching such training with as little as an hour of their time to those who have invested years to master techniques and develop strength is something that needs addressing in the discipline. The possibility that hand-delivered weapons require not only significant training for accuracy in throwing but also strength, power, and technique in spear thrusting may be a significant limitation of hand-delivered spears. This thesis therefore in part supports Cundy's (1989) hypothesis that the advantage conferred by complex projectiles relates to ease-of-use rather than greater distances and/or energy or force at impact. Intriguingly, the cognitive demands of launching complex projectiles may be greater than those for hand-delivered spears, a suggestion that warrants further study (Williams et al. 2014). A release on the time and energy needed to master and use hand-delivered spears, which would need to be budgeted for, could be a major advantage of complex projectiles.

9.4.13 Hand-delivered wooden spears: a brief summary of performance

In contrast with simplistic characterisations of hand-delivered wooden spears, this research has highlighted some areas of performance where the weapons have exceeded expectations, while other areas appear to suggest limitations that later innovations may have helped address. As hand-thrown spears they can be summarised as being optimised as medium-distance projectiles, effective at distances as close as 5 m and as far as 20 m against a range of prey sizes. Being functional as both thrusting and hand-thrown weapons, wooden spears are versatile, and are relatively simple to manufacture. A clear understanding of wood properties and design is in place with the earliest examples MP wooden tools. As thrusting spears they are by nature a dangerous weapon for the user given the proximity to prey and/or dangerous carnivores, but as hand-thrown weapons they would not necessarily be significantly less safe than spearthrowers given the distances demonstrated to be effective in this thesis, as well as the KE they possess. They are less portable than bow/arrows, with an individual likely able to be able carry and use up to perhaps three of the heavier spears at most, possibly throwing one or two and reserving one for dispatching prey and/or self-defence. Experimental use demonstrated their difficulty in impacting through dense areas of bone, creating relatively small, lenticular wounds which may not bleed as effectively as larger wounds. Together these findings suggest that aim for vital organs is key for wooden spears, as a hit to a scapula on a large mammal would be unlikely to be capable of being lethal; this further suggests that accuracy is more important for wooden spears than for osseous- or lithic-tipped weapons, and that therefore skill and training for accuracy is very important. It is probable that this accuracy would require significant time investment; furthermore stature, body mass, and strength may contribute to higher energy at impact with both thrusting and throwing. Together these last two points imply a long period of training, and perhaps natural selection for powerfully-built hominins to use hand-delivered spears. Mechanically-aided weaponry may well require less training and a smaller physique to master, potentially allowing more variability in design and permitting more gracile humans to effectively use the weapons (e.g. see Whittaker et al. 2017). Thus mechanically-aided weaponry might be adaptive partly because of the relaxation on both time investment and a powerful physique for both thrusting and throwing. Because the spears frequently broke during use, and because there would be a limit on the number that an individual could carry, this strongly implies cooperative hunting strategies of larger and dangerous animals, though smaller solitary animals with flight responses could be hunted with smaller groups or solitary hunters as well. The material properties of wood may well be another significant limitation, as they break and bend during use as hand-delivered weapons, sometimes catastrophically, whilst at the same time do not impact easily through bone. A direct and systematic comparison of breakage between different materials and the implications of the materials (rather than shape) for wound ballistics would be useful in testing this hypothesis. This summary uses data derived from the archaeological, experimental and ethnographic research in this thesis, rejecting certain characterisations of limitations of hand-delivered wooden spears, while supporting others. As others have pointed out (Iovita & Sano 2016a), it is important in moving forward in weaponry research to evaluate the paradigm that mechanically-projected and composite weapons conferred a distinct and overwhelming advantage by every measure over simpler weapons. This thesis has contributed to this goal by providing performance data on hand-delivered wooden spears from multiple angles.

9.5 Identifying the use of wooden spears in the archaeological record

Overall, the experimental use of wooden spears left few marks to bone, and none of these are particularly diagnostic of spear use (section 8.4). When used as thrusting spears, there was no visible bone damage, and as throwing spears, there was identifiable damage 23% of impacts. Although prey profiles and butchery patterns suggest that hominins were hunting prior to the first appearance of weaponry (section 2.2.2), there are extremely few examples of potential hunting lesions from before the Late Pleistocene. Neither of the two proposed hunting lesions from the MP - those from Boxgrove and Swanscombe - bear damage that can be considered diagnostic of impact from a wooden spear. Intriguingly on the basis of the experimental work and the morphometric analysis of the damage, the damage on the Boxgrove scapula fragment from GTP17 is a better match to hammerstone percussion damage (8.5), an activity well-evidenced both at GTP17 and elsewhere at the site (Chapter 4). These findings illustrate the methodological challenges for zooarchaeologists in evaluating the cause of bone damage during this key period. Experimental archaeologists can help those conducting taphonomical analyses of bone assemblages by continuing to systematically produce reference collections and provide a morphometric and descriptive analysis of the results along with clear photographs and/or microscopic images for comparative purposes.

Similar to evaluating bone damage, there are challenges ahead in evaluating damage to wooden spears that may indicate use. Although some possible similarities between the archaeological examples and experimentally-used wooden spears were noted, there are many possible causes of damage to wooden weapons, from pre-depositional through to excavation and conservation. This thesis did not explicitly aim to evaluate damage to spears, but the resulting damage from use (Appendix 1) provides a useful comparative dataset, particularly for the Schöningen sample. Identification of wooden artefacts from the Pleistocene, including wooden spears, would be greatly aided by future research comparing manufacturing marks with wear damage from use in a variety of activities. The morphometric analysis of distal parts of spears should also help identify possible fragments of spears, providing a comparative dataset.

9.6 Significance: Middle Pleistocene hominins, their weapons, and implications for human behaviours

9.6.1 Hominin physiology and weaponry during the MP

It is evident from the fossil record that later MP hominins, from ca. MIS 13 through MIS 6, were robust and tall (Trinkaus et al. 1999; Trinkaus 2009; Froehle et al. 2013; Gallagher 2013). Modern day male javelin athletes are larger than average, with body masses of around 96 kg and heights of around 1.88 m, with height affecting the ability to throw at a distance (Mero et al. 1994). It appears that body mass is at least a partial contributor to force, though the full extent of the influence was not clear probably due to the sample size of participants (section 7.2.3.6). Therefore it is reasonable to infer that increases in body mass and height may affect the effectiveness of MP spears. The large diameters and by extension mass of wooden spears made by the MP European hominins vs. those of recent hunter-gatherers may imply that adaptations for throwing were under selection during this period. Increases in body mass and stature during the MP could at least in part reflect physiological changes necessary for effective spear use, with factors such as gene flow, mobility, nutrition and climate also potentially influencing MP hominin physiology (Holt & Formicola 2008). A connection between robusticity and weapon use is not a new hypothesis (e.g. Brues 1959; Frayer 1981) and it is likely that multiple factors affected body mass and stature (Bridges 1995; Holt & Formicola 2008). Alternatively, the overall reduction in diameters of wooden spears, including the distal points, could reflect differences in prey size between those associated with the archaeological and ethnographic examples. Whether or not they are connected, this study provides original data on distal spear morphologies, and collates the evidence of spear morphometrics including lengths, diameters and by extension mass, of the currently known Pleistocene examples, making direct comparisons with a large sample of ethnographic hand-delivered spears, and providing additional data with which to test models comparing hominin body size and prey size with weapon use.

9.6.2 Human-human and human-animal relationships in the MP: implications drawn from the use of spears

Interactions between humans, prey, and carnivores in the European landscape would have been shaped by weapons, beginning at the latest during the second half of the MP. Examples of hominin remains being gnawed by carnivores include the Boxgrove tibia (Stringer & Trinkaus 1999), while the Schöningen hominins used a carnivore bone as a tool (Serangeli et al. 2015). The relationship between hominins and large carnivores must have been fraught with competition and danger: would hominins, with their crafted spears, have felt or thought themselves somehow different from their prey, dependent upon extrinsic tools for survival that could easily be put down, lost, or broken? The weapons may have promoted a growing feeling of ‘otherness’ while at the same time becoming an extension of the body necessary for survival, potentially promoting a sense of identity and/or an awareness of a differentiation between being human vs. being animal.

Given the danger of hunting and power scavenging of large mammals such as horses, it seems likely that multiple hominins would be needed for a hunt (Voormolen 2008b). The likelihood of group hunting behaviours suggests cooperation, planning, and coordination, which many suggest implies syntactic language (Gärdenfors & Osvath 2009; Conard et al. 2015), although the execution of hunts by social carnivores including multiple and sequential predation without the use of language (section 2.2.3.1) needs to be taken into account. Perhaps even more than hunting, learning to manufacture and skillfully use thrusting and throwing spears is likely to have required communication including language, particularly given the long period of learning inferred by analogy with recent hunter-gatherers and athletes as well as by the importance of aim for lethality of wooden spears. Similar to the manufacture and use of handaxes, these teaching-learning activities would also have placed demands on hominins in terms of time budgeting and is also interesting when considering intra-group relationships (Ashton 2015). Intriguingly at Schöningen, Schoch et al. (2015) suggest that the 'throwing stick' could represent a child's spear, as it is similar to the spears in every way except its dimensions, measuring 775 mm x 30 mm. Oakley et al. (1977) report dimensions of 1587 x 11 mm for a children's spear intended for throwing, over twice the length of the example from Schöningen. Further research on the morphometrics of throwing sticks would help clarify a likely function for the Schöningen example. It is not yet clear whether females would have been taking part in hunts during the MP, as sexual dimorphism appears similar to recent humans (Gallagher 2013) and hunting and mothering are not *a priori* mutually exclusive behaviours as seen both by female chimpanzees who hunt with spears, and recent hunter-gatherer women both passively and actively engaging in hunting behaviours (e.g. Roth 1890, p.98; Goodman et al. 1985). A whole group of hominins could have been directly partaking in, or learning by watching the entire process of a hunt, from tooling up through to butchery, consumption, and discard.

The findings in this thesis also have implications for the shift from the European Lower Palaeolithic to Middle Palaeolithic between MIS 9 and 6 (Hérisson et al. 2016) including hypotheses about early and later Neanderthal hunting strategies, landscape use, increasing behavioural complexity and changing technologies (e.g. Scott et al. 2014; White et al. 2016; Rodríguez-Hidalgo et al. 2017). The outcomes of research in this thesis suggest that the innovation of adding a stone point to a weapon, which is suggested to have occurred around MIS 7 or 6 (section 3.1.3), may have had a greater direct impact on lethality than later weaponry innovations by modern humans. This thesis indirectly supports hypotheses that complex projectiles may be easier to use both in terms of aim as well as physical power needed than hand-delivered weapons, and that the advantages therefore of complex weaponry relate more to demands on physiology, skill, and time rather than factors such as kinetic energy or effective distances. Advanced cognitive abilities are evident in the awareness of the raw material properties of wood, including selection for dense and/or elastic wood, and the shaping of distal tips to avoid the soft pith (Thieme & Veil 1985; Schoch et al. 2015); this thesis adds to these previous assessments of wooden spears that hominins made clear connections between design and ballistic performance as early as MIS 11, with a preliminary suggestion here that there may be continuing improvements in choices regarding tip design through time (section 4.3.4). Similar awareness of raw material properties can be seen, for example, in the form of hafting adhesives used in Europe by MIS 7 or 6 (Mazza et al. 2006; Kozowyk et al. 2017), but also - as this thesis has demonstrated - by the desire to hafting a stone point to a wooden spear shaft in the first place, as the wooden spears had difficulty cutting through dense bone of large mammals (section 8.6). The cognitive abilities represented in an awareness of raw material and tip design of wooden spears thus represent cognitive capacities for subsequent innovations.

9.6.3 Behavioural shifts in the MP

No longer simply viewed as a jumble of disconnected and disparate lines of evidence (Isaac 1975), our understanding of European MP hominin behaviours has improved significantly in recent decades due to advances in analytical techniques of existing collections and hominin fossils, improvements in dating techniques, as well as new discoveries of some extraordinary sites (see Hosfield 2011; Ashton 2015; Shaw et al. 2016). In the early MP, hominins had adapted to a wide range of climates and habitats ranging from warm Mediterranean to cool temperate and even marginal boreal conditions with a preference for river systems and/or coastal locations (Hosfield 2011; Ashton 2015; Gosden 2015). But from between 600,000 and 500,000 BP in northern Europe (>45° N) the hominin fossil record indicates a substantial increase in encephalisation, more sites with larger assemblages, indications of structured behaviours, repeated use of landscapes and sites, organic tools, cooperative group behaviours including food sharing, understanding of raw material properties for technological purposes, sustained *chaînes opératoires*, and indications of systematic large mammal hunting and butchery (Roberts & Parfitt 1999; Pope & Roberts 2005; Hosfield 2011; Ashton 2015; Gosden 2015; Ravon, Monnier & Laforge 2016; Shaw et al. 2016). After MIS 12, what Gamble called ‘the hinge’ (Gamble 1999, p.107), MIS 11 brings the earliest direct evidence for weaponry, the earliest clear use of fire, and the earliest evidence of interpersonal violence, although this last behaviour comes from Sima de los Huesos in southwest Europe (Oakley et al. 1977; Preece et al. 2006; Preece et al. 2007; Ashton 2015; Sala et al. 2015). Like the manufacture of handaxes and control of fire, making of wooden spears requires ‘modular cultural capacity’, defined as ‘the development and use of a set of independent cultural units which can be used as behavioral modules, combined in different ways and put in an effective sequence by acting on and modifying each other’ (Haidle et al. 2015). This ability is thus in evidence in northwest Europe by MIS 11 (Oakley et al. 1977). At Schöningen, dated to the end of MIS 9, we see a coalescence of many earlier behaviours including complete examples of wooden spears, bone and additional wood tools, clear signs of hunting, systematic butchery and consumption of large mammals, repeated use of a site, with the possible new addition of the preparation of hides (Voormolen 2008b; Conard et al. 2015). Therefore the behavioural shift is observed piecemeal during MIS 13-11, while Schöningen, potentially an early Neanderthal site, represents an extraordinarily preserved and excavated site that captures many of these earlier behaviours together.

Where we place the technological origins of MP wooden spears in the context of this significant behavioural shift remains to be debated. Were prototypes of MP wooden spears present as early as 2 million years ago in Africa, as Henry Bunn and colleagues tentatively suggest (Pickering & Bunn 2007; Bunn & Pickering 2010; Bunn & Gurtov 2014)? Did they appear in Europe carried by a new, handaxe-wielding species emerging out of Africa during the Middle Pleistocene, or were they an innovation of European MP hominins around this threshold of MIS 13-11? The latter seems unlikely, because even if power scavengers, hominins would still require a method of self-defence against dangerous carnivores with whom they would have been competing for food, and the fact that chimpanzees can make and use wooden spears for predation demonstrates that the cognition needed to make a simple version of what eventually emerges as the sophisticatedly designed and crafted weapons seen at Schöningen is not beyond the abilities of our closest extant primate relatives. Chimpanzees do form groups to scare off predators, but they are extremely strong and have sharp canines, which Pleistocene *Homo* lacked, and even still chimpanzees often end up as dinner (Boesch 1991). However, even if wooden spears were a very early innovation designed for hunting, power scavenging, and/or self-defence, there were likely developments in design and awareness of raw material properties over a long period of time: in comparing the 'spears' manufactured by chimpanzees with the beautifully crafted examples from Germany, the fundamental materials and intent may be similar but the skill, knowledge, and experience evident in the outcome are incomparable. This may imply a long period of use of these wooden spears prior to their appearance in the European MP archaeological record, with development over time resulting in a basic conceptual understanding of the mechanics of weaponry, material properties of the general structure of wood as well as of different species, and of the connections between design and both terminal and wound ballistics. Wooden spears continued to be in use alongside subsequent innovations in weaponry, including by recent modern human hunter-gatherers, indicating an economic value for hunting, violence and self-defence. Similar to increasing variability in behaviours and technologies over the entire Pleistocene, subsequent innovations in weaponry do not represent a replacement of but rather an addition to this earliest and longest-serving weapon.

Appendix 1. Wooden spears and traces of manufacture and use

Appendix 1 provides some background information and additional observations made throughout the research on wooden artefacts from the Pleistocene, including in particular traces of manufacture, use and macrofractures of wooden spears.

A.1.1 Pleistocene archaeological sites with wooden artefacts

Table A.1.1 shows a list of Pleistocene archaeological sites containing wooden objects that potentially bear evidence of working and/or use by humans. Many of these objects are disputed, partly because methodologies for determining human modification on wood are more problematic and less developed than for stone and bone. Furthermore signs of modification vary by properties of the wood being worked, as well as by the manufacturing process. Marks caused by actions such as scraping with a lithic tool edge can be removed by secondary manufacturing processes such as polishing and smoothing, and can be further removed by handling, use, or post-depositional processes.

Table A.1.1 List of Pleistocene sites with potential wooden artefacts

Stage	Sites and artefacts	References
MIS 18-20		
	Gesher Benot Ya'aqov*, *Israel Wooden plank with polish	Belitzky et al. 1991; Goren-Inbar et al. 2002
MIS 11		
	Clacton-on-Sea, UK Distal end of a humanly modified yew branch, most commonly interpreted as spear point	Warren 1911; Oakley et al. 1977; Bridgeland et al. 1999
	Kärlich-Seeufer, Germany Two cylindrical wooden objects, previously interpreted as 'weapons', human modification disputed	Bosinski 2006; Boskinski 1995; Gaudzinski et al. 1996
MIS 9		
	Bilzingsleben, Germany Possibly worked wood, poorly preserved making interpretation problematic	Mania & Mania 1998; Schoch et al. 2015
	Kalambo Falls, Zambia Many artefacts of worked wood, variety of shapes (possibly MIS 11)	Clark 2001 Duller et al. 2015
	Schöningen, Germany 12 B and 13 II-4 9 double-pointed spears 1 distally-pointed spear interpreted as a 'lance' double-pointed stick (also called 'throwing stick') possible burnt wooden artefact (also called 'Bratspieß") worked bases of branches (also called 'Klemmschäfte' or 'clamp shafts')	Thieme 1997; Schoch et al. 2015
MIS 7		
	Cannstatt I, Germany 2.2 m long, 4 cm thick, interpreted as possible broken 'lance' didn't preserve, difficult to assess	Wagner 1995; Schoch et al. 2015
	Torralba*, *Spain	Biberson 1964, p.224

	small fragments of pine with traces of working and burning; a cast of a wooden object 50 cm in length, 1.5 cm diameter with a sharp conical point, interpreted as a possible spear but these traces have been contested	Freeman 1975, p. 674, 680 Santonja 2013
MIS 6		
	Poggetti Vecchi, Italy Collection of wooden artefacts manufactured from Boxwood Buxus sempervirens interpreted as multipurpose sticks, probable use including as digging sticks Evidence for use of fire in manufacture	Aranguren et al. 2018
	Krapina, Croatia Cylindrical piece of hard wood with possible burnt end, interpreted as possible fire drill Age and stratigraphic location uncertain	Oakley 1955 Plate II; Rink et al. 1995
MIS 5e		
	Lehringen, Germany 2.39 meter long, 3.1 cm thick (base) worked yew branch/trunk, pointed distally, broken in 11 fragments, found in association with butchered elephant, interpreted most commonly as a 'lance', i.e. thrusting spear	Adam 1951 Thieme & Veil 1985
	Florisbad Peat I, South Africa MSA site, ca. 125,000 BP (dating uncertain) Segment of a curved ovoid stick, interpreted as a possible throwing stick	Clark 1982 Fig 4.13, 3; Kuman & Clarke 1986 Grün et al. 1996; Bamford & Henderson 2003
MIS 5a		
	Königsaue, Germany Pointed pieces of wood	Mania & Toeffer 1973; Koller et al. 2001
MIS 3		
	Abric Romani, Spain 49-45,000 BP several possible shallow wooden vessels, poorly preserved and little indication of working cylindrical pseudomorphs (wood imprints)	Carbonell & Castro-Curel 1992 Castro-Curel and Carbonell 1995; Vallverdú et al. 2005
	Ljubjansko Barje, Slovenia Pointed wooden object, interpreted as possible wooden projectile point, ca. 40,000 BP; not accepted by all (see Schoch et al. 2015)	Gaspari et al. 2011
	Border Cave, South Africa Wooden artefact interpreted as digging stick, ~39,000 BP	d'Errico et al. 2012
MIS 2		
	Border Cave, South Africa Wooden artefact, interpreted as a poison applicator, ~24,000 BP (but see Evans 2012 on other possible interpretations)	d'Errico et al. 2012
	Ohalo II, Israel Selection of wooden artefacts, includes plank with polish and signs of use, pencil-shaped objects, uses uncertain Ca. 23,000 BP	Nadel et al. 2006
	Mannheim, Germany possible wooden bow fragment, Ca. 15,000 BP	Rosendahl et al. 2006
MIS 1		
	Monte Verde Level II, Chile Worked wooden structural components, 'pointed sticks, wedge-shaped pieces, possible digging sticks, architectural logs, tool handles, a burned point, concave or flat planks, crude basins and several miscellaneous items'; possible spears, partially charred 1.0-1.2 meters in length, 4.8-5.5 cm in diameter, made of *mañío* (Dillehay 1989 p. 153, 156) Ca. 14,500 cal BP	Dillehay et al. 1997; Dillehay et al. 2008 Dillehay et al. 2015
	Stellmoor, Germany Wooden arrows, pine, fragment from a possible spear 12,680-11,590 cal BP (Destroyed in WWII)	Villa and Soriano 2010 Litt & Stebich 1999 Tyldesley & Bahn 1983
	Guitarrero Cave, Peru Wooden dowels, battens 12,380-10,710 calibrated, AMS dating	Jolie et al. 2011
	Quebrada Manî (site QM12), Chile 12,800-11,700 BP cylindrical wooden artefact (possibly proximal fragment of atlatl spear shaft), pointed wooden stick with burnt end, wooden artefact with groove	Latorre et al. 2013
	Wyrie Swamp, Australia Boomerangs and boomerang fragments, spear and	Luebbers 1975 Luebbers 1978

fragments of a possible barbed spear Dates: 10,200 ± 150 and 8,990 ± 120 BP (ANU-1,293)	
Paisley 5 Mile Point Caves, Oregon USA 12,300 14C BP wooden pegs	Gilbert et al. 2008

In addition, a single wooden artefact from the undated Acheulian site of Amanzi Springs, South Africa may have evidence of working (Deacon 1970, Plate 15, P. 152), and a single artefact from the undated Late Acheulian site of Lac Karâr, Algeria bears an anthropogenic modification (Boule 1900; Sahnouni et al. 2013, p. 313).

A.1.2 Identifying and evaluating traces of manufacture and use on wooden spears

A.1.2.1 Introduction

Archaeological wooden artefacts, when they preserve well, can capture traces on their surfaces that reflect their manufacture, use, cause for discard and depositional environment. The ‘life’ of an artefact spans the procurement of raw materials (in this case both the wood itself and any materials for any tools used to procure the wood); its manufacture; possible transportation, storage and/or use; and discard. Its ‘life’ does not end upon discard, as it then undergoes post-depositional processes. Excavation and post-excavation processes including preservation, study and museum curation practices can also leave traces on wood. As wood is a relatively soft material, these phases all have the possibility of leaving traces that connect us with humans who interacted with the material in a variety of ways, sometimes recording individual or repetitive gestures. In some cases the marks are so distinct that we can literally see a moment in time captured: that of a human scraping a stone tool edge across a wood surface hundreds of thousands of years before. Many Pleistocene wooden objects are disputed as anthropogenic in origin, partly because methodologies for determining human modification on wood are more problematic and less developed than for stone and bone. Furthermore signs of modification vary by properties of the wood being worked, as well as by the manufacturing process. Marks caused by actions such as scraping with a lithic tool edge can be removed by secondary manufacturing processes such as polishing and smoothing, and can be further removed by handling, use, or post-depositional processes.

A.1.2.2 Evidence of manufacture

Researchers assessing Pleistocene wooden artefacts rely upon the artefact’s morphology, along with evidence for manufacture, and specifically tool marks, to determine their anthropogenic origin. An absence of tool marks, even with a convincing morphology, results in skepticism that the wood was humanly modified (e.g. Gaspari et al. 2011 vs Schoch et al. 2015). When we can observe and interpret tool marks on wooden finds, we are not only able to demonstrate human involvement, we are also presented with unique opportunities to understand the manufacturing processes of these objects.

Experimental research on manufacturing wooden spears has focused around hypotheses of tool selection, manufacturing, use of fire, properties of wood, and functionality of and use-wear to lithic tool edges (e.g. Oakley et al. 1977; McNabb 1989; Veil 1991; Fluck 2015; Fehrenbacher 2008). Oakley et al. (1977) observe that in experimental reconstruction of the Clacton spear point, striations are caused by tiny projections on lithic tool edges. They point out that unretouched flakes can produce striations due to natural projections on the tool edge, while retouched flakes produce these striations as a 'matter of course'. The use of short, sharp strokes was found to be more efficient than long scraping. Veil's (1991) experimental replication of the Lehringen spear provides the most complete exploration of wooden spear manufacture, detailing macrofractures resulting from cutting of the yew tree, some particular marks created by use of lithic tools, and their relationship to marks on the Lehringen spear and processing time (around 4-5 hours). This work was in relation to an analysis of the Lehringen spear (Thieme & Veil 1985) and makes a helpful comparative study.

Observations have also been made regarding 'polish' on wooden spears, possibly due to use (e.g. Oakley et al. 1977) but also as a possible result of a manufacturing technique (Thieme 2005 p.125; Schoch et al. 2015). Polish could be a feature of manufacture, use or possibility a result of the harder heartwood exposed as Oakley et al. (1977) suggest for the Clacton spear point. If the spears were indeed 'polished' to a fine finish as a part of the manufacturing process, further questions pertain to the processes and raw materials involved as well as the effects this would have on point durability. Thieme and Veil (1985) suggest that the polished, rounded nature of the proximal end of the Lehringen spear could have resulted from using the proximal end during walking, or potentially for digging, and that it is probably not taphonomic.

There have been several experiments aimed at replicating the shape of wooden spears, primarily to understand the use of different lithic tool types and time investments (e.g. Crabtree & Davis 1968; Oakley et al. 1977; McNabb 1989: Veil 1991; Fluck 2015), though these studies have not focused on the tool marks resulting from the complex interaction between tool types/edges, techniques, or wood properties (but see Moir 1926). While Oakley et al. (1977) made an effort to describe the morphology of different tool marks on the Clacton spear, this has not yet been achieved for the Lehringen or Schöningen spears. It is important to stress that the identification of tool marks is not only in order to confirm that a given object was humanly modified, but is also of interest because the tool marks can be matched to a given tool edge, and thus help us identify potential tool kits and manufacturing techniques as well as phases of manufacture, and there remains a possibility that striations from tool edges will be distinguishable from those created by use or by post-depositional environments. Experimental work presented by Greenfield & Kolska Horwitz (2012) suggests that there may be microscopically visible differences between lithic tool types and edges. The experiment was conducted with the aim of identifying tools used on bone in butchery, but although wood was also tested, few SEM images are provided to utilise as reference images. In general, the study seems to indicate a discernable difference between unretouched flake and scraper edges, at least when used as slicing tools. A similar set of experiments aimed at woodworking would provide a better reference dataset for wooden artefacts.

Lozovskaya & Lozovski (2013) conducted experimental work aiming to recreate wooden objects from the Russian Mesolithic. They used a variety of wood species and tools for woodworking, including retouched flakes and blades, modified beaver mandibles, and bone tools. Their aim was to understand marks on the wooden tools in two assemblages, and their experimental work found that retouched flakes produced marks with a lower relief on the surface than unretouched flakes. They noticed significant morphological differences in marks (both in length and width) created using a single hand holding a lithic tool to scrape, using two hands to use a blade to 'plane' the surface. Surfaces created by planing can be either smooth and glossy or marked with striations.

Because no system exists for describing tool marks created by lithic tool edges, in order to adequately describe tool marks in the following section, the definitions of Sands (1997) in describing Bronze Age tool marks on wood will followed in this thesis:

- Facet: individual tool mark, single strike of a tool, confined by unworked wood, or by raised areas between tool facet
- Feature: aspect of a facet that can be recorded
- Entry heel: top of the facet
- Jam: bottom of a facet (not always present)
- Side features: left and right sides of facets
- Signature features: series of features running down long axis of a facet, includes ridges and grooves

Sands' (1997) text on prehistoric woodworking focuses on bronze and iron age tool marks, but methods in that text may prove useful for assessing tool marks from the Pleistocene. Significantly, Sands (1997 p.18) emphasises the utility of the use of the naked eye and low power (up to 50x) magnification, as higher powers tend to lose information due to resolution. SEM can be a useful approach, but again in terms of tool facets and features, high resolutions tend to obscure any useful information.

Evidence for controlled use of fire by hominins during MIS 11 comes from sites such as Beeches Pit and Qesem Cave (Gowlett 2006; Karkansas et al. 2007; but see Stahlschmidt et al. 2015b), indicating a possibility for use of fire in the manufacture of wooden artefacts. However, evidence of burning on wooden artefacts, which in themselves are comparatively rare in the Pleistocene, can be difficult to assess without invasive methods (Fluck 2015). Potential evidence of the use of fire in the manufacture of Pleistocene wooden spears has been speculated upon for the Clacton spear point (e.g. Oakley et al. 1977; Fluck 2015), the Lehringen spear (e.g. Jacob-Friesen 1956; Thieme & Veil 1985; Veil 1991) and the Schöningen spears (see Stahlschmidt et al. 2015b and references therein) as well as other wooden artefacts from Schöningen including the so-called *Bratspeiß* (roasting spit) (e.g. Thieme 2005 p. 125) and *Fackelkopf* (torch) which have been suggested to be anthropogenically burnt. The latter of these, from the site Schöningen 12 B, was analysed using organic petrology which demonstrated that the artefact is darkened by humification and not burning, showing the importance of microscopic analysis of wooden objects with discolouration (Stahlschmidt et al. 2015b).

Speculation about the burning of wooden spears for hardening or manufacture arises in part from the widespread ethnographic accounts of the use of fire in the manufacturing process of spears including both point shaping, shaft straightening or drying the wood (e.g. Noetling 1911; Woodburn 1970 pp. 40-41; Gould 1969 p.99; Robinson 1966 p.532), as well as point hardening (e.g. Forde 1931 p. 170; Swanton 1946 pp. 582-583; Hiatt 1968 p. 205; Greenwood 1978 p. 522; Goodale 1971 p. 158; Turnbull 1965 p. 36). A few experiments have addressed hypotheses around use of fire in shaping wood (e.g. Crabtree & Davis 1968) and in particular spear point manufacture (e.g. Fluck 2015). Cosner (1956) experimented with charring different wood types and comparing surface abrasion with uncharred wood, and whilst this was a relatively limited experiment, found no discernible differences in abrasion on heat-treated wood vs. untreated wood. A recent study (Ennos and Chan 2016) found that while fire does somewhat harden wood, it also makes it more brittle leading to questions about the efficacy of ‘fire hardening’ spears (though see Evans 1958; Warfel 1986). While the technique, where verified, was potentially employed primarily as a means of aiding in the shaping of the point, controlled experimental work regarding the effects of heat treatment as well as fats on durability are clearly warranted. No known published experiments have documented differences of tool marks on unburnt vs. burnt wood.

A.1.2.3 Defining use traces

Research into macrofractures of composite weapon tips has a rich history, including the seminal work on macrofractures to lithic points by Fischer et al. (1984). Decades of experimental research on projectile points indicates that antler, bone, and stone, all have their own suite of properties, and fracturing and wear will vary accordingly (Knecht 1997a). Wood also has its own properties, and can be expected to produce its own unique fracture and wear patterns.

Some of the observations made throughout the research will be noted and described as a reflexive exercise for future studies. A suitable nomenclature that relates to stone and osseous impact macrofractures, while encompassing the unique fracture types that occur in wood needs to be developed. As a step forward, two new terms are proposed here, including ‘blunting’ and ‘splitting’.

‘Blunting’ of the tip, refers to situations where it is clear that the original point material has been compressed and flattened, or in some cases bent without being removed. ‘Blunting’ is similar to ‘crushing’ as defined in papers on bone technology, in that material is displaced, but dissimilar to the term ‘crushing’ for lithic impact fractures in that material is not necessarily removed (e.g. Odell & Cowan 1986; Bradfield & Lombard 2011; Sano & Oba 2015). Therefore, the term ‘blunting’ is used here to avoid confusion with impact fractures on other materials that are dissimilar in nature. In other cases, ‘splits’ from the tip backwards have been observed both experimentally and archaeologically. ‘Splitting’ refers to the breaking apart of the grain of the wood without the separation of the two sections and may occur at the tip itself or along the shaft.

There are no known use-wear studies on untipped wooden spears. A few studies have been conducted on other types of wooden tools, demonstrating that use-wear methods developed for stone and bone tool research can be applied to wooden tools. Caruso Fermé et al. (2014) applied use-wear and residue analysis to wooden tools from a Patagonian hunter-gatherer site, concluding that one of the artefacts was possibly used for rock art. Dillehay (1997, p.119) developed methods of analysis relating to woodworking, use-wear and taphonomic for wooden artefacts found at Monte Verde, providing further methodological foundations for use-wear analysis on wooden artefacts, and discusses evidence of charring, manufacturing and design trace features, taphonomic alterations, as well as possible marks from use such as polishing and features such as flattening possibly reflecting contact friction. Whilst few of these features are illustrated macroscopically, and none microscopically, this provides an example of the potential scope of research to be done on other wooden spears. d’Errico et al. (2012) suggest that a wooden artefact from Border Cave, South Africa retains residues suggesting it may have been a poison applicator (but see Evans 2012 for alternative explanations). Studies such as Koda’s (1993) on use-wear, including good experimental replication and use, of wooden farming tools further demonstrates that the development of methods to assess use-wear and residue analysis to wooden artefacts is both possible and fruitful.

Bone tools provide the closest analogy for understanding manufacturing marks and use-traces on wooden artefacts. However, woodworking has its own *chaîne opératoire*, quite different from bone working, and the use-life of wooden tools is also different (Hurcombe 2007). Because of differences in structural and material properties between stone, bone and wood, comparisons of traces and fractures created in their manufacture and use must be made with caution. In spite of these differences, use-wear and manufacturing studies on lithic and bone technologies provide useful models in understanding wood technologies, particularly regarding the manufacture and use of hand-held wooden tools (including larger examples such as wooden spears), as opposed to the use of wood as structural material. These models and methodologies, developed for lithic and bone tools but rarely applied to Pleistocene wood technologies, must be further developed to create a better understanding of the use-lives of wooden artefacts. This section will briefly review the background of research relevant to the study of humanly-modified Pleistocene wooden artefacts. It must be re-emphasised that the aim of this thesis is to analyse the design and effectiveness of wooden spear technologies as hand-delivered hunting weapons. Access to archaeological, ethnographic, and experimentally-used wooden spears to capture design data provided unique opportunities to document surface traces, in order to assess the current limitations of understanding and scope for future analytical approaches to these rare objects, but a targeted systematic analysis of traces has not been a key aim of the research.

The use-life of a weapon is directly connected to the potential for curation (*sensu* Shott & Scott 1995), particularly of the point of the weapon. In the case of wooden spears, curation practices are poorly understood, and do not factor into concerns over typology as it does for lithic tools. Resharpening of a blunted, split or broken point is the most likely type of curation for an untipped wooden spear.

The mechanical properties of wood are highly variable. The variability includes general properties of a species, as well as growth conditions for an individual tree, humidity content at the time of fracturing ('seasoning' of the wood) as well as internal 'faults' or points of weakness in the wood, such as knots or grain orientation (Pirinen 2014). Spruce and yew are the species most typically used for the Pleistocene archaeological examples analysed in this research, though there are exceptions such as the example of use of Pine for Schöningen Spear IV, and the use of she-oak for the Wyrie Swamp spear. There are differences in mechanical properties of these two most commonly used species. Yew (*Taxus baccata*) has a higher mean density (0.551 g/cm^3) than spruce (*Picea abies*, 0.370 g/cm^3) (Zanne et al. 2009), making it a harder wood both for working and for use. This density would most likely result in yew spears having a higher mass than one manufactured to the same dimensions from spruce. As mass affects kinetic energy, the selection of a denser and thus heavier wood would influence spear performance along with macrofracturing and surface traces.

Most lithic raw materials suitable for knapping are isotropic (Crabtree 1982 cited in Knecht 1997a; Holdaway & Stern 2004; Andrefsky 2005 p. 24), meaning that the properties of the material are identical in every direction. Bone is classified as anisotropic, as its properties vary by two planes, with a higher strength transversally than longitudinally (Knecht 1997a). Orthotropic materials are subset of anisotropic materials, where there are three planes. Wood is an orthotropic material; that is, the strength, stiffness and ductility vary, and are dependent on the direction and the type of stress (Pirinen 2014). The three directions that can be measured in wood include axially (or along the grain), radially, and circumferentially (Pirinen 2014). Axially, wood has more strength and stiffness than it does across the grain (Pirinen 2014). As a result of this, wood when used in weaponry, will fracture macroscopically in different ways than projectiles made of stone or bone. As stated above, functional analyses relating use-wear and residues on wooden spears from use are unknown, and will be necessary for future efforts to tease apart causes of marks such as striations on wooden spears. In particular Schöningen, with its excellent preservation conditions, offers the most promising collection to undertake such a study.

A.1.2.4 Archaeological evidence of manufacturing and use traces

A jam facet (e.g. Fig. A.1.1) shows that the spear was worked towards the distal point (contra Veil 1991), which is the opposite direction of working on the Clacton spear. This figure illustrates the discussion about direction of manufacture made by Veil (1991), though it must be highlighted that the location of the manufacturers body in relation to the working of the spears cannot be known for certain.

Figure A.1.1. Jam feature of a tool mark on the distal section at 50x magnification, showing that the point was worked at least in part in a proximal-distal direction.

While tool marks on archaeological spears have been mentioned for examples from Clacton (Oakley et al. 1977), Schöningen (Schoch et al. 2015) and Lehringen (Thieme and Veil 1985) the cause for marks have not been systematically reproduced and analysed in comparison with experimental samples. Oakley et al (1977 p. 17) mention that striations present on the Clacton spear point are ‘probably “tool marks: left by flint implements during its manufacture; however, other causes cannot be entirely excluded’. The significance of this remark becomes all the more stark when the dearth of research on the taphonomic effects such as trampling and fluvial transport on wood surfaces (though see Dillehay 1997), as well as marks resulting from the use of wooden spears as hunting weapons, is recognised. McNabb (1989) conducted experimental work aiming to recreate the shape of the Clacton point. He used unretouched flakes, clactonian notches, true notches and a unifacial chopper to work staves of yew. The conclusion was that Clactonian notches shaped wood into a spear point very effectively, and that retouched edges proved ineffective at shaping the wood, due to a failure to 'bite' into the wood. There is no mention of the manufacturing traces left by different techniques and tools.

Thieme (e.g. 2005 p. 125) described the surface of the Schöningen spears as being 'very carefully worked and intentionally polished and cleaned'. The recent publication, including further spear finds, goes into more detail of the evidence of manufacture. Schoch et al. (2016) specify evidence of:

- emerging tree rings
- truncated branches (cutting off knots)
- Traces of cutting, scraping and smoothing
- re-sharpening of the tip (cut marks)

Manufacturing traces demonstrate the use of flint tools (Schoch et al. 2015), and marks are concentrated at the distal ends on spears I, II and III , and at the proximal ends of spears I and III. Striations are described as being clear around a knot on spear III. These authors also mention a 'smoothed surface', but no further explanation is provided of where this occurs on the spears, nor what type of process this might reflect, which might include manufacture, handling, use, and/or post-depositional processes including water action (Dillehay et al. 1997 p 128).

Schoch et al. (2015) point out cut marks on the broken point of Spear II, suggesting it indicates the use of the weapon due to resharpening, but no further explanation is given as to why these particular marks indicate reworking of the point. Similarly, it is remarked that spears I, II and III bear toolmarks from lithic tools but the photographic documentation is limited to macroscopic documentation and there is no discussion of the morphology of these marks, making any analysis of woodworking techniques and lithic tool edge types difficult to assess. Schoch et al. (2015) suggest that the point of Spear X was broken and that the presence of several cut marks indicate that the point was resharpened. The point is illustrated photographically, but no further explanation is given of how this resharpening was executed. Whether cut marks at the point indicate resharpening needs more exploration via replicative work.

Oakley et al. (1977 p. 17, 28) state that the Clacton spear point does not bear traces of burning, as the x-rays demonstrate that the tracheids are not sealed, as would have occurred had the surface been charred, though Fluck (2015) points out that scraping off of the charred material during manufacture would have eliminated this evidence. Dark patches were observed during the original research for this thesis (Fig. A.1.2). While likely to be the result of post-depositional staining, these marks could be investigated with modern techniques such as organic petrology, used recently to investigate potentially burnt wooden artefacts from Schöningen (Stahlschmidt et al. 2015b).

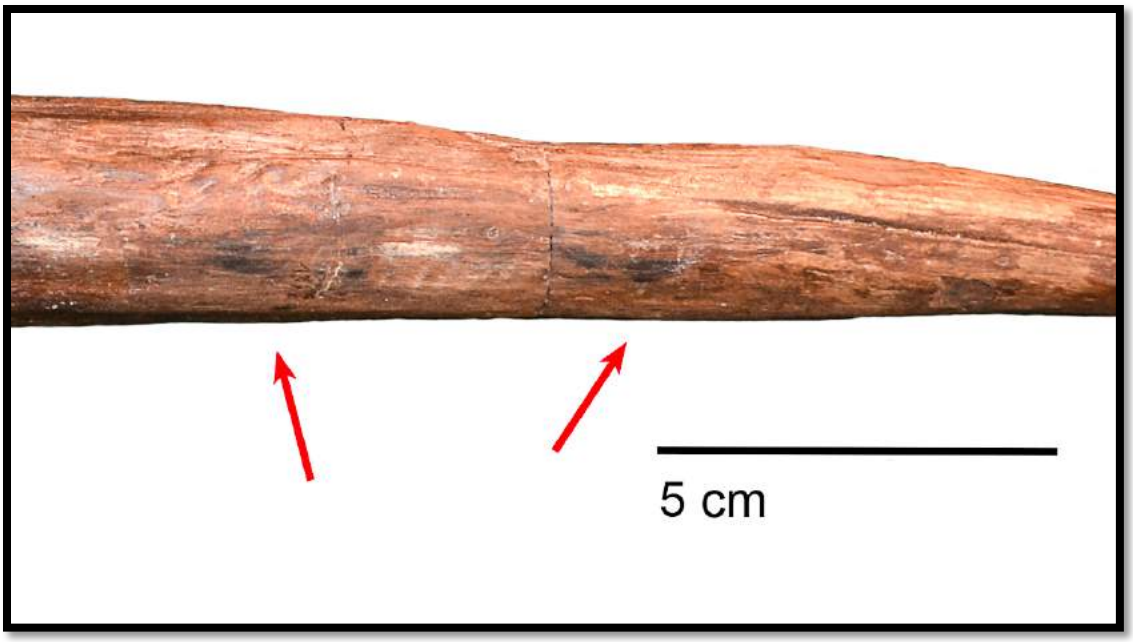

Figure A.1.2. Some of the dark patches on the Clacton spear point, indicated by the red arrows

Jacob-Friesen (1959, p.30) described the tip of the Lehringen spear to have been hardened in fire:

> Die Spitze war nicht etwa mit einter Stein- oder Knochenspitze bewehrt, sondern mit Hilfe von Steinmessern zugeschnitz, wie dies deutlich schmale Schnittflächen zeigen, dann aber im Feuer gehärtet.

Unfortunately he did not provide any evidence for this observation. Veil (1991) agreed that the use of fire on the Lehringen lance is possible, as the removal of the parafin for the study of the lance in the 1980s (Thieme & Veil 1985) revealed a marked difference in colour between the light reddish brown of the shaft and the darkened tip, the differences of which are unfortunately not easily visible in the photographs in that publication.

Regarding the Schöningen spears, neither Thieme himself nor the current research team have ever suggested any evidence of fire on the shafts or tips (Stahlschmidt et al. 2015b). Furthermore, Stahlschmidt et al. (2015b) examined the *Fackelkopf* using organic petrology, a methodology using microscopic investivation looking at reflectance and fluorescence on the material. They found no evidence of burning on that artefact, casting doubt on the burned nature of the *Bratspeiß* as well (Stahlschmidt et al. 2015b). Along with the overturning of evidence of hearths at Schoningen, the use of fire in the manufacture of the Schöningen wooden spears is unlikely (Conard et al. 2015). Overall, we cannot rely upon qualitative or macroscopic assessments such as discolouration to indicate the use of fire on these archaeological wooden spears (Conard et al. 2015).

Polishing on wooden spears has been suggested for the Clacton (Oakley et al. 1977), Lehringen (Thieme and Veil 1985) and Schöningen spears (Thieme 2005 p.125; Schoch et al.

2015). In the case of Clacton and Lehringen spears, the authors refer specifically to the distal points of the artefacts, while in the case of the Schöningen spears it is implied that this is a feature along the lengths of the shafts:

> Common features of all of the Schöningen spears include: the use of small trunks as raw material, the removal of branches and polishing of the surface, and the placing of the tip away from the central axis of the trunk. (Schoch et al. 2015, p.9)

It is clear that further research investigating the microscopic signatures of different manufacturing techniques and uses of wooden spears would further aid in evaluating the surface features of archaeological examples of wooden spears, with experimental research likely to provide the best way forward.

A.1.2.5 Experimental Breaks from use

This section details some of the damage and breaks on wooden spears that occurred during experimental use in the thesis.

A.1.2.5.1 Human performance thrusting trial

Resharpening was undertaken of the removable spear tips during the trial in order to ensure a sharp point for penetration. Tips became blunted and split during the experiment, presumably through impacting with the foam backing, necessitating rejuvenation (Fig. A.1.3). The resharpening was focused on the location of minor damage, and therefore was only necessary in the front 30mm - 40 mm from the point, slightly altering the morphology of the point, a phenomenon also evident in resharpening of lithic and osseous weapon points (e.g. Doyon and Knecht, 2014; Shott and Ballenger, 2007).

Figure A.1.3. Example of a resharpened tip from the thrusting trial

Replica 1A broke in the human performance spear thrusting trial. The spear broke on its 22nd use at a force of 967 N and an impact velocity of 5.5 m/s. The break is an example of how fracture patterns would differ from those of lithic and osseous materials. The break occurred between the two hands of the participant[1] (Figs. A.1.4 and A.1.5), near an area with several knots, though internally no features signalling a weakness at that point in the wood were evident. It is possible that the spear broke at this point due to the weakness of the group of knots. The spear broke at 1038 mm from the distal point at longest point of the break, 45% of the way from the tip of the spear. The other spear shaft, replica 2A was used in 17 thrusts and did not break.

[1] Note that the participant was not injured.

Figure A.1.4. Breaking of spear shaft during human performance spear thrusting trial

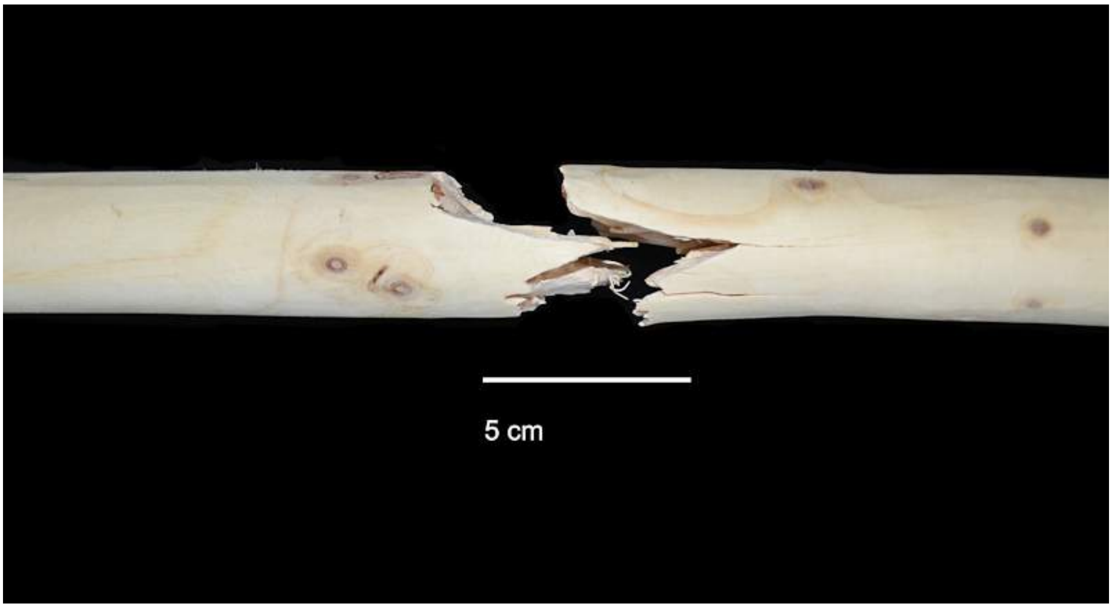

Figure A1.5. The break on replica 1A from the human performance spear thrusting trial.

A.1.2.5.2 Human performance throwing trial

Replica 1B was thrown for a total of 90 throws. Landing repeatedly in the hay bale or on grass-covered ground, it developed a small amount of blunting, and began to develop what might have become a split in the tip along an emerging tree ring. Replica 1B broke upon impact with the ground on its 90th throw, aiming for a target set at a 25 meter distance. The impact velocity was not captured for this throw as the impact was outside the range of the camera. The break occurs at 627 mm from the distal end, or 27% of the distance from the tip. The spear broke at an area of internal weakness in the wood (Fig. A.1.6).

Figure A.1.6. The distal portion of broken replica 1B

Replica 2B had the distal 25 mm of its tip removed during this throwing experiment (Fig. A.1.7). Three refitting tip fragments were recovered which show bending at the tip as well as the fracturing (Fig. A.1.8). Replica 2B was thrown 30 times and developed only tip fractures. Both replicas had sediment and grass embedded in both the distal and proximal ends, as well as along the shaft.

The spear replicas in the throwing study underwent extensive use, and although they were not impacting upon an animal target, they impacted with the ground multiple times at high velocities. It is therefore somewhat surprising that the spears did not break more easily. By the end of the experiment, both spears would be considered unusable. Replica 1B was broken beyond repair, while 2B could have undergone resharpening for re-use. Although the embedding of grass and sediment in both ends and on the shafts of the spears is interesting, it seems unlikely that archaeologically a distinction between such sediment and plant tissues embedded from use would be easy to distinguish from those occurring from post-depositional factors. The breaks however may begin to form an experimental dataset on how the weapons break during use, potentially enabling a distinction between breaks in use and post-depositional damage.

Figure A.1.7. Distal tip of replica 2B after final throw with a beveled break.

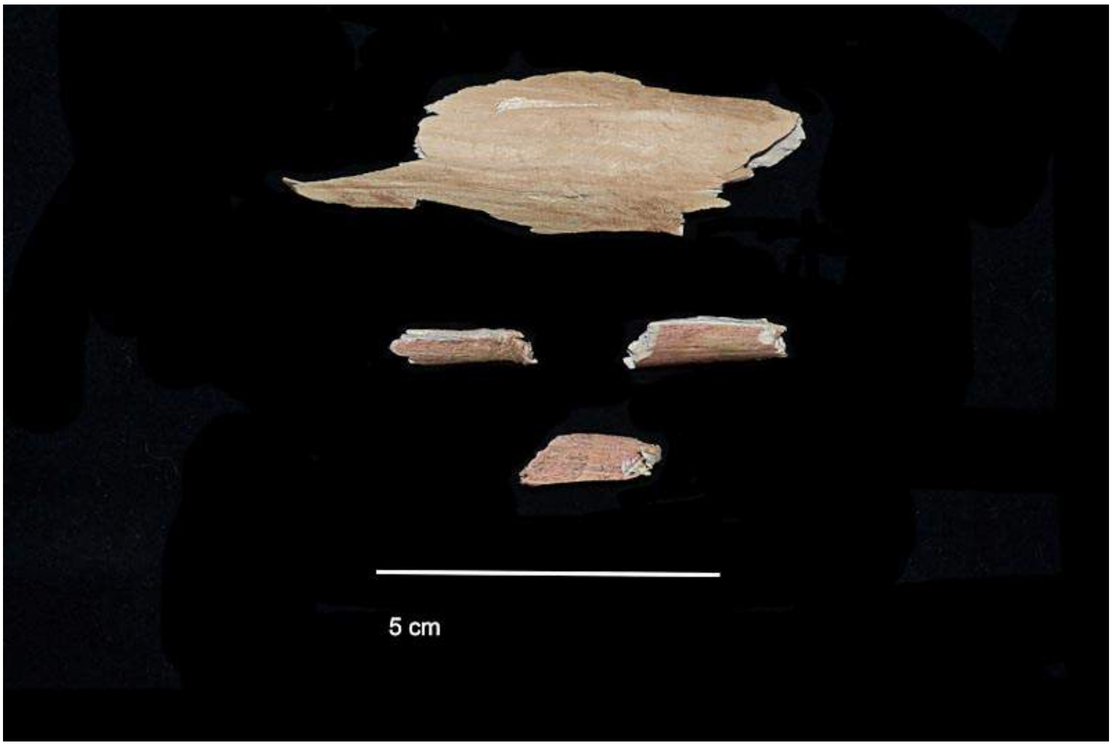

Figure A.1.8. Refitting tip fragments from replica 2B

A.1.2.5.3 Thrusting spears on carcass

Two of the replicas, 2C and 4C were each used for a single thrust. Replica 2C, used for TE 10 impacted the scapula area at a velocity of 4.59 m/s. The impact, which failed to penetrate the carcass, blunted the tip and would have required repair to reuse (Fig. A.1.9). Replica 4C broke on its first use (TE 6) at an impact velocity of 6.46 m/s. The tip of this replica did not blunt at all, but the distal 273 mm of the spear broke after achieving a DoP of 59 mm (Fig. A.1.10).

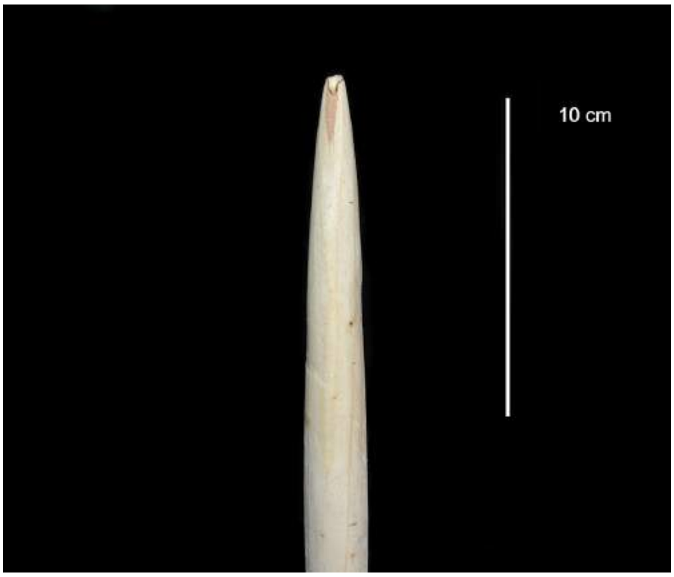

Figure A.1.9. Distal point of replica 2C, showing bending damage of tip

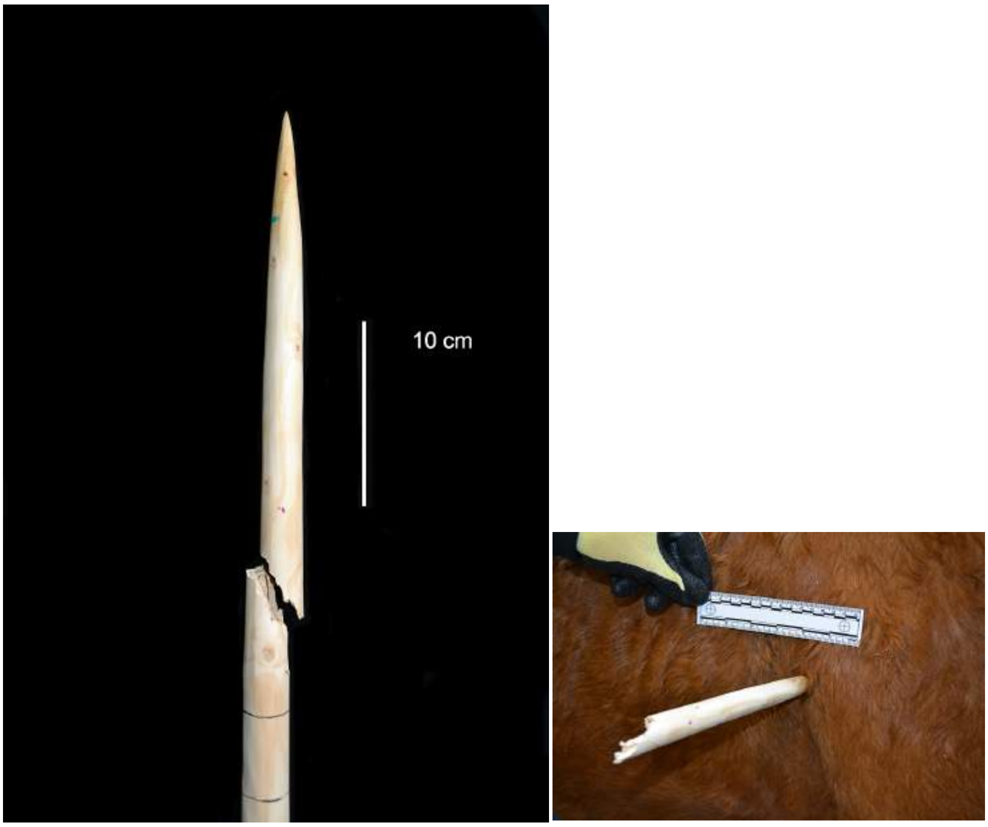

Figure A.1.10. Replica 4C damage. Left: both sections of broken spear replica, right: replica 4C tip embedded in horse carcass

Replica 1C was used in four thrusts, and was resharpened after three thrusts. After its final use (TE 12), the point was again damaged to a degree that it would have required resharpening again to use. Figure A.1.11 shows the sequence of damage to replica 1C.

Figure A.1.11. Sequence of tip crushing on replica 1C, from left to right following TE's 4, 5, 7 and 12

Replica 3C was used for five thrusting events. The first resulted in a very small amount of blunting to the tip, and then sustained little further damage, with no resharpening necessary. On TE 13 (the fourth use of this replica), a tiny split at the tip appeared, but this did not render the spear unusable, as the following thrust without resharpening achieved a DoP of 270 cm (Fig.

A.1.12). Blood, tissue and/or hair residues were visible on replicas 1C, 3C and 4C after final use (Figs. A.1.12 and A.1.13).

Figure A.1.12. Replica 3C was used for five thrusts, underwent no resharpening, and suffered only very minor damage. Image is of replica after final use.

A.1.13. Left, Thrust 1 and right, Thrust 11 respectively, showing tip splitting. A similar developing split is evident on the Clacton spear point and cast studied.

A.1.2.5.4. Throwing spears on carcass

Replicas were used between one and three times in the throwing experiment. Resharpening was undertaken on replicas 2D, 3D, 5D and 7D, while replicas 1D, 4D, and 6D were not resharpened and were used for only a single Impact Event (IE). Damage ranging from the entire removal of the tip (e.g. Figs. A.1.14 - A.1.17) to slight tip bending (e.g. Fig. A.1.18) occurred as a result of nine impacts. Four impacts resulted in little or no spear damage. In two cases relatively large fragments of the spear points were embedded in the tissue after breaking off upon impacting with scapulae, which were recovered (Fig. A.1.16) Some fragments feature the worked surface of the outside of the spear, and can be refitted.

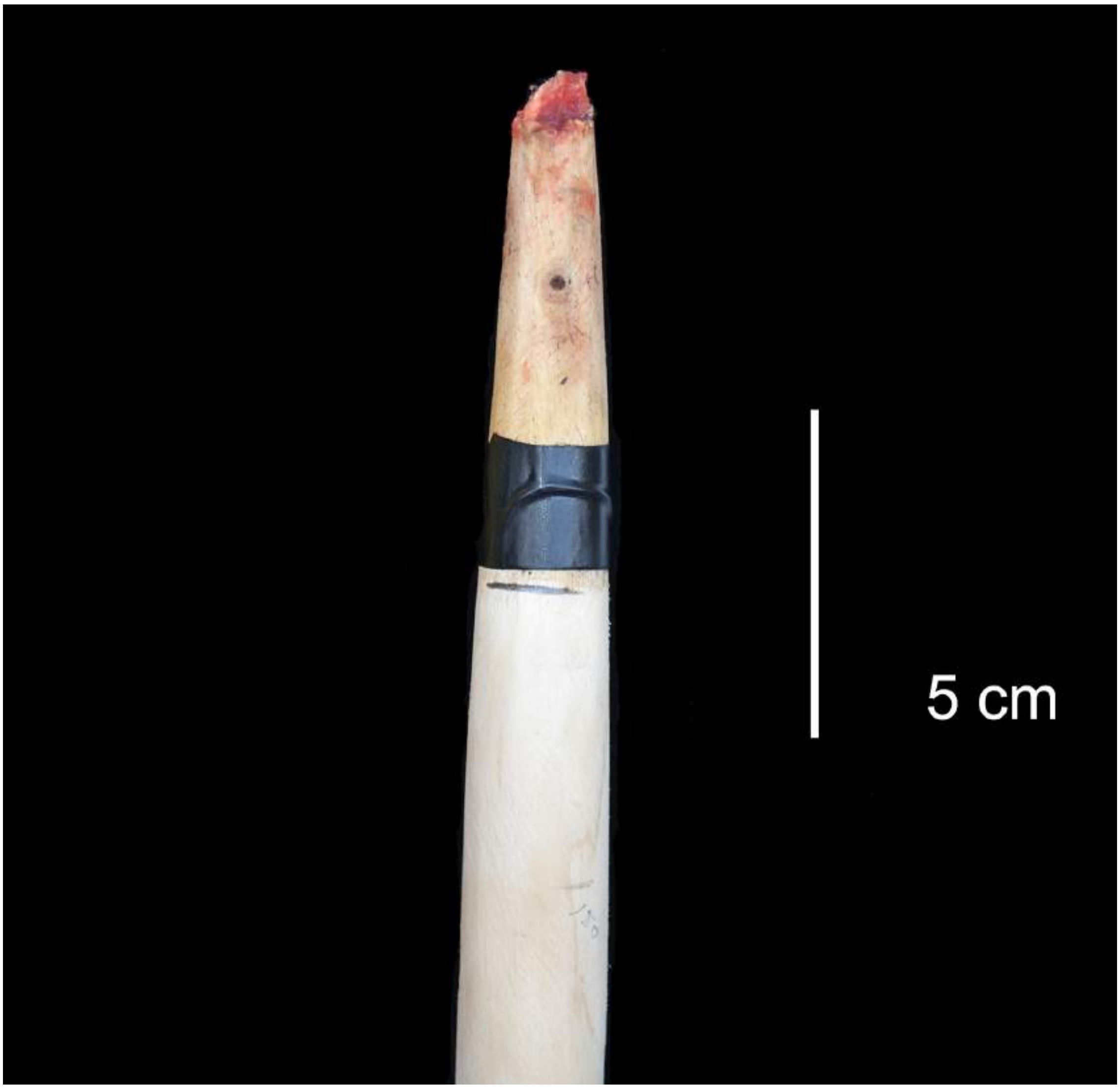

Figure A.1.14. Beveled break on replica 2D after IE 4, hit scapula at 17 m/s sustaining major tip damage, but did not damage the scapula.

Figure A.1.15. Beveled break on replica 2D, which had been resharpened after IE 4 and used again in IE 9.

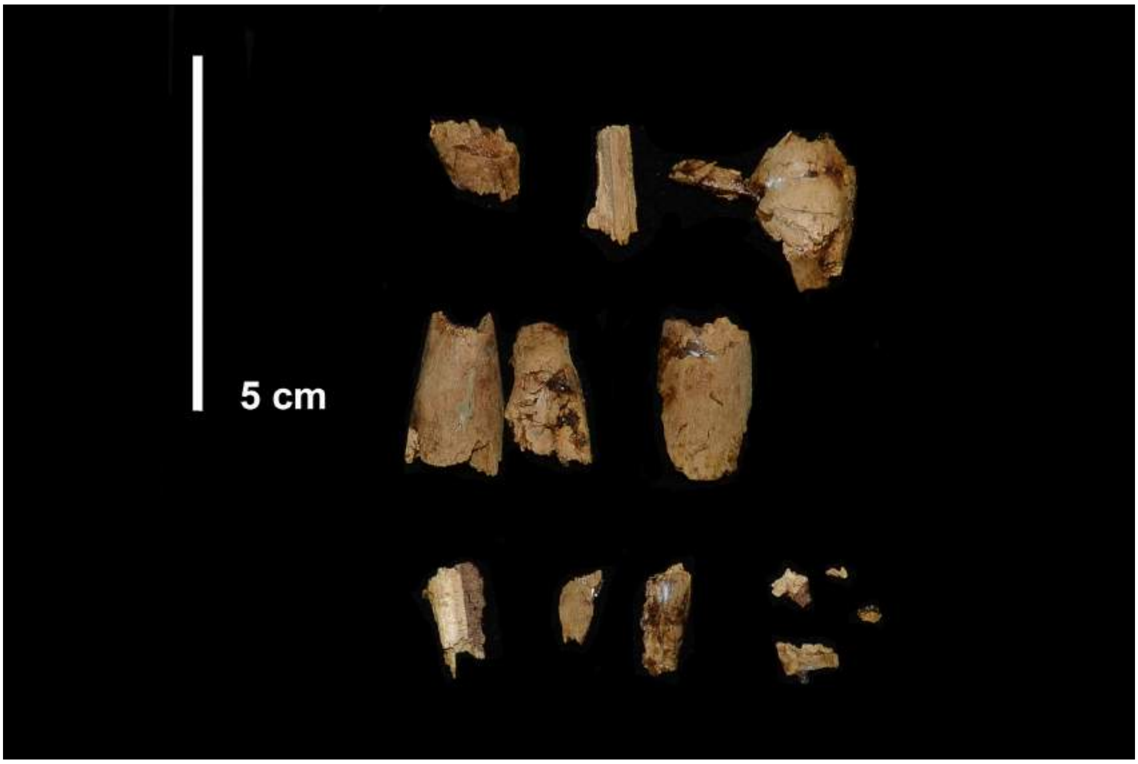

Figure A.1.16. Spear tip fragments from replica 2D after one of the spear impacts with a scapula

Replica 1D was only used once (IE 2), and impacted through a rib at 25 m/s (Fig. A.1.17). As discussed in 8.4.3.4, this impact would have likely been lethal to the animal, but the damaged spear tip would have required extensive reworking before further use.

Figure A.1.17. Replica 1D after only use for IE 2

Other use marks observed in the weapons include striations on the shaft of the spears, particularly at the tip of the weapons. A clear example is Replica 4D, used in IE 1, which impacted at 23 m/s and penetrated 284 mm. This replica was only used once. Fig. A.1.18 shows the damage to the tip, with Fig. A.1.19 showing the damage at 50x magnification. Both macro- and microscopically, this damage is best described as ‘gouging’ facets running obliquely to the shaft of the spear, with irregular side features, some with evidence of a jam and no regular signature features. These would clearly be distinguishable from tool marks illustrated on archaeological and ethnographic examples in Chapters 4 and 6.

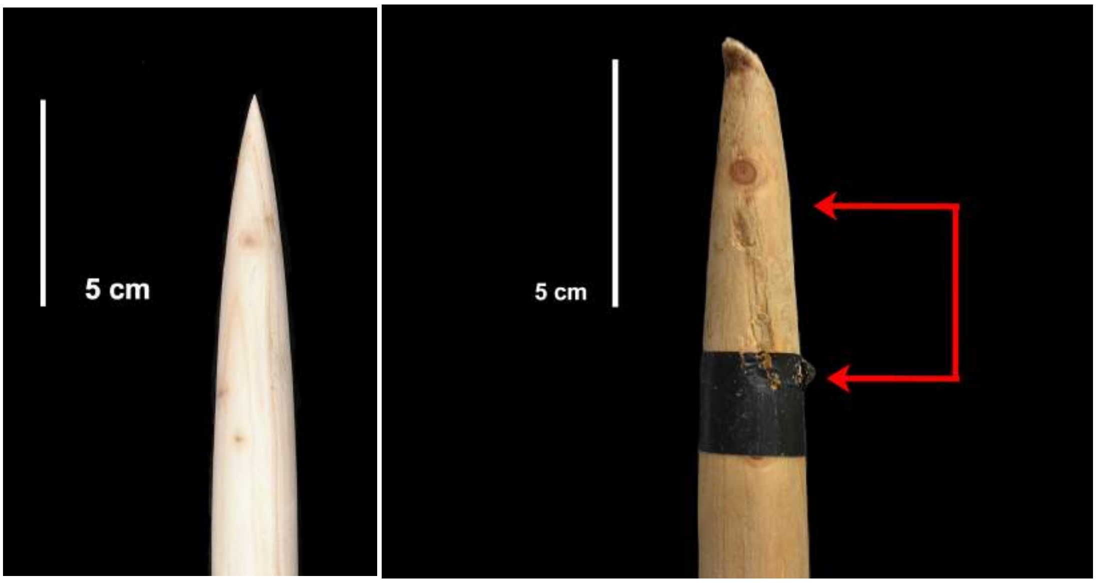

Figure A.1.18. Left: Replica 4D prior to use. Right: Replica 4D after a single use. Red arrows mark the use-wear striations on the shaft, also note the bending of the tip

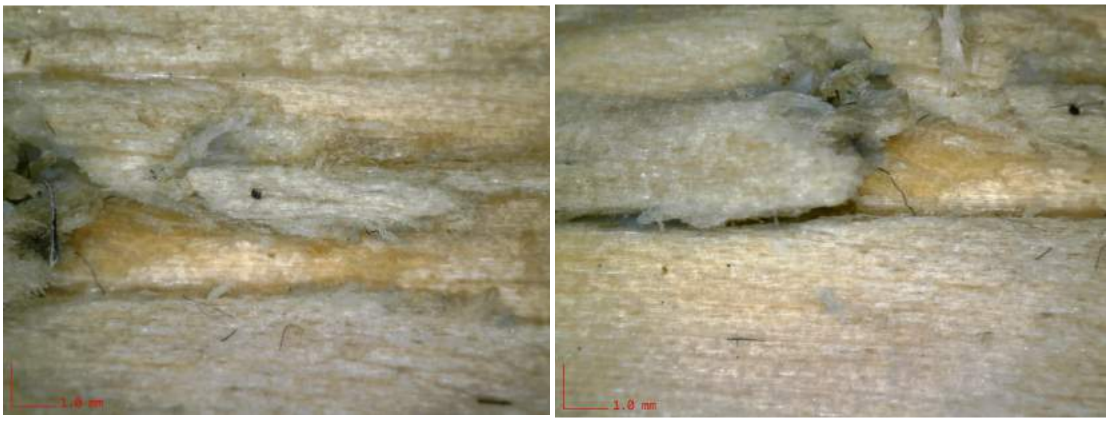

Figure A.1.19. Left and Right, use damage to replica 4D at 50x magnification

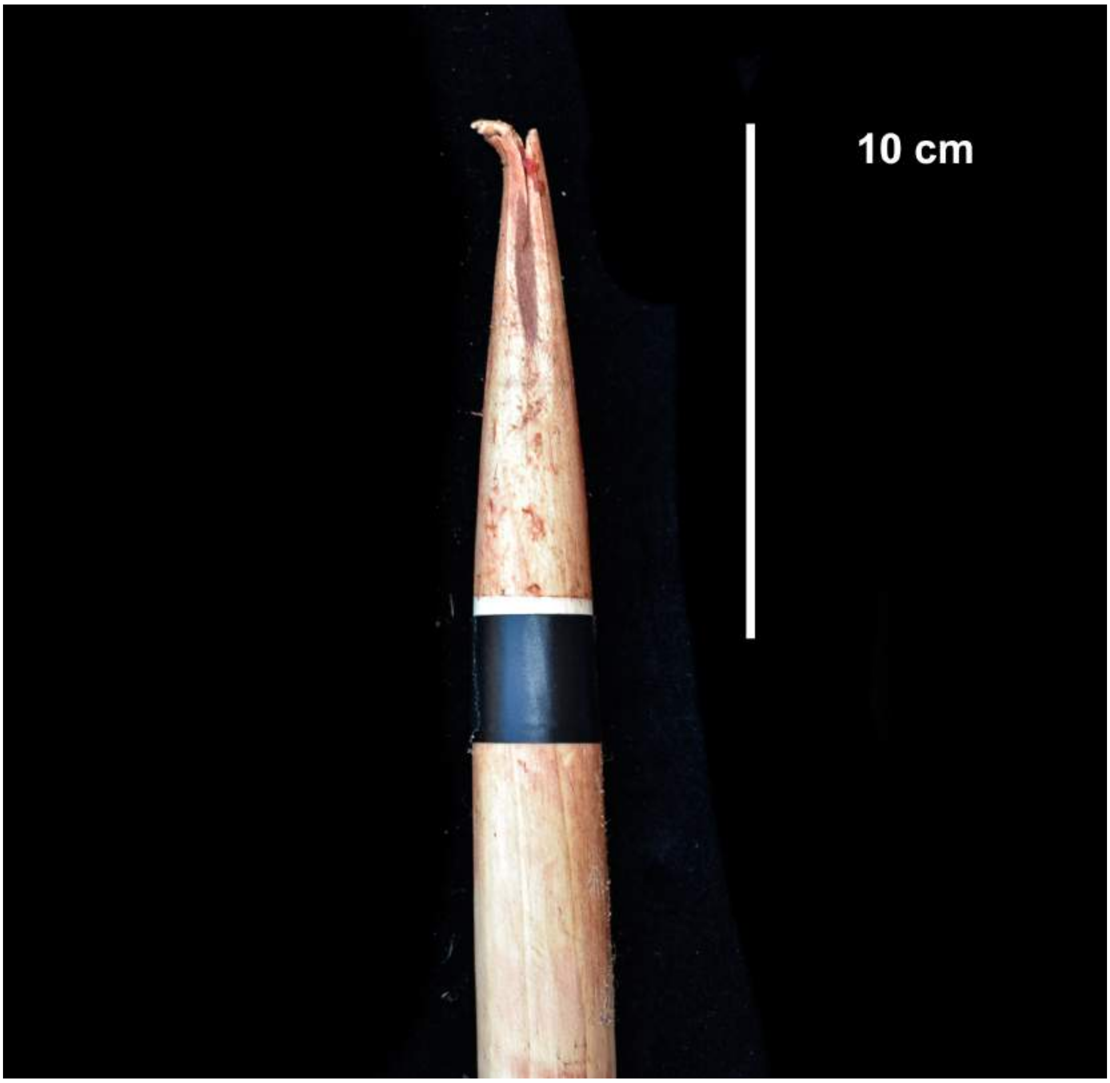

Figure A.1.20. Tip split from Throw 7

These experiments show that hand-delivered wooden spears would rapidly incur visible but often repairable tip damage. Whether the results of these experiments together reflect a greater robusticity of resharpened points or not would require a bigger study sample, but this possibility is worth consideration in terms of spear point design and effectiveness. Further experimental work focussing specifically on durability, including experiments on resharpening with lithic tools, as well as testing different wood species and densities would facilitate systematic testing of this hypothesis. The experiments confirm the hypothesis that residues including blood, tissue and hair adhere to the distal ends of wooden spears in use as both thrusting and throwing weapons. Although it was not the primary focus of these experiments to evaluate damage to spears, the observations made in the course of these experiments, together with those presented in Chapter 7 serve as a reference sample for use-marks, impact damage and residues on wooden spears. With these experiments serving as a pilot study, a systematic approach to understanding damage and breaks would facilitate interpretation of the archaeological examples.

Appendix 2: Supplementary information on experimental approaches

Appendix 2 provides a discussion on the theory behind and some definitions of experimental archaeology (A.2.1), some information and justification for sample sizes (A.2.2) as well as some sample information sheets and data recording sheets used in the experimental research (A.2.3) and details of the costs for experimental work (A.2.4).

A.2.1 Defining experimental archaeology

Experimental research forms a significant portion of this thesis and so it is important to discuss what various researchers mean by ‘experimental archaeology’ and the related terminology used throughout. The following definition of ‘experimental archaeology’ provides a series of terms and concepts which facilitate a discussion on not only terminology but process:

> Experimental Archaeology is a sub-field of archaeological research which employs a number of different methods, techniques, analyses, and approaches within the context of a *controllable* imitative experiment to *replicate past phenomena* (from objects to systems) in order to *generate and test hypotheses* to provide or enhance *analogies for archaeological interpretation*.
>
> Mathieu 2002, p.1

Fairly uncontentious is the term ‘experiment’, which can be defined as a procedure using scientific methods, i.e. the procedure is structured and replicable, to test a hypothesis or research question (Outram 2008). However the above definition is too narrow to encompass much of archaeological experimentation, including most systematic experimentation. Many currently published archaeological experiments would not fall within a strictly ‘controlled’ experimental approach, but rather would be classified as ‘replicative’ or ‘actualistic’. In a true ‘controlled’ experiment, taking place in laboratory-type conditions, all variables but one are controlled. Few archaeological experiments fulfill these criteria in spite of frequent use of the term; not all hypotheses can be tested using a strictly controlled experimental approach, and alternative terms are helpful. The term ‘controlled’ is value-laden, and will only be applied here in this thesis in the strictest sense.

Outram (2008) dislikes the use of the word ‘replicate’ in scientifically-oriented experimental archaeology as it is too close to the ideas of re-creating/re-enactment activities so often undertaken in archaeology. Outram (2008) argues that as we cannot know what the past was like there is little utility in attempting replication and prefers the term ‘actualistic’ for systematic experimental research that takes place outside controlled laboratory conditions. This term has been particularly used in studies of bone modification and taphonomy (e.g. Capaldo &

Blumenschine 1994; Karr & Outram 2012; Bunn & Gurtov 2014; Pobiner 2015). Others (e.g. Flennikan & Raymond 1986; Churchill et al. 2009; Hutchings 2015; Iovita et al. 2016) use ‘replicative’ as a useful way of categorising systematic experimentation that may not meet strict criteria of controlled experimentation. This thesis includes several sub-types of ‘replicative’ experiments, including those focusing on ‘human performance’, alongside ‘actualistic’ and ‘observational’ studies, and ‘controlled’ experiments. Another term frequently used in this thesis, though not strictly mentioned in the above definition is ‘replica’, meaning either ‘an object that matches as closely as possible to a specific original’ or more broadly ‘a new-made object that possesses attributes relevant to better understanding prehistoric artifacts’ (both Eren et al. 2016 p.105).

In all experimental studies undertaken for this thesis, as many variables as possible for addressing each experiment question were controlled for; all others were recorded in as much detail as possible. The research was carried out systematically, using state-of-the-art equipment and facilities, trained volunteers, and high quality software programs for data analysis to minimise potential bias. The present experimental research did not attempt to re-enact past behaviours, but rather sought to systematically test explicitly defined questions about the weapons themselves, their effectiveness on prey, and the archaeological signatures that their use may have left behind. Whether the experiments presented in this thesis follow a strictly controlled approach or a replicative one, entirely depended upon the question(s) addressed in the individual experiment.

Perhaps most importantly, Mathieu’s defintion acknowledges that *results* of experimental research generate new questions, and not just about the materials being experimented with but also about behaviours, which *should* be a feature of any archaeological experimentation. That final part of the definition reminds us that the goal of experimental work is to interpret the archaeological record.

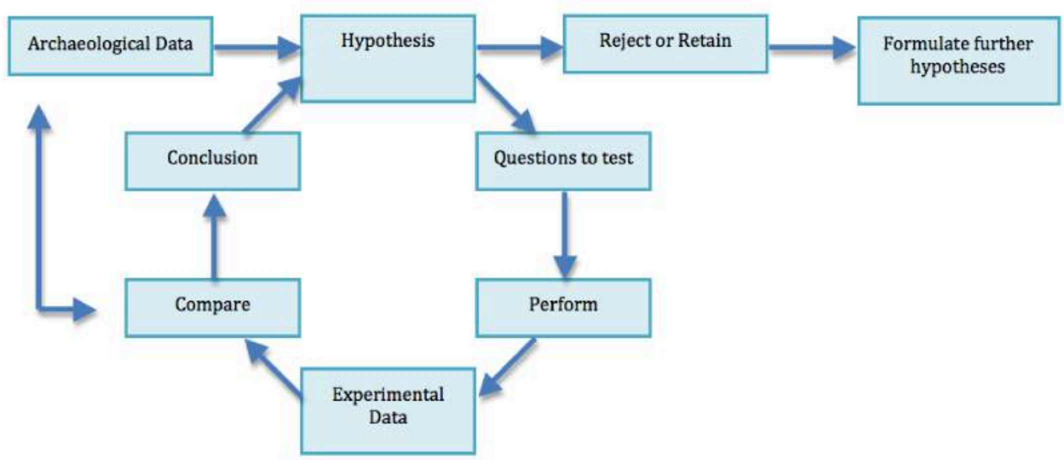

Figure A.2.1 Cycle of experimental research (Revised after Lammers-Keijsers 2005, p.18)

Although Lammers-Keijsers (2005) emphasises that hypothesis-*forming* experiments are not controlled, and therefore are pre-tests or pilot experiments, it is also true that generating experimental data from systematic experimental work, often creates new and sometimes unexpected research questions, which need further testing. Figure A.2.1 is therefore a modified version of Lammers-Keijsers' (2005) diagram, clarifying that formal hypotheses are to be 'retained or rejected', whilst research questions can be more open-ended. In the scientific method, hypotheses are better viewed as being rejected or retained, as a hypothesis is never 'true' or proven, only disproven (Outram 2008).

A.2.2 Sample sizes in experimental work

Because the studies in Chapter 7 were relied upon to establish testing parameters for phase 2 experimentation (Chapter 8) it is important to address the sample size of the trials presented in Chapter 7. Large sample sizes are indeed important in experimentation, particularly in order to conduct statistical analysis on the results. However, as with research involving equipment or materials with high costs and ethical considerations, for example fMRI studies or those using lab animals, sample sizes are constrained by financial and temporal, ethical considerations, and availability of appropriate participants. Rather than reject the utility of smaller studies, they provide an important basis for future experimentation. In the cases of both human performance trials, considerations of sample size were balanced with the need for extremely high quality data acquisition. For the thrusting trial, participant sample size and the number of stabs per participant per type compare favourably with several knife stabbing studies (e.g. Cowper et al. 2015; Horsfall et al. 2005; Kemp et al. 2009; Miller & Jones 1996) and are an improvement on spear thrusting studies (Connolly et al. 2001; Schmitt et al. 2003). In the throwing trial, six participants were used, and a total of 120 throws. In comparison with previous studies using human participants throwing wooden spears the trial used six times the number of participants (Rieder 2001; Smith 2003) and up to 12 times the number of throws (Rieder 2001). Additional throws would have been possible in the spear throwing trial had the high speed video not been used, as each file takes time to save. Decisions were made on the day to save certain files but not others, balancing the need for a larger sample of throws with the need to capture data with such equipment. The use of expensive equipment such as high speed cameras and technicians to operate them were a requirement for this study. The sample sizes of both studies are vast improvements to previous studies regarding plain wooden spears. Appropriate statistical methods are used that match the sample sizes, and most importantly the range of performance data provides appropriate velocity and force testing ranges, which was the primary objective.

It was not the aim of the human performance throwing trial to evaluate the javelin throw itself, which has been studied and published elsewhere (e.g. Miller & Munro 1983; Hubbard 1984;

Hubbard & Bergman 1989; Tidow 2008). The effects of different parameters in this experiment were not studied, though a few observations on flight trajectory are presented. One limitation in this experiment is the disagreement on the throwing capabilities of Middle Pleistocene hominins in comparison with *H. sapiens,* resulting in a poor understanding of their ability to project such weapons by hand (Larson 2015; Roach & Richmond 2015a; Roach & Richmond 2015b). Additionally, although javelin athletes practice aiming as part of routine training (David Parker, pers. comm.), the goal of the javelin throw is to achieve maximum distance, and not to hit a target in a hunting scenario, and therefore their ability to hit a target is unlikely to be as developed as that of a prehistoric hunter.

A.2.3 Sample forms

Information Sheet for Mphil/PhD dissertation research: Human Performance Trial – Javelin throwing with wooden spears

You will be given a copy of this information sheet.

Dissertation title: Lethal Threshold: The evolutionary implications of Middle Pleistocene weaponry

Researcher name:	**Error! Contact not defined.**
Contact details:	a.milks@ucl.ac.uk
Supervisor's name:	Dr. Matt Pope

We would like to invite you to participate in this research project. There are two pages to this information sheet. Please read all of the material.

Details of Study:

- We are looking to understand how our human ancestors such as Neanderthals might have used simple wooden spears as hunting or defence weapons.
- We are using replicas of archaeological examples of wooden spears dating to 300,000 years ago, and wish to conduct some experimental work using expert javelin athletes.
- This experimental research will help us to understand what kinds of speeds these spears might have been thrown at, at what kinds of distances they fly well, how effectively experienced throwers can hit a target at a series of distances, and what the impact speeds are.
- This information will significantly increase our understanding of how our human ancestors behaved, how and what animals they may have hunted using these spears, and how they might have worked together as a group to make the spears and use them.

- The results of the research are primarily for my PhD thesis. We are also hoping to publish the results of the research so that others in archaeology and anthropology can benefit from the work we have done and have a better understanding of our human ancestors.

Explain the role of the participant

- Male javelin athletes over the age of 18 will be asked to participate.
- Participants will be asked to throw wooden spears, designed after archaeological spears, at a series of distances (5, 10, 15, 20 meters etc), in order to hit a target.
- Participants age, weight and previous throwing records will be requested. Each throw in the experiment will be recorded on a high-speed video camera to capture release data, and tracked using doppler radar to capture speeds. Distances for each throw will be recorded.
- We will not record participants names in the data, but will assign a number to each participant. Video footage and photographs of the experiment used in publication and/or conference presentations will exclude the faces of partipants.
- Risks associated with the project include the throwing of heavy and sharp objects! Appropriate safety measures will be in place, but participants are well-versed in safety in such procedures as you are experts.
- You will be witnessing first hand the results of the throws and distances, and we will inform you of any published results. We can also give you your individual throwing speeds if you wish. If you wish to have copies of the high speed video footage of your own throws in order to analyse them and study your throwing arm, we are happy to provide you with a copy of this.

Additional information

- If you agree to take part you will be asked whether you are happy to be contacted about participation in future studies. Your participation in this study will not be affected should you choose not be re-contacted.
- If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form.
- As participation is anonymous it will not be possible for us to withdraw your data once you participated in the experiment

Informed Consent Form Mphil/PhD dissertation research

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Project Title: Lethal Thresholds: The evolutionary implications of Middle Pleistocene weaponry

Researchers: Dr. Debra Carr, Dr. Matt Pope

Thank you for your interest in taking part in this research. Before you agree to take part, the person organising the research must explain the project to you.

If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you to decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

Participant's Statement

I agree that:

- I have read the notes written above and the Information Sheet, and understand what the study involves.
- I understand that if I decide at any time that I no longer wish to take part in this project, I can notify the researchers involved and withdraw immediately.
- I consent to the processing of my personal information for the purposes of this research study.
- I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.
- I agree that the research project named above has been explained to me to my satisfaction and I agree to take part in this study.
- I understand that my participation will be video recorded and photographed and I consent to use of this material as part of the project.
- I agree to be contacted in the future by UCL researchers who would like to invite me to participate in follow-up studies.
- I understand that the information from my participation will be published as a report after the completion of the PhD thesis. I also understand that the information from my participation may be used in conference presentations. Confidentiality and anonymity will be maintained and it will not be possible to identify me from any publications or

presentations

- I agree that my non-personal research data may be used by others for future research. I am assured that the confidentiality of my personal data will be upheld through the removal of identifiers.

Name:

Signature: Date:

THRUSTING SPEAR EXPERIMENT RECORDING SHEET

Date 21/7/2014	**Time**

PARTICPANT NUMBER	
GENDER	
WEIGHT	
HEIGHT	

SPEAR REPLICA ID	
RESHARPENED? Y N	

SPEAR MEASUREMENTS	
Length (mm) Weight (g) Max Diameter (mm)	

Replication	**1**	**2**	**3**	**4**	**5**	**6**	**7**
VELOCITY (m/s)							
PEAK FORCE (N)							
D.O.P. (mm)							
KE (J)							

Other Observations

(angle, breakage/blunting of tip, approach, stab type etc)

A.2.4 Experiment Costs

Table A.2.1 Actualistic Hammerstone experiment costs (section 8.2)

Date	Category	Description	Cost	Number of units	Total
418/06/14	Equipment	plastic containers	£43.96	1	£43.96
24/06/14	Equipment	gloves, rubbish bags, cloths, scrubber	£24.46	1	£24.46
24/06/14	Equipment	Metal rubbish bin & bbq rack	£55	1	£55
24/06/14	Equipment	detergent	£7.50	2	£15.00
TOTAL					**£138.41**

Table A.2.2 Impact Drop test experiment costs (section 8.3)

Date	Category	Description	Cost	Number of units	Total
11/08/14	material	plasticine	£11	1	£11
12/08/14	material	plastic tube	£2.08	1	£2.08
12/08/14	material	metal weight (tank connector)	£9.74	1	£9.74
16/07/14	material	casting putty	£39.92	1	£39.92
16/07/14	material	casting resin	£25.43	1	£25.43
29/07/15	material	3D printed cones	£40	1	£40
05/08/15	material	plastiline	€26.54 (c. £22)	1	£22
TOTAL					**£150**

Table A.2.3 Human Performance Thrusting experiment costs (section 7.2)

Date	Category	Description	Cost	Number of units	Total
18/12/13	Travel	Taxis Swindon - DA	£25	1	£25
18/12/13	Travel	Taxi DA - Swindon	£19	1	£19
18/12/13	Travel	Train to DA	£51.50	1	£51.50
11/04/14	Travel - spears	Petrol	£25.03	1	£25.03
11/04/14	Travel - spears	Van Rental	£42.50	1	£42.50
30/06/14	Shipping	Courier - spears to DA	£16.43	1	£16.43
22/07/14	Equipment	High Speed Video rental	£200	1	£200
22/07/14	Equipment	Force Data acquisition	£250	1	£250
22/07/14	Staff time	various	£1,800	1	£1,800
22/07/14	VAT	VAT on Cranfield work	£450	1	£450
21/07/14	Travel	Mess accomodation	£20	1	£20

18/07/14	Equipment	Spear replicas	£80	3	£240
TOTAL					**£3,139**

Table A.2.4. Human performance throwing trial costs (section 7.3)

Date	**Description**	**Cost**	**Number of units**	**Total**
25/09/14	Stickers – athlete ID	£4.98	1	£4.98
01/10/14	Van Rental	£30.00	1	£30.00
01/10/14	Petrol – van rental	£15.00	1	£15.00
12/01/15	Stavertons nursery: Haybale target	£4	1	£4
14/01/15	30 metre tape measure	£13.98	1	£13.98
14/01/15	Morrisons Food and drink Athletes	£46.32	1	£46.32
14/01/15	Spear Replica manufacture	£320	1	£320
17/01/15	Morrisons Food and drink Athletes	£32.98	1	£32.98
17/01/15	Morrisons petrol – generators and travel for A. Milks from Sussex	£39.25	1	£39.25
17/01/15	High speed camera rental and technician fees	£500	1	£500
19/01/15	HSS Hire – 3 generators	£188.48	1	£188.48
Total				**£1,194.99**

Table A.2.5 Spear Thrusting on Carcass costs (section 8.4)

Type	**Description**	**Cost**	**Number of units**	**Total**
Materials: consumables	carcass	£250/carcass + VAT	1	£300
Materials: consumables	spears	£80/spear	5	£400
Materials: equipment hire	high speed video rental	£333/day + VAT	1	£400
Staff time	Krishna Godhania: consultant	£500/day	1	£500
Travel/Accom.	Hotel for 2 participants	£70/night	2	£140
TOTAL				**£1740**

Table A.2.6 Spear Throwing on Carcass costs (section 8.4)

Type	**Description**	**Cost**	**Number of units**	**Total**
Materials: consumables	carcass	£250/carcass + VAT	1	£300
Materials: consumables	spears	£80/spear	3	£240
Materials: equipment hire	air cannon rental	£200/day plus VAT		£240
Materials: equipment hire	high speed video rental	£200/day plus VAT	1	£240
Travel/Accom.	mess accom DA	£20/night	1	£20
Lab costs/materials	Bone cleaning	£100 materials	1	£100
TOTAL				**£1140**

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