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## Bronze Age Swordsmanship: New Insights from Experiments and Wear Analysis

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<b>Abstract:</b>	<p>The article presents a new picture of sword fighting in Middle and Late Bronze Age Europe developed through the Bronze Age Combat Project . The project investigated the uses of Bronze Age swords, shields, and spears by combining integrated experimental archaeology and metalwork wear analysis. The research is grounded in an explicit and replicable methodology providing a blueprint for future experimentation with, and wear analysis of, prehistoric copper-alloy weapons. We present a four-step experimental methodology including both controlled and actualistic experiments. The experimental results informed the wear analysis of 110 Middle and Late Bronze Age swords from Britain and Italy. The research has generated new understandings of prehistoric combat, including diagnostic and undiagnostic combat marks, and how to interpret them; how to hold and use a Bronze Age sword; the degree of skill and training required for proficient combat; the realities of Bronze Age swordplay including the frequency of blade-on-blade contact; the body parts and areas targeted by prehistoric sword fencers; and the evolution of fighting styles in Britain and Italy from the late 2<sup>nd</sup> to the early 1<sup>st</sup> millennia BC.</p> <p>All primary data discussed in the article are available as supplementary material (Appendix) so as to allow scrutiny and validation of the research results.</p>	

## Bronze Age Swordsmanship: New Insights from Experiments and Wear Analysis

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### Abstract

The article presents a new picture of sword fighting in Middle and Late Bronze Age Europe developed through the *Bronze Age Combat Project*. The project investigated the uses of Bronze Age swords, shields, and spears by combining integrated experimental archaeology and metalwork wear analysis. The research is grounded in an explicit and replicable methodology providing a blueprint for future experimentation with, and wear analysis of, prehistoric copper-alloy weapons. We present a four-step experimental methodology including both controlled and actualistic experiments. The experimental results informed the wear analysis of 110 Middle and Late Bronze Age swords from Britain and Italy. The research has generated new understandings of prehistoric combat, including diagnostic and undiagnostic combat marks, and how to interpret them; how to hold and use a Bronze Age sword; the degree of skill and training required for proficient combat; the realities of Bronze Age swordplay including the frequency of blade-on-blade contact; the body parts and areas targeted by prehistoric sword fencers; and the evolution of fighting styles in Britain and Italy from the late 2<sup>nd</sup> to the early 1<sup>st</sup> millennia BC.

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### Key words

European Bronze Age; experimental archaeology; metalwork wear analysis; warfare and violence; combat archaeology.

## 1. Introduction

1 The last two decades have witnessed a substantial change in the study of interpersonal violence in prehistoric and  
2 preliterate societies. Spearheaded by Keeley's seminal monograph *War before Civilization* (1996), and aided by  
3 the new cultural and political milieu that followed the end of the Cold War, archaeologists and anthropologists  
4 have increasingly turned their attention to the nature and social significance of sanctioned aggression and warfare  
5 (Fry 2013; Otterbein 1997, 2004). In the field of European Bronze Age studies, this novel disciplinary interest has  
6 intersected longstanding research strands investigating warrior burials, hoarding practices, fortified settlements,  
7 martial imagery on rock art, osteological markers of injury, and weapon studies (Dolfini et al. 2018; Horn and  
8 Kristiansen 2018; Kristiansen and Larsson 2005; Kristiansen and Suchowska-Ducke 2015; Molloy 2017;  
9 Vandkilde 2013). The latter had long focused on one of the most iconic inventions of the Bronze Age world: the  
10 sword.

11 The new awareness that intergroup violence may have played a major role in the social transformations of Bronze  
12 Age Europe has had an invigorating effect on the discipline, spurring an array of specialist studies that investigated  
13 early metal weapons and armour by integrated archaeological and scientific analysis. In continuity with previous  
14 developments, the sword has enjoyed pride of place within this fast-developing research strand, somewhat  
15 overshadowing similar lines of enquiry into Bronze Age halberds, spears, and shields (Anderson 2011; Horn 2013,  
16 2014, 2017; Lull et al. 2017; Molloy 2009; O'Flaherty 2007, 2011; Uckelmann 2011, 2012). Two principal  
17 methods have been employed, jointly or otherwise, to research how swords might have been used in prehistory:  
18 experimental archaeology and metalwork wear analysis.

19 Sword experiments are normally carried out with bespoke bronze replicas of the objects to be tested. They fall into  
20 two overarching categories: laboratory tests and field tests. Laboratory tests, such as those conducted by Bridgford  
21 (1997, 2000), offer the distinctive advantage of being more controllable and easier to record than those carried out  
22 in the field. They normally make use of drop-testers or other mechanical devices, which allow excellent control of  
23 variables and good understanding of wear formation processes (Crellin et al. 2018). However, they offer limited  
24 scope for reproducing the complexity of human gesture. The problem is especially acute for swordsmanship, which  
25 is predicated upon the human body *and* the weapon working together, powered by fine motor skills and experiential  
26 knowledge (Molloy 2008).

27 Field experiments may appear to overcome this weakness. In experiential tests such as those conducted by Molloy  
28 (2006, 2007, 2008) and Gentile and van Gijn (2019), the human body is placed at the centre of the experiment. By  
29 allowing combatants to enact complex and 'realistic' fighting sequences, such tests provide an opportunity to  
30 correlate the mechanical properties of the weapons with the biomechanical properties of their bearers (Molloy  
31 2008: 118). However, this is achieved at the expense of control over the experiment's many variables including  
32 wear formation (Gentile and van Gijn 2019: 131; Schenck 2011: 87-88). A further limitation of experiential tests  
33 is that they need to be grounded in a predetermined body of knowledge, which is normally provided by medieval  
34 and post-medieval fencing manuals. These, however, often contain cryptic or partial information, whose  
35 interpretation is far from straightforward (Forgeng and Kiermayer 2007; Molloy 2008). Moreover, European  
36 fencing manuals arose out of specific historical contexts determining the correct way (or indeed ways) in which  
37 swords had to be used, by whom, and in which encounters and settings. As Melheim and Horn (2014) perceptively  
38 argued, drawing on Mauss' (1973) notion of *les techniques du corps*, learning to use a weapon involves the

1 incorporation of socially specific bodily techniques. We cannot presume that Bronze Age bodies and  
2 medieval/Renaissance bodies would act in the same ways whilst fighting because fighting is a socially constituted  
3 activity, which is predicated upon a corpus of embodied knowledge unique to each society (Crellin et al. 2018).  
4 Finally, one must note that bronze and steel greatly differ in their material properties. This consideration provides  
5 a further obstacle to interpreting prehistoric swordsmanship in light of historic fencing styles.  
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8 To some extent, the shortcomings of both laboratory and field tests can be tempered by investigating the combat  
9 marks visible on prehistoric swords through Metalwork Wear Analysis (MWA). This analytical method centres  
10 upon the microscopic observation of the manufacturing and use marks visible on ancient copper-alloy artefacts  
11 (Dolfini and Crellin 2016; Gutiérrez-Sáez and Martín-Lerma 2015). Despite its limited time depth, MWA has had  
12 a significant impact on Bronze Age weapon studies. For instance, it has overturned undemonstrated assumptions  
13 about the purely symbolic value of early weapons, and has generated terrific new insights into their uses (e.g. Horn  
14 2013, 2014, 2017; O’Flaherty et al. 2011). Despite its centrality to weapon studies, however, MWA relies on  
15 experimentation to elucidate prehistoric wear formation. This brings us back to the need to codify *meaningful yet*  
16 *formalised* tests with replica weapons and to cross-reference experimental and archaeological combat marks to  
17 generate credible interpretations (Crellin et al. 2018: 291).  
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21 With these problems in mind, in 2013 we launched the *Bronze Age Combat Project*, coordinated by one of the  
22 authors (AD). The project sought to investigate uses of Bronze Age swords, shields and spears based on integrated  
23 MWA and replica weapon tests. The aim of the project was to understand how prehistoric bronze weapons were  
24 used, in what kinds of combat situations, and with what weapon strikes and bodily engagements. One of the  
25 project’s main objectives was to explore the possibility of linking distinctive combat marks with specific uses of  
26 the weapons including strikes, parries, stabs, and throws. At a broader level, we wanted to gain a firm foothold  
27 into Bronze Age fighting practices including issues of weapon training, skill, and spatial/temporal variation in  
28 combat practices. A related objective was to develop a reflexive research methodology allowing new knowledge  
29 to arise from the critical nexus between controlled weapon experiments, experiential combat tests, and the wear  
30 analysis of archaeological and experimental weapons.  
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34 In this paper, we present results of our sword tests and wear analysis. Section 2 investigates the material properties  
35 of the experimental and archaeological swords and discusses the research methodology including weapon testing  
36 and MWA. Section 3 presents the wear marks generated during the sword tests vis-à-vis those observed on Bronze  
37 Age swords from Britain and Italy. Section 4 discusses the new knowledge generated by weapon testing and MWA  
38 including how to hold a Bronze Age sword, how to fight with it, and how swordsmanship changed from the 2<sup>nd</sup> to  
39 the early 1<sup>st</sup> millennium BC. Finally, Section 5 summarises the research results and suggests further avenues for  
40 enquiry.  
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44 The article is solely concerned with our sword tests and wear analysis. Further data and reflections concerning the  
45 *Bronze Age Combat Project* are published (or will be published) elsewhere. In particular, Hermann et al. (2019)  
46 outline project aims and structure; Crellin et al. (2018) critique the experimental methodology; and Hermann et al.  
47 (in press) provide an unabridged account of all weapon experiments. The spear and shield tests (and related MWA)  
48 will be discussed in Crellin et al. (in preparation) and Uckelmann et al. (in preparation).  
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## 2. Materials and methods

To gain new insights into prehistoric swordsmanship, and to escape from the tyranny of the laboratory tests versus field tests dichotomy (see above), we grounded our research methodology in an innovative four-step approach. First, we conducted a set of controlled weapon tests in which replica Bronze Age swords were tested in single-strike actions (e.g. a single slash or stab) against other swords, spears, and shields made of wood, leather, and bronze. Secondly, helped by Historic European Martial Arts practitioners, we designed bespoke experiential (or ‘actualistic’) tests by adapting combat sequences drawn from the *Commentary by Andre Lignitzer on Sword and Buckler*, a 15<sup>th</sup> century fencing manual (Farrell 2012), to Bronze Age sword-and-shield combat. Thirdly, we carried out MWA on the swords, spears, and shields used for both controlled and experiential tests. Fourthly, we conducted MWA on a sample of Middle and Late Bronze Age swords from Britain and Italy, and cross-referenced the marks observed on them with the marks generated experimentally, thereby grounding our interpretations in a knowable body of evidence. Details of our research methodology are provided below.

### 2.1 The replica swords: archaeology and manufacturing process

All swords and spears used in our project, as well as the bronze and leather shields, were made by Neil Burrige, a traditional bronzesmith ([www.bronze-age-craft.com](http://www.bronze-age-craft.com)). Jake Newport, a skilled amateur woodcarver, made the wooden shield using purpose-made bronze tools. Burrige cast and prepared seven swords based on the following British and continental templates: one Middle Bronze Age Group IV rapier, c. 1300-1150 BC; one European continental *Vollgriffschwert* classified under Kemenczei’s type S, c. 1200-1000 BC; one type Wilburton sword, c. 1150-975 BC; one Carp’s Tongue sword, c. 950-800 BC; and three Ewart Park swords, c. 925-800 BC (Burgess and Colquhoun 1988; Kemenczei 1991). All swords were made from 12% tin-bronze alloy; they were subjected to a single cycle of work-hardening and were mechanically sharpened. Finally, oak hilt plates and pommels were added to all swords except the *Vollgriffschwert* specimen, which had the hilt and pommel cast in solid bronze (Fig. 1). We thought it useful to select a variety of sword types displaying significant differences in weight, balance, blade length, and blade geometry, for this would enable us to test the combat capabilities of different weapons, as well as their limitations.

**Fig. 1** a: Group IV rapier (658 mm, 565.0 g); b: Kemenczei type S *Vollgriffschwert* (595 mm, 938.2 g); c: Wilburton type sword (562 mm, 511.5 g); d: Carp’s Tongue type sword (745 mm, 761.5 g); e: Ewart Park type sword, the two nearest the bottom were used for the actualistic tests (top: 658 mm, 701.4 g; middle: 696 mm, 753.0 g; bottom: 695 mm, 752.1 g)

Replicating these objects involved in-depth research into the manufacturing technology, alloy composition, and post-casting treatment of Bronze Age swords. The last two factors were judged to be of particular consequence because, even within a self-contained area and period, prehistoric swords show a wide variety of alloy compositions and post-casting treatments (see below). To reduce the variability inherent in the archaeological record, our sword replication process entailed several informed decisions, which we discussed with Neil Burrige. First, we decided to have all swords cast using 12% tin-bronze. This alloy sits near the higher end of the spectrum documented for Bronze Age swords in Northern and Central Europe and Britain (see Bunnefeld 2016; Mödinger 2011a, 2011b; Northover 1988), but is also common in Italian swords, particularly those from Olmo di Nogara, which make up over 50% of the Italian specimens analysed for this project (Angelini et al. 2003). The alloy was

1 selected as it improved the quality of the cast and reduced the risk of potentially dangerous defects developing  
2 within the objects. It is also the alloy with which Burrige is most familiar. All swords were cast with the same  
3 alloy composition to avoid introducing further variables into the experiment (Dolfini and Collins 2018). We  
4 deliberately chose not to add any lead to the replica swords, although lead is sometimes found in British and  
5 European continental swords from the Late Bronze Age (Mödlinger 2011b; Northover 1988). Lead is insoluble in  
6 copper and usually concentrates between the grains in copper alloys. As such, its presence effectively weakens the  
7 weapons. Gentile and van Gijn's study has shown that a small quantity of lead in copper alloys has no drastic  
8 influence on the formation of wear marks (2019: 139).  
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12 Secondly, we relied on a smithing technique of Burrige's own design to work-harden the blade edges. This  
13 involved a single cycle of expert edge hammering using a bronze hammer and anvil, followed by mechanical  
14 sharpening to a razor finish. All swords were worked and finished in the same way. Whereas the swords made by  
15 Burrige *looked like* excellent replicas of Bronze Age weapons, we needed to know if they *were* such in terms of  
16 microstructure and edge hardness, as these parameters may affect functionality and wear formation (Soriano-  
17 Llopis and Gutiérrez-Sáez 2009). Hence, upon completing the sword tests and MWA, we took cross-sections from  
18 the cutting edge to the centre of the blade of four replica swords for compositional, microstructural, and micro-  
19 hardness testing (sample size: 1x2 cm).  
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25 The samples (named SW1-4) were mounted in epoxy resin, ground, and polished using diamond paste to a finish  
26 of 1  $\mu\text{m}$ . They were examined with a Zeiss AXIOVERT 100A microscope for the metallographic study and a  
27 Hitachi S-3700N variable pressure scanning electron microscope (SEM) equipped with energy-dispersive X-ray  
28 spectrometry (EDX) for compositional analysis. The SEM-EDX analyses were run at an accelerating voltage of  
29 20 kV at low vacuum of 50 Pa and working distance of 10 mm.  
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34 The samples were found to have a tin content of 12.9-14.2%, higher than that in the original charge. Faoláin and  
35 Northover (1998) have reported slightly exaggerated tin contents in experimentally cast swords, measured by XRF  
36 analysis, compared to the original charges. Wang and Ottaway (2004), on the other hand, measured the tin contents  
37 of their experimental casts by ICP-OES, with results close to the nominal bronze composition. It is presently  
38 unclear if higher-than-expected tin content in our casts had resulted from a weighing error in the original charge  
39 or is a function of the SEM-EDX analysis.  
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44 The samples were subjected to micro-hardness testing using an Indentec ZHV $\mu$ -M tester. For each specimen, five  
45 points were tested from the cutting edge to the centre of the blade, with 150-300  $\mu\text{m}$  intervals. The mean value  
46 and standard deviation for each sample are listed in Table 1. Overall, there is no clear increase in hardness values  
47 from blade centre to the cutting edge, although there are noticeable variations in the five points tested on each  
48 specimen.  
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52 **Table 1** Vickers hardness (HV) and standard deviation (s.d.) values of the experimental swords vis-à-vis the HV  
53 values of metal sheets left at different states (Point 1 is in the centre of the blade, Point 5 near the cutting edge).  
54 The original charge of all samples contained 12% Sn and 88% Cu  
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57 Subsequently, the samples were etched using alcoholic ferric chloride to reveal their metallographic structures. All  
58 samples were found to have dendritic structures with little distortion: SW1 features a normal structure of ( $\alpha$ + $\delta$ )  
59 eutectoids, while ( $\alpha$ + $\delta$ ) eutectoids in SW2-4 appear to be unusually concentrated on the boundaries of the  $\alpha$  phase.  
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1 This indicates that SW2-4 cooled at a faster rate than SW1 (Avner, 1974; Scott 1991). Samples from SW1-2 are  
2 very porous but otherwise differ in terms of pore size (much larger in SW1 than SW2), while samples from SW3-  
3 4 are dense (Fig. 2). Overall, all swords examined had undergone some 10% thickness reduction by cold-working.

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5 **Fig. 2** Photomicrographs of the replica sword samples. Left column (unetched, low magnification; scale bar =  
6 1mm): samples SW1 and SW2 showing porous structure, and SW3 and SW4 showing dense structure. Right  
7 column (etched with alcoholic FeCl<sub>3</sub> solution, high magnification; scale bar = 50µm): all samples showing slip  
8 lines indicating cold-working  
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11 Most British Bronze Age swords analysed to date contain 7-14% Sn, with added lead in some of them. Their  
12 hardness values lie between 100 and 200 HV on the Vickers scale, and their microstructures include as-cast, cold-  
13 worked, partly recrystallized, fully recrystallized, and recrystallized and cold-worked objects. Thickness reduction  
14 ranges from none to over 50% (Allen et al. 1970; Bridgford 2000; Brown and Blin-Stoyle 1959; Faoláin and  
15 Northover 1998; Northover 1988; Northover and Bridgford 2002). Such extreme diversity in alloy composition,  
16 microstructure, and hardness values is also found in swords from continental Europe (Bunnefeld 2016; Kouï et al.  
17 2006; Mödinger 2011a, 2011b; Molloy 2018). This strongly suggests that Bronze Age sword production did not  
18 follow a standardised manufacturing process, not even within a single region and period. It appears that swords,  
19 as much as other bronze tools and weapons, were manufactured based on the smith's technical skill and experience,  
20 in relationship to the material properties of the metal and cultural notions of what a finished sword should be like  
21 (Kuijpers 2018a, 2018b).

22  
23 The compositional, microstructural, and micro-hardness analysis demonstrates that our replica swords fall within  
24 the technical parameters of Middle and Late Bronze Age swords from the Britain, and compare well with  
25 continental European specimens, too. The high degree of variation witnessed in prehistoric bronze weapons  
26 suggests that any meaningful replication process must be predicated upon informed choices concerning the alloy  
27 composition, edge hardening, and thickness reduction of the original cast blanks. As a result, the replicas will  
28 compare well with *certain* Bronze Age swords and less well with others. This is a function of the diverse  
29 archaeological record. While further research is needed to understand how differences in alloy composition and  
30 edge hardening may affect sword performance in combat experiments (building on Soriano-Llopis and Gutiérrez-  
31 Sáez 2009), we are satisfied that our replicas provide a good match for the archaeological swords, thus validating  
32 the test results and MWA discussed below.  
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## 47 2.2 Controlled Weapon Tests

48 The Controlled Weapon Tests (CWTs) were designed to recreate prehistoric one-on-one combat. Presuming that  
49 different kinds of weapons would have encountered one another in prehistoric armed clashes, we tested the swords  
50 not just against other swords but also against spear-heads, spear-shafts and replica wood, leather, and bronze  
51 shields. To allow for chronological consistency, all tests were carried out with weapons that would have existed  
52 contemporaneously (e.g. Ewart Park and Carp's Tongue swords). We chose not to mount the weapons on testing  
53 rigs as this would severely limit the range of actions we could replicate. Instead, we opted for rigorous field tests  
54 carried out by experienced sword fencers. Depending on their nature, and also for health and safety reasons, certain  
55 tests were carried out by two combatants, while others (e.g. full-force sword thrusts) were aimed at static shield  
56 targets. During person-on-person tests, the combatants wore full body protection comprising knee-length padded  
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1 gambesons, metal gauntlets and fencing masks. Overall, the CWTs involved 148 individual tests unfolding over  
2 six days. They were carried out at two open-air facilities in the North-East of England: Bede's World Museum  
3 (now Jarrow Hall) and the Durham University Botanic Garden.

4  
5 The guiding principle in our CWT design was to break down 'real-life' combat sequences into their elemental  
6 components (e.g. a single strike or parry). This strategy ensured full control of wear formation processes as well  
7 as test consistency and repeatability. Working strike by strike and parry by parry, each action was individually  
8 filmed and photographed, and all marks thus generated were recorded photographically, with the location and  
9 shape of each mark being also noted and labelled. This allowed us to build direct links between specific combat  
10 moves and specific marks. Repeats of every experiment were built into the protocol so that we could investigate  
11 the reliability of our results. The CWT experimental protocol is described in Table 2.

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16 **Table 2** Controlled Weapon Tests: experimental protocol

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18 All CWTs comprised static, kinetic and dynamic sword parries. Our dynamic parries most closely mirrored live  
19 combat situations, in which both fighters would place force and speed behind the weapons, as one would in a real  
20 fight. Static parries, on the other hand, involved holding the defensive weapon still to receive the attacking strike,  
21 while during kinetic parries the defender met the attack with a controlled movement towards the incoming weapon  
22 (Fig. 3). The force and velocity of the strikes were controlled empirically. Consistency between similar tests was  
23 ensured by having the same combatants hold the attacking and defending swords. Separating out static, kinetic and  
24 dynamic parries allowed us to examine the relationship between different marks and the conditions in which they  
25 were generated, and to test the conclusions arrived at by other researchers in a non-laboratory environment.  
26 Moreover, certain tests (e.g. full-force blade-on-blade strikes) gave us insights into the ritual destruction of swords,  
27 and how to differentiate combat marks from 'sword-killing' marks (Knight 2019).

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34 **Fig. 3** Controlled Weapon Tests practice

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36 This approach to sword testing has offered several advantages over either machine-run experiments or experiential  
37 fighting tests. Firstly, it has allowed us to connect specific combat actions with specific wear marks, generating a  
38 comprehensive reference collection that could be used for the wear analysis of archaeological swords. Secondly,  
39 it has given us insights into which part of the blade is affected the most during sword fighting, and enabled us to  
40 discriminate between attack and defence marks. Thirdly, it has allowed us to move beyond some of the sword-  
41 centric work carried out in the past and let us consider how different weapons can be used in combination with  
42 one other (e.g. in a melee). Finally, it has provided an opportunity to investigate the grey area that exists between  
43 marks originating from use and those derived from acts of deliberate destruction (Crellin et al. 2018: 296).

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45 However, the CWTs have also had several disadvantages. First and foremost, they provided poor proxies for the  
46 sophistication of a real sword fight, whose aim arguably is to hit the opponent in a vulnerable part of their body,  
47 not leave a mark on their weapons. Due to their nature and goals, our tests largely failed to capture the wear patterns  
48 that may arise from weapons hitting human bodies and armour (although the latter was partly achieved in our  
49 shield tests). As such, some of the marks created during our tests are best interpreted as instances of 'failed combat',  
50 in which unplanned strikes or parries are carried out and weapons clash against the will of the combatants, while  
51 other marks may be good proxies for the ritual decommissioning of swords prior to deposition (Knight 2019).  
52 Additional weaknesses of the CWTs encompass: limited control of strike force, velocity, and other variables

1 affecting wear formation compared to laboratory experiments; the need to scale down the experimental protocol  
2 due to higher-than-expected rates of sword damage; unexpected variability arising from the use of several sword  
3 types featuring varying blade lengths, points of balance, weights, and geometries; and the vagaries of in-field  
4 recording, with all the problems one might expect to be caused by an open environment and the lack of a fully  
5 equipped microscope laboratory (Crellin et al. 2018: 296-9). In order to offset these problems, we designed a series  
6 of experiential (or ‘actualistic’) weapon tests based on radically different principles and experimental protocols.  
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### 10 11 2.3 Actualistic Weapon Tests

12 Like the controlled tests discussed above, the Actualistic Weapon Tests (AWTs) aimed to recreate prehistoric one-  
13 on-one sword fighting. However, they were not informed by the need to generate combat marks for wear analysis,  
14 but intended to test the capabilities of Bronze Age swords and combatants *as an integrated functional unit*, as  
15 would happen in real-life fencing. Creating marks on the weapons was simply a useful by-product of the  
16 experiment, not its ultimate goal. As in the approaches advocated by Molloy (2007, 2008) and Gentile and van  
17 Gijn (2019), our AWTs fell between what Mathieu (2002) labelled ‘functional replication’ and ‘phenomenological  
18 studies’. The term ‘actualistic’, introduced by Molloy (2008) and Outram (2008), describes an experimental setup  
19 that “investigates activities that *might* have happened in the past using methods and materials that would actually  
20 have been available” (Outram 2008: 2; original text) through scenarios that are designed to be as close to real life  
21 as possible.  
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29 In such an approach, the functional controls that validate the accuracy of the analogy between ancient and  
30 experimental fighting are the morphology and mechanical properties of the weapon *plus* the biomechanical  
31 properties of the human body (Molloy 2008: 118). Weapon and body are understood here as a single biomechanical  
32 unit that is controlled by internalised cultural norms, instinctual responses rooted in neurological processes, and  
33 embodied practice (Malafouris 2008; Yun 2009). Here lies a crucial difference between the CWTs and AWTs: in  
34 the former, the human body operated the weapon, but did not provide any knowledge-based inputs beside  
35 experienced handling and fine motor skills. The AWTs, on the other hand, were informed by bodily grounded  
36 knowledge about how to use a sword, which had been attuned through many years’ learning and training. An  
37 important implication of this approach to the AWTs is that the tests had to be anchored to a predetermined body  
38 of knowledge acting as a methodological ‘scaffold’. As with other experiential weapon tests, we selected a historic  
39 fencing manual: the 1452 *Commentary by Andre Lignitzer on Sword and Buckler* from folios 80r-80v, Codex  
40 44.A.8, by Peter von Danzig (see Farrell 2012 for an English translation). Lignitzer’s *Commentary* was interpreted  
41 through both academic scholarship and contemporary practice of Historic European Martial Arts (HEMA). HEMA  
42 is a growing international movement that strives to understand, practise, and popularise (mostly) late medieval and  
43 Renaissance combat treatises through scholarship and knowledgeable re-enactment (Anglo 2000; Clements 1997,  
44 1998; Forgeng 2003; Talhoffer 2000; Wagner and Hand 2003).  
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54 We chose this treatise for several reasons. Firstly, the weapons described in it – short swords and bucklers (small  
55 round shields) – are typologically similar to the swords and shield replicas used in our tests, although the materials  
56 are different. Secondly, while the *Commentary* does not contain any images, it provides detailed descriptions of  
57 the combat actions, unlike many other sources from the time, which mainly rely on depictions. Thirdly, the  
58 *Commentary* has long been studied by various scholars, who have proposed broadly similar interpretations for the  
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1 combat actions described therein (e.g. Warzecha 2017; Griswold 2016; Winslow and Winslow 2011). This gave  
2 us confidence that our tests would be grounded in accepted specialist knowledge. Working with distinguished  
3 HEMA specialists Robert Brooks and Andrew Milburn (Hotspur School of Defence), we replicated five combat  
4 sequences out of the six described in the *Commentary* (plays one to five, Table 3). The sixth play is designed to  
5 take the opponent's shield and does not involve any sword contact; as such, it was left out of the protocol (Fig. 4).  
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8 **Fig. 4** Actualistic Weapon Tests: final stance of the fifth play  
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10 To overcome the complications of in-field recording experienced during the CWTs, we decided to hire an indoor  
11 location (St. Luke's Church hall, Newcastle upon Tyne), which provided us with a safe and sheltered space to  
12 conduct the AWTs. We were also able to set up an in-situ microscopy laboratory in a side room of the church hall,  
13 where full identification and recording of marks took place immediately after each combat sequence. This offset  
14 the risk that later plays would cause earlier marks to be erased or damaged. The combatants fought with two brand-  
15 new Ewart Park replica swords (exact copies of the replicas used during the CWTs) and the two Cloonbrin replica  
16 leather shields used in the previous experiments. They practised each play repeatedly with wooden training swords  
17 before carrying out the tests. Although plays one to four were only conducted once each, the individual actions are  
18 often repeated in the different plays (e.g. *Versetzen* appears in four of the five plays; see 3.1.3). This ensured a  
19 better understanding of mark formation processes. The fifth play was conducted twice, as the first attempt created  
20 no marks on either sword and we wished to rule out that this was just a chance occurrence. During the live tests,  
21 the combatants wore personal protective equipment consisting of fencing masks, thick padded gambesons, and  
22 steel-clad gauntlets. Videos and photographs of the combat sequences were taken with a SONY Cyber-shot  
23 DSCH300B Bridge Camera and Olympus Stylus Touch, respectively. The AWT experimental protocol is  
24 described in Table 3.  
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34 **Table 3** Actualistic Weapon Tests: experimental protocol. English transcriptions of plays after Farrell (2012)  
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36 The AWTs featured several notable strengths complementing those of the CWTs. First, they were firmly grounded  
37 in 15<sup>th</sup> century swordsmanship, which is characterised by high degrees of sophistication and finesse (Gassmann et  
38 al. 2017: 119). This, we posited, would provide a compelling historical analogy for Late Bronze Age sword  
39 fighting, which, like its late medieval counterpart, stood at the cusp of a sword fighting tradition going back several  
40 hundred years. Secondly, the AWTs did not subject the weapons to the same mechanical stresses as the CWTs.  
41 This ensured excellent cutting edge preservation throughout the combat sequences, allowing us to complete all  
42 actions planned. Finally, we were able to microscopically record the combat marks on the swords immediately  
43 after each fighting sequence, thanks to the 'flying laboratory' we had set up next to the experimental hall.  
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48 As for the limitations of our AWTs, the most notable was the difficulty to identify exactly which mark was caused  
49 by which action during a combat sequence. The problem was partly offset by keeping the sequences short (typically  
50 four seconds) and using high-speed cameras and digital photography, supported by inputs from the combatants, to  
51 understand which action had caused which mark. Another notable disadvantage of the AWTs was their being tied  
52 to a specific historic fencing style. This presented a significant risk of circularity in test design, data generation,  
53 and data interpretation, whereby we would make certain preconceived assumptions about how Bronze Age swords  
54 would be used, we would test the swords based on these assumptions, and, with perhaps the odd exception, we  
55 would demonstrate our assumptions experimentally. This is one of the greatest risks of grounding prehistoric  
56 weapon testing in historic sources. We knowingly offset this risk not only by comparing and contrasting the marks  
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generated by both actualistic and controlled tests, but also by validating both through the wear analysis of archaeological swords.

#### 2.4 Metalwork Wear Analysis

In order to identify and record archaeological combat-related wear traces, and to interpret them by reference to both CWTs and AWTs, we analysed 110 Middle and Late Bronze Age swords from British (70 specimens) and Italian (40 specimens) museum collections. The swords were selected on account of chronology, typology, and degree of overall surface preservation. Only complete swords with excellent visibility of wear marks were included in the study (Table 4).

#### **Table 4** Bronze Age swords examined as part of the research, by museum

The analysis was conducted by one of the authors (RH) following the methodology described in Dolfini and Crellin (2016), adapting the analytical protocol laid out in Dolfini (2011) and Crellin (2018). No casts of the prehistoric swords were taken. The analysis was carried out on the original objects at museums, using a Huviz HSZ stereoscope equipped with a GX-Cam 9 camera and built-in cold light source. Additional lighting was provided by a portable gooseneck spotlight. In a few instances, it proved impractical to carry the bulky Huviz microscope to the museums. In these cases, the analysis was carried out with a GXM-DinoLite Pro AM-413T digital microscope. A sample of Bronze Age swords from the Great North Museum collections, Newcastle upon Tyne, was analysed with both microscopes to evaluate consistency in data collection and recording. It was found that all marks described below could be identified and classified correctly using either device, although the microphotographs taken with the DinoLite could be of inferior quality.

All swords were visually inspected, described, weighed, drawn, and photographed. Subsequently, they were microscopically examined at magnifications ranging from  $\times 8$  to  $\times 40$ , and all macroscopic and microscopic wear marks were noted on the 1:1 drawings, recorded in a MS-Excel database, and digitally photographed. As no universally accepted terminology for metalwork wear traces has yet been established (Gentile and van Gijn 2019: 136), the use marks were classified using a nomenclature originally created for this research (see Section 3), drawing on the literature (Bridgford 2000; Horn 2013; Molloy 2011; O'Flaherty et al. 2011; Uckelmann 2012). To prevent misinterpretation and facilitate comparison with the literature, we described each mark type individually rather than grouping similar (or functionally related) traces under overarching labels. All primary MWA data including the MS-Excel database and micrographs can be accessed as supplementary online material.

### **3. Data analysis**

The wear analysis of the archaeological swords has revealed 23 different types of use-related marks (Table 5), all of which were covered by a thin layer of oxidation products, or patina, as is mostly the case with ancient marks (Roberts and Ottaway 2003: 120). Manufacturing and post-depositional marks (disturbing the patina) were noted during the analysis (included in supplementary material) but are not discussed in this paper. Fourteen of the archaeological use marks were recreated during the weapon experiments, either controlled or actualistic (or both: Table 5). Some of these marks can securely be linked to specific combat actions (e.g. bulges and tip pressure) or weapon encounters such as sword vs. spear (e.g. wide-angled notches and indentations). Others, however, were

caused by a number of different actions (e.g. notches, grazes, flattening, and bending). Blow marks, rectangular indentations and irregular grazes were each only recreated once, and it is therefore doubtful if they can solely be interpreted by reference to the action described.

**Table 5** Use-related marks identified on 110 archaeological Bronze Age swords from Britain and Italy. Of these, 14 were recreated during the combat experiments. The table details whether the marks were created during the controlled or actualistic weapon tests, and if they were caused by an attacking or a defending motion (limited to the controlled tests)

Limited to the CWTs, it was often possible to link use marks to the attacking or defending motions executed with the replica swords, as the two motions were clearly differentiated. Such distinction was lost in the AWTs as, by their very nature, these tests did not rely on a clear-cut separation between attack and defence, but on fluid combat sequences in which a defensive action could quickly be turned into a counterattack, and vice-versa (see 4.2). Of the 14 marks recreated during the combat tests, six were deemed diagnostic, i.e. were created by a single, specific combat action. As such, they provide prime direct evidence of Bronze Age swordsmanship. To these, we can add a distinctive pattern of blade damage caused by a blocking action on the defending sword, which finds exact parallels in the archaeological record. These damage patterns and their causes are discussed in Section 3.1.

### 3.1 Diagnostic combat marks

#### 3.1.1 *Wide-angled notch*

Wide-angled notches (Fig. 5) have a wide, shallow angular profile. They were exclusively created when the sword's cutting edge impacted on the cutting edge of a spearhead. Due to the difficulty of connecting the sword with the spearhead, these marks were only created twice during the CWTs (Figure 6). This is reflected in the archaeological record, which has yielded only 64 wide-angled notches on 36 swords from Britain and Italy (Figure 5B).

**Fig. 5** a: Replica wide-angled notch from test 31e.4; b: Archaeological wide-angled notch, mark ID 151

**Fig. 6** Controlled Weapon Test 31e.4: long spearhead (on a short shaft) vs dynamic sword edge parry. This caused the formation of a wide-angled notch on the sword's cutting edge

#### 3.1.2 *Indentation*

Indentations are wide and shallow, and have a distinctively rounded profile (Fig. 7). They are caused by the sword's cutting edge connecting with the round socket or wooden shaft of a spear (Fig. 8). During the experiments, it proved easy to achieve good contact between sword and spear shaft due to the length of the latter. The archaeological record (Fig. 7B) reflects this well, for the wear analysis has revealed 693 indentations on 91 swords.

**Fig. 7** a: Replica indentation from test 27g; b: Archaeological indentation, mark ID 106

**Fig. 8** Controlled Weapon Test 27g: sword vs kinetic strike on the socket of the spear head. This caused a distinctive indentation in the cutting edge of the sword

### 3.1.3 Bulge

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Bulges are defined as material displacements of the cutting edge, whereby the metal is deformed in such a way that it bulges out to the side (Fig. 9). They were solely created during the AWTs as a result of a *Versetzen* (displacement). *Versetzen* is a fencing technique that seeks deliberate contact with the opponent's blade in order to bind and control it (The Association for Renaissance Martial Arts 2019; Fig. 10). As the blades are twisted during the bind and the cutting edges come into contact, millimetre-sized bulges are left on the blades. Bulges occur in roughly equal measure on both the controlling and the controlled weapon. Interestingly, the HEMA swordfighters observed that *Versetzen* was exceptionally well suited to bronze swords as the material properties of this metal caused the two blades to 'stick together' in ways not experienced with steel swords. This suggests that similar sword binding techniques may have been practised by Bronze Age fighters. The inference is supported by the wear analysis of archaeological swords, which shows 111 bulges on 39 specimens (Fig. 9B).

**Fig. 9** a: Replica bulge from test 304b; b: Archaeological bulge, mark ID 127

**Fig. 10** Actualistic Weapon Test 304b: the defender binds the swords to control the opponent's blade. This caused a distinctive bulge in the cutting edge of the attacking sword

### 3.1.4 Tip pressure

Tip pressure is a characteristic flattening of the sword point created as the sword is thrust against a hard surface (Fig. 11). In the CWTs, tip pressures were created by sword thrusts against both the wooden and the bronze shield (Fig. 12). In contrast, the sword point was not flattened or otherwise damaged when thrust against the leather shield, which proved relatively easy to pierce. Tip pressures were observed on 35 archaeological specimens from the sample (Fig. 11B).

**Fig. 11** a: Replica tip pressure from test 104b; b: Archaeological tip pressure on sword ID 5

**Fig. 12** Controlled Weapon Test 104a: static sword thrust to the face of the bronze shield mounted on hay bales

### 3.1.5 Irregular graze

An irregular graze is a triangular mark in the cutting edge with one flank noticeably longer than the other (Fig. 13). The long flank is jagged and does not follow a distinctive profile. During the CWT, an irregular graze was only created on one occasion as a result of a sword slash to the wooden shield (Fig. 14). Irregular grazes are common in the archaeological record, with 182 recorded on 63 Bronze Age specimens (Fig. 13B).

**Fig. 13** a: Replica irregular graze from test 201b; b: Archaeological irregular graze, mark ID 186

**Fig. 14** Controlled Weapon Test 201b: glancing sword blow to the face of the wooden shield. This caused an irregular graze in the cutting edge

### 3.1.6 Rectangular indentation

Rectangular indentations are similar to indentations (see 3.1.2), but instead of a rounded impact profile they have angular outlines (Fig. 15). In the CWT, a rectangular indentation was created in the attacking sword as the result

of a shoulder strike defended with a static edge parry (Fig. 16). Rectangular indentations are a rare occurrence on archaeological swords, with only 25 recorded examples on 17 specimens (Fig. 15B).

**Fig. 15** a: Replica rectangular indentation from test 36a; b: Archaeological rectangular indentation, mark ID 216

**Fig. 16** Controlled Weapon Test 36a: shoulder strike vs. static edge parry. This caused a rectangular indentation in the attacking sword

In addition to these marks, a distinctive damage pattern was identified on four archaeological swords (IDs 11, 59, 71 and 105; Figs. 18-19). This consists of oblique striations on the flat of a bent blade, with bending in the range of 10° from the original longitudinal axis. We hypothesised that this recurring damage pattern could have been caused by flat parrying – a fencing technique that uses the flat of the blade to block an incoming attack, typically by another sword, in order to preserve the defending sword’s cutting edge. The method was routinely practised in medieval and post-medieval fencing as it suited the tensile strength, toughness and ductility of steel blades (Clements 2002). Despite notable differences in the material properties of bronze and steel, it has been suggested that flat parries might have been carried out with prehistoric swords, too (Mödlinger 2011a: 164). We put this suggestion to the test.

The controlled test consisted of a sword strike directed to the leg, which was blocked by a dynamic flat parry. We used the Wilburton type sword replica for the attack and the *Vollgriffschwert* (which has a wide leaf-shaped blade and narrow midrib) for the parry (Fig. 20). The forceful impact of the attacking blade caused the defending blade to bend by about 10°; it also left a distinctive pattern of striations on the blade flat. This is the same combination of marks and blade bending found in the archaeological swords (Figs. 17-19). As the damage was so severe that it disabled the defending replica sword, one presumes that Bronze Age fencers would have avoided flat parries as much as possible. This begs the question as to what may have caused the damage observed on the archaeological swords: was it a planned combat action gone wrong? Was it a last-resort hard block, perhaps to save one’s life? Or was it intentional ritual damage carried out before the sword was committed to the ground or water? While the latter cannot be excluded, it is noteworthy that Gentile and van Gijn (2019: 137-8) report sword bending during their experiential combat tests, caused by either hard blocks (similar to our flat parries) or deflections. Although they do not elaborate on the observation, the Gündlingen-type swords used for their tests ostensibly sustained less damage than our *Vollgriffschwert*, and their damage pattern seems also different from ours. These discrepancies can probably be ascribed to the dissimilar testing protocols and degree of force applied in the two experiments, with alloy composition, blade geometry, hardness, and microstructure also being possible factors.

**Fig. 17** Replica sword used in Controlled Weapon Test 01k. Note the 10° curvature from the original weapon axis

**Fig. 18** Archaeological sword ID 71. Note the 10° curvature similar to Fig. 17

**Fig. 19** a: Striation patterns on the flat side of the blade (replica sword) caused in CWT 01k (Fig. 20); b: Striation patterns on the flat side of the blade of archaeological sword ID 71, near the curvature

**Fig. 20** Controlled Weapon Test 01k: leg strike vs dynamic flat parry. Note the defending sword (a *Vollgriffschwert* with wide leaf-shaped blade and narrow midrib) being bent by the incoming strike

### 3.2 Patterning and clustering of wear marks

As the flat parry case study suggests, the association of wear marks into distinctive patterns, as well as their clustering in certain sections of the blade, can be more informative about prehistoric fighting styles than individual marks. Clusters are defined here as groups of two or more marks, of any type, lying next to one other, while a pattern is the spread (or the extent) of one mark type along the entire sword (Fig. 21). Whilst no clustering was created either in the CWTs or the AWTs, the wear analysis has revealed several instances of mark clusters on both British and Italian archaeological swords. Overall, 325 clusters have been identified on the 110 swords examined for this study, comprising 742 combat-related marks in total, which resulted from repeated impacts on the same section of the blade (Fig. 22). Most clusters consist of two marks (254 clusters), followed by 53 clusters of three marks, 15 clusters of four marks and three clusters of five marks (Table 6). The most common marks represented within the clusters are indentations (31.8%, 236 marks), round notches (19.0%, 141 marks) and sharp notches (9.4%, 70 marks).

**Fig. 21** Schematic drawing of a sword displaying a pattern (of one mark type) and a cluster of four (in this case four different mark types)

**Table 6** Clusters of two, three, four and five marks found on the sample of 110 Bronze Age swords from Britain and Italy analysed for this study

Although mark clustering could potentially be a chance occurrence, its frequency suggests that this is not the case. Clustering is more likely to be the result of carrying out the same combat action or fighting sequence numerous times, using the same part of the blade. This suggests that the fighter must have achieved excellent control of the weapon through sustained training. It is unfortunately difficult, in all but a handful of cases, to determine the exact nature of the action or sequence that generated the cluster as most marks are unspecific, i.e. they may be caused by several strikes or other uses of the weapon (Table 5). Clusters of multiple (primary) marks must be distinguished from micronotching. Like clusters, micronotches are found in close proximity to other marks. However, fighting experiments suggests that they are to be interpreted as secondary marks caused by the attacking sword rebounding on the defending weapon, as the kinetic energy of the attack is not entirely dissipated by the first impact (Gentile and van Gijn 2019, 135; Hermann et al. in press). Though easy to identify due to their tiny size and their location next to a larger primary mark, micronotches rarely survive in the archaeological record due to surface corrosion or possible repair in prehistory. In this study, we have been able to identify only 35 micronotches out of 2367 combat-related marks (Fig. 23).

**Fig. 22** Cluster of four marks (from left to right: round notch, round notch, sharp notch, sharp notch) on the right cutting edge of Sword ID 60

**Fig. 23** Primary impact marks surrounded by smaller micronotching. a: Cluster of two sharp notches and one micronotch (red) created during CWT 36b, as the result of a rebounding impact. The right sharp notch was the result of CWT 3f. b: Archaeological micronotching (red) surrounding a primary sharp notch, mark IDs 119 (primary mark), 117, 118, 120, 121 (micronotching)

1 Unlike clusters, which group together any mark types, a pattern is defined as the spread of a single mark type along  
2 the entire blade. The most common are indentations, bulges, notches, and grazes. While bulges and indentations  
3 are caused by specific, knowable combat actions (see 3.1.1-2), notches and grazes are more difficult to interpret,  
4 as they may have multiple causes (Table 5). As with clusters, the extent of patterns of combat marks can suggest  
5 a repeated deliberate use of that particular portion of the blade, which implies a certain degree of motor control  
6 due to weapon training.  
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10 Interestingly, if one breaks down mark patterns by sword chronology, one can see distinctive developments in  
11 their occurrence and concentration over time. To visualize where the main patterns are located along the cutting  
12 edges and how patterning changed over time, the dataset must first be normalised. To compare swords of different  
13 lengths, the formula  $y = (d/D)*100$  ( $d$ =distance of mark from the tip,  $D$ =total length of sword) is used to express  
14 each mark's distance from the blade tip as a percentage of the entire length of each sword. The decision to calculate  
15 the distance as a percentage of the sword length, rather than of the blade, was due to the difficulty of establishing  
16 the exact limits of each sword blade. Unlike medieval swords, in which the length of the blade can be expressed  
17 as the distance from tip to crossguard, Bronze Age swords have no crossguards marking the end of the blade. Other  
18 indicators such as the length of the bevel lines from tip to ricassi (i.e. the unsharpened portions of the blade just  
19 above the shoulders) are not uniformly present in the sword sample either. In fact, many Bronze Age swords lack  
20 bevel lines, ricassi or shoulders altogether, while in others the bevels are of different lengths, the ricassi are askew,  
21 and the midrib starts from the hilt. The whole length of the sword was therefore thought to be the only reliable  
22 variable to consider for cross-comparison. Deviations due to fractured tips or grip tongues are negligible as broken  
23 or incomplete swords were excluded from the sample (see 2.4). The swords were analysed in chronological order:  
24 for Britain, by metalworking stage (i.e. Penard, Wilburton, Ewart Park and Llyn Fawr; Needham 1996, 122;  
25 Needham 1997, 82; Roberts et al. 2015, 19), and, for Italy, by chronological phase (i.e. Middle, Recent and Final  
26 Bronze Age, followed by Early Iron Age; Nicolis 2013, 694; Fig. 24). For each mark type, the outliers were  
27 removed and the interquartile range (IQR) was calculated to illustrate the spread of marks along the cutting edges  
28 (Fig. 25).  
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40 **Fig. 24** Chronology of British metalworking stages and north Italian chronological sequencing from the Middle  
41 Bronze Age to the Early Iron Age. Absolute chronologies after Roberts et al. (2015) and Nicolis (2013)

42 **Fig. 25** Normalised distances of indentations, notches, grazes and bulges on swords from the British Penard,  
43 Wilburton, Ewart Park and Llyn Fawr phases and the Italian Middle and Recent Bronze Age. Each sword displays  
44 the first and third quartile as well as the interquartile range  
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50 In Britain, a clear trend towards mark concentration can be observed from the Middle to the Late Bronze Age,  
51 until it suddenly reverses with the emergence of the Iron Age, in the Llyn Fawr Phase. During the Penard Phase,  
52 mark patterns are predominantly evenly spread along about 70% of the sword length. This changes in the  
53 Wilburton Phase, in which marks are overall grouped within 50% of the sword. In this phase, notches and bulges  
54 are clustered within only 26% of the sword length, normally just above the leaf-swelling of the blade. The trend  
55 continues in the Ewart Park Phase, in which marks are clustered within approximately 45% of the blade, but  
56 reverses in the Llyn Fawr Phase, when marks are once again spread along the entire length of the cutting edge.  
57 Similar trends are observed on Italian swords. During the Middle Bronze Age, mark patterns are located roughly  
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1 within 50% of the blade, while in the Recent Bronze Age they are tightly clustered within only 35% of the sword  
2 length. No trends can be observed for the Final Bronze Age or Early Iron Age as the dataset solely includes one  
3 specimen each for these phases. Notably, bulges are absent from the Middle Bronze Age Italian record, but become  
4 common in the Recent Bronze Age. The significance of this finding (and of the other data presented above) is  
5 discussed in the next section.  
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#### 10 **4. Discussion**

11 This section considers the social realities of Bronze Age sword fighting as inferred from the experiments and  
12 analytical data discussed above. It explores in-depth several problems in Bronze Age swordsmanship including  
13 how to hold a sword and to fight with it, target areas, and the evolution of fencing styles from the Middle to the  
14 Late Bronze Age.  
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##### 17 **4.1 Holding a Bronze Age sword: grip, handedness and edge dominance**

18 Before discussing how Bronze Age swords could have been used, we should consider how they were held. The  
19 shapes, weights, points of balance, and geometries of these weapons, especially their short hilts, lack of crossguards  
20 and frequent ricassi, enable fighters to grip them in different ways (see Molloy 2007, 2010 for discussion). Three  
21 ways of holding swords were experimented with during our controlled and actualistic tests: ‘hammer grip’, in  
22 which the four fingers of the hand form a fist around the weapon and the blade is held perpendicular to the forearm  
23 (Molloy 2010, footnote 121); ‘sabre grip’, in which the fist is stretched to an angle so that the blade is aligned with  
24 the forearm (Molloy 2010, footnote 122); and ‘thumb grip’, in which the sword is twisted by 90° so that the cutting  
25 edges lie sideways and the thumb is pressed on the flat of the blade (Gener 2018, 167; Fig. 26).  
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32 **Fig. 26** How to hold a Bronze Age sword: a: ‘hammer grip’ with the hand locked into place by the shoulder and  
33 pommel; b: ‘sabre grip’ with the index finger curled around the ricasso; c: ‘thumb grip’ with the thumb pressing  
34 on the flat of the blade  
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37 Hammer grips are suitable for most Bronze Age swords. Kristiansen (2002: 321) suggests that the short hilts and  
38 pommels typically found on these weapons help ‘lock’ the fighter’s hand into place, providing excellent control  
39 of the weapon. Our experiments support his suggestion. Hammer grips allow rapid changes of direction and  
40 trajectories of attack, as well as percussive strikes using a combination of force and finesse (Molloy 2010: 419).  
41 Sabre grips, on the other hand, enable users to align the cutting edge to the natural trajectory of the strike, as well  
42 as curl their index finger around the shoulder – an opportunity that was not lost to early fencers considering the  
43 frequency of ricassi on Bronze Age swords. Holding the sword in such a way limits the user’s ability to make  
44 percussive strikes but allows fine control of the weapon in cutting attacks (Molloy 2010: 418). Finally, thumb grips  
45 permit excellent command over the weapon, including the ability to make quick changes of direction and execute  
46 thrusts as well as backhand strikes (i.e. strikes executed with the back cutting edge). Our experiments suggest that  
47 there is no ‘correct’ way of holding a sword, although certain swords may favour certain grips over others due to  
48 their length, balance, and other features (e.g. ricassi). In most cases, however, all grips can be used interchangeably  
49 during a sword fight to deliver different kinds of attack, depending on the fencer’s preferred combat style and other  
50 circumstances. Bronze Age swords can afford further grips including inverted grips (enabling downward thrusts)  
51 and pommel grips (for increased reach; see Clements 1998: 77-81, for discussion; Fig. 27). These, however, were  
52 not experimented with during the project.  
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**Fig. 27** How to hold a Bronze Age sword (continued) a: reverse sword grip; b: pommel grip

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2 To some extent, how a sword is held and used depends on the bearer's handedness. The functional implications of  
3 handedness, including its influence on wear formation in prehistoric tools, have long been explored in archaeology  
4 and human evolution studies (Spenneman 1987; Steele and Uomini 2005; Uomini 2009). Generally, these studies  
5 have shown that most tool users would conform to the natural 85/15 approximate ratio of right-handed vs left-  
6 handed individuals found in human populations (Steele and Uomini 2005: 217). Unless it was discouraged by  
7 cultural norms or weapon training deterring left-handedness (Gentile et al. 2018), we would expect early sword  
8 bearers to conform to this ratio, as they would hold the weapon with their hand of choice. In our actualistic tests,  
9 both HEMA fighters held the sword with their right hands and had the same cutting edge always pointing forwards.  
10 They both remarked that it 'felt natural' to maintain edge dominance over time, even when the weapon is perfectly  
11 symmetrical. This being the case, a greater number of marks formed on the forward edge than on the back edge of  
12 the replica weapons, with those on the back edge mostly ascribed to backhand strikes. This is consistent with the  
13 wear analysis of archaeological swords, which has demonstrated unambiguous edge dominance on 31 out of 110  
14 specimens in the sample. It is presently unclear why two-thirds of the weapons do not show clear edge dominance.  
15 Reasons may range from multiple ownership of the sword to 'edge flipping' as wear built up on the forward cutting  
16 edge, making it increasingly blunted and ineffective.  
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#### 27 4.2 Prehistoric sword fighting: attacks, defences, and blade-on-blade contact

28 In popular culture, it is an enduring trope that sword fighting can be divided into attacking strikes and defending  
29 blocks, which would be exchanged with flamboyant swinging blows from some distance. This view, however, is  
30 far removed from the reality of historic sword fencing, which is often predicated upon simultaneous,  
31 interchangeable attacking and defensive stances. This can be appreciated in most traditional and contemporary  
32 martial arts, such as Wing Chun (Cheng 1986) and Krav Maga (Ben Keren 2014). It was also remarked upon in  
33 medieval and post-medieval European fencing manuals (e.g. Liechtenauer's MS Chart.A.558 from 1443). In the  
34 latter, certain common engagements are referred to as a *Meisterhau* (master strike), which is meant to attack and  
35 defend simultaneously (wiktenauer.com). Instead of offensive and defensive stances exchanged by the fighters in  
36 turn, the historic sources agree in suggesting that swordplay consists of offensive actions that simultaneously  
37 defend *and* prime the weapon for the next attack.  
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45 This notion bears significant implications for the interpretation of our experimental and archaeological wear marks.  
46 None of the marks created during the AWTs, which better reflect actual swordplay, can exclusively be classed as  
47 offensive or defensive. This includes notches, bulges, grazes, flattenings, and striations (Table 5). Although this is  
48 partly a function of the historic fencing style adopted for the experiment, it is notable that other experiential sword  
49 tests have generated similar results using different protocols and weapon types (e.g. Gentile and van Gijn 2019).  
50 To some extent, this is also true of our controlled tests. Although we clearly separated out attacking and defending  
51 weapons in the CWTs, certain wear marks (though not all: see Table 5) were created on both swords. This provides  
52 an important behavioural interpretation for the archaeological wear marks, suggesting that notions of mutually  
53 exclusive attacking and defending actions, as well as the view that certain sections of the blade would primarily  
54 be used for either (e.g. Kristiansen 2002: 323), should be rejected.  
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1 Interestingly, while popular-culture ideas of swordplay are predicated upon clearly defined weapon exchanges,  
2 students of prehistoric fencing have suggested that fighters would avoid blade contact as much as possible to limit  
3 damage to their weapons (Molloy 2017: 288). This is due to the higher ductility and (generally) lower hardness  
4 values of tin-bronze compared to steel, which would cause higher rates of damage on prehistoric swords vis-à-vis  
5 historic bladed weapons (Wang et al. 2016). While our experiments have demonstrated that violent clashes would  
6 likely disable bronze swords (see 3.1), they have also shown that bulges, which are found regularly on  
7 archaeological swords, are caused by low-velocity blade-on-blade impacts. As discussed above, bulges provide  
8 prima facie evidence of binding and twisting motions; they are created when a sword is intentionally connected  
9 with the opponent's blade to stifle and control it. Marks other than bulges were also created by deliberate low-  
10 velocity impacts with the opponent's weapons (Table 5). Overall, the evidence indicates that Bronze Age fighters  
11 would have accepted a small amount of wear to their blades in order to bind the opponent's. Hence, most marks  
12 found on prehistoric swords should not be interpreted as accidental (Horn 2013: 40), but rather as the result of  
13 distinctive fighting styles favouring close-quarter engagement and involving deliberate blade contact. This is  
14 underscored by the HEMA swordfighters' observation that, due to their material properties, bronze swords tend to  
15 'stick together' as they meet, making blade-controlling moves easy to practise (see 3.1.3). Furthermore, the  
16 geometry, balance, and relative shortness of most Bronze Age swords indicate that these weapons had been  
17 designed for close-range engagements. Taken together, the archaeological, analytical, and experimental data  
18 contribute a strong case for prehistoric swordsmanship being a contact martial discipline involving a certain  
19 amount of wilful, skilfully controlled blade contact. This is not something that one could improvise. As was the  
20 case in later times, mastering sword-twisting and binding techniques would require initial guidance and regular  
21 follow-up practice – in other words, structured weapon training.  
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#### 34 4.3 Bent swords, straight swords, and target areas 35

36 The damage pattern discussed in Section 3.1 suggests that Bronze Age swords were not suited for hard blocks  
37 executed with the flat of the blade. This view is supported by the wear analysis of archaeological swords, revealing  
38 that only four specimens (out of 110) had sustained comparable blade damage. This ties in with the broader  
39 archaeological record (Horn 2013; Mödlinger 2011a, 2011b; Molloy 2007, 2010, 2011, 2017, 2018; see also  
40 Burgess and Colquhoun 1988). The bending of swords has been discussed by Kristiansen (2002). He argues that  
41 prehistoric swords were often deliberately bent by fencers so that the blade tip would point towards the opponent's  
42 heart. He grounds his proposal in an analogy with modern fencers who, he claims, would bend the tips of their  
43 swords in a similar fashion (Kristiansen 2002: 320).  
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49 This reading presents several problems. Firstly, bending the blade to point at the opponent's heart implies that  
50 early swords were primarily used as thrusting weapons – an argument disproved by a wealth of research on  
51 prehistoric swordsmanship, as well as our experiments (Anderson 2011; Knight 2019; Molloy 2007, 2008; Gentile  
52 and van Gijn 2019). Furthermore, experience shows that thrusting with a bent sword is dangerous and ineffective,  
53 as it inhibits fine control of the weapon and makes it hard to predict where the point would hit the target.  
54 Conversations with HEMA specialists support the view that double-edged swords lose functionality if the point is  
55 bent. Although he does not say, we presume that Kristiansen's proposal is based on a conversation with a foil  
56 fencer. Modern foil blades consist of thin, wire-like steel bands which significantly bend under pressure and are  
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1 exclusively used for thrusting (British Fencing 2017: 10). These blades are deliberately bent downwards to prevent  
2 the tip from sliding under the opponent's mask. The slight bend also assists in reaching around the opponent's  
3 arms to hit the target, which, in this fencing discipline, is limited to the upper body (Fig. 28). Contemporary foil  
4 fencing, however, provides a poor analogy for prehistoric swordsmanship as bronze swords feature radically  
5 different designs, balances, and material properties to foils.  
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8 **Fig. 28** Foil fencer holding a downward-bent foil; the target area is marked in orange (www.wikipedia.org)  
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10 A further problem with the foil fencing analogy is the implication that prehistoric sword fighters would mainly  
11 have targeted the chest. This is partially contradicted by the osteological evidence, showing that the skull and  
12 pelvis were hit more often than the chest (see Hermann 2018, 30-34; Mödlinger 2011b, 88-92, for review).  
13 Although certainly biased, as it does not account for soft-tissue injuries, the evidence is in line with what we know  
14 about sword combat cross-culturally. It is often remarked that targeting the chest in a thrusting attack carries the  
15 risk of trapping the weapon in the ribcage or sternum (Molloy 2007: 101). This area, moreover, is frequently  
16 protected by armour. Instead, sword fighters would target primarily soft body parts that (a) provide an easy entry  
17 towards major blood vessels and/or life-supporting organs, and (b) are most difficult to protect with armour. These  
18 are the neck and abdomen/pelvis. Notwithstanding the instances of broken sword (and spear) points lodged in bone  
19 (Bennike 1985: 109-10; Bóna 1975: 150; Knight et al. 1972), it seems likely that Bronze Age fighters would have  
20 predominantly aimed their thrusting attacks at the neck and abdomen/pelvis, plunging their weapons into the flesh  
21 at an angle in order to cause major blood loss and severe incapacitation, whilst minimising the risk of the sword  
22 getting stuck in a bone. Depictions of sword fights on Minoan and Mycenaean gem stones, such as the Pylos  
23 Combat Agate (Stocker and Davis 2017; see also Molloy 2010: 409-12), illustrate this point with graphic intensity  
24 (Fig. 29). Although these are idealised images reflecting the heroic symbolism of a lightly armed, near-defenceless  
25 fighter defeating a heavily armoured foe, they are likely grounded in the grisly realities of Bronze Age  
26 interpersonal violence.  
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29 **Fig. 29** Composite drawing of the Pylos Combat Agate showing two warriors engaged in close-quarter combat.  
30 The winning male on the left is plunging his sword into the opponent's neck, having twisted it over the shield.  
31 Note the sword bearer's 'hammer grip' enabling swift moves and rapid changes of direction (Stocker and Davis  
32 2017)  
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35 Other combat stances would have aimed at different body parts. Molloy (2007, 2008, 2017) points out that nearly  
36 all Bronze Age swords are suitable for both stabbing and cutting attacks. However, the novel features introduced  
37 towards the end of the period, namely the full hilt and leaf-swelling of the blade, as well as the bias towards longer  
38 and heavier swords with more forward-shifted points of balance, would have made cutting strikes more effective  
39 and, therefore, more likely to be attempted. Based on comprehensive combat experiments, Molloy argues that deep  
40 cutting could be achieved by drawing the blade along the target in a smooth and controlled manner, rather than  
41 swinging it in a percussive axe-like strike. Such draw-cuts would have sliced through muscles and tendons, causing  
42 blood-letting and limb incapacitation. Osteological evidence of blade cuts to the arms and legs suggests that,  
43 indeed, Bronze Age fighters would have targeted the limbs in their slashing attacks, occasionally causing the  
44 opponent's death through bleeding or intervening sepsis (Canci et al. 2005; Mödlinger 2011: 88-89). Even when  
45 they were not lethal, deep cuts to the limbs would have impacted significantly on the dynamics of a melee fight,  
46 as one cannot fight with a disabled arm or leg, and their screams would conceivably have had a demoralising effect  
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1 on their comrades. The head was also targeted by cutting and slashing strikes. This is demonstrated by several  
2 skull injuries in the osteological record, and is further underscored by experimental research showing that even  
3 relatively light and short bronze swords are capable of inflicting wide incisions to synthetic analogues of human  
4 skulls (Canci et al. 2005; Downing and Fibiger 2017; Mödler 2011b, 89-92). Overall, injury patterns and  
5 experimental evidence show that, if held by proficient fighters, prehistoric swords were extremely effective  
6 weapons for close-range combat, and could be used for thrusting *as well as* cutting and slashing stances (Clements  
7 2007; Molloy 2007). This contradicts earlier arguments that these objects would be too small and flimsy to be  
8 useful on the field of battle, or that they would be primarily suited to either cutting or thrusting depending on  
9 weapon design and hilt technology (Burgess and Gerloff 1981; O'Connor et al. 1995; Osgood 1998: 13).

#### 16 4.4 The evolution of Bronze Age swordsmanship: spatial and temporal trends

17 As argued in Section 3.2, the patterning and clustering of sword combat marks over time and geography can be  
18 used to illuminate the development of fighting styles in the European Bronze Age. Arguably, mark patterns and  
19 clusters contain higher quality information about prehistoric fighting styles than individual marks. This is because  
20 they are generated by repetitive, normative actions grounded in prolonged engagement with the weapon, muscle  
21 memory, and the mental and physiological changes caused by martial training and practice (Malafouris 2008;  
22 Melheim and Horn 2014; Molloy 2008; Warnier 2011). Fighting styles, we posit, emerge from the historically  
23 contingent nexus of cultural, physical, and neurological transformations brought about by sustained weapon  
24 engagement. While this is broadly true of all weapons (and all societies), certain weapons are more conducive than  
25 others to generating contingent fighting styles, as they may require lengthy training or advanced skilled practice  
26 to be operated effectively. This, we maintain, was the case with Bronze Age swords, as their proficient handling  
27 was predicated upon fine motor skills and long-term familiarity with the weapon (Molloy 2017).

34 The data presented in Section 3.2 indicate that British swords of the Penard Phase lack distinctive mark patterning  
35 and clustering. We interpret this as the result of a yet immature martial tradition. Although Penard Phase swords  
36 would have been used skilfully to preserve the cutting edge and point, avoid undue blade damage, and strike at the  
37 opponent before being struck by them, swordsmanship at this time would not have involved repetitive moves  
38 internalised through combat routines. This seemingly changed in the Wilburton and Ewart Park Phases, when  
39 noticeable shifts in mark location, and their denser clustering, speak for the emergence of a fencing style featuring  
40 combat actions that were routinely executed, in broadly similar ways, by multiple sword fighters. In particular, the  
41 bulges frequently observed on swords from these phases suggest that the new combat style centred on the desire  
42 to control the opponent's weapon through binding techniques akin to those carried out in the late Middle Ages.  
43 Intriguingly, a similar shift towards more frequent slashing attacks and finer blade control was observed on a  
44 sample of 304 Danish swords from Periods II (c. 1500-1300 BC) and III (c. 1300-1100 BC) of the Nordic Bronze  
45 Age (Kristiansen 1984: 189-95; absolute chronology after Olsen et al. 2011: 267-8). This independently validates  
46 the results discussed here.

54 The picture changed yet again in the Llyn Fawr Phase, marking the transition to the Iron Age. The recurring mark  
55 patterns and clusters created by the previous martial practices disappeared. These were replaced by combat marks  
56 that are evenly spread along swords blades, in a manner that is not too dissimilar to Middle Bronze Age swords. It  
57 is not clear what might have caused this apparent loss of established fighting routines. The change could perhaps  
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1 be ascribed to the introduction of iron swords, which would have upended time-honoured combat practices.  
2 Another factor to consider is the growing importance of equestrian warfare in the early 1<sup>st</sup> millennium BC  
3 (Anthony and Brown 2011; Drews 2004; Howard 2011), which would have led to new developments in weaponry  
4 (e.g. longer swords) and fighting techniques. These are questions for future experimentation and research.  
5

6 Interestingly, Italian swords present us with similar trends and developments. As with their British counterparts,  
7 Italian swords display a noticeable increase in mark clustering in the Recent Bronze Age. This may be due to the  
8 introduction of sophisticated fighting practices relying on sustained weapon training and the repetition of  
9 internalised gestures. On most swords, the marks are grouped around the leaf-swelling of the blade (i.e. about 1/3  
10 from the blade tip), which, in itself, is a distinctive morphological development dating to this time. We maintain  
11 that this is not a chance occurrence, for advancements in sword design and fighting practices are intimately  
12 connected. Molloy (2007, 2017) argues that the leaf-shaped curvature of Late Bronze Age swords (and their  
13 growing weight, which shifted the point of balance further towards the tip) enabled blades to cut deeper into the  
14 flesh as they were drawn along exposed body parts. While draw-cuts would have been practised with earlier  
15 swords, too, the new blade geometry and balance made such strikes more effective and, therefore, more desirable  
16 and common. This ties in neatly with the wear data gathered in our research: as many attempted draw-cuts would  
17 hit amour, or be deflected before they could bite into soft tissue, marks would be left on the blade swelling in ever-  
18 growing numbers.  
19

20 Another feature of Italian Recent Bronze Age swords is the appearance of bulges. As discussed above, this mark  
21 type can be ascribed to a fencing technique that seeks to bind the opponent's blade not only to prevent injury, but  
22 also to control it in such a way that their attack could be countered with a quick twist of the blade. The trend is  
23 clearer in Italian swords (as no bulges are recorded in the Middle Bronze Age record) than in British swords, where  
24 bulges are found on weapons from all periods including the Middle Bronze Age Penard Phase. The difference,  
25 however, is entirely due to the vagaries of archaeological terminology in the two regions, as the Italian Middle  
26 Bronze Age, c. 1650-1300 BC, precedes the British Penard Phase; this, in turn, is roughly contemporary to the  
27 Italian Recent Bronze Age (Fig. 23). Based on this consideration, we propose that fencing styles would have grown  
28 in sophistication and complexity in similar ways, and in a broadly contemporary fashion, in most of Europe. By  
29 about 1350/1300 BC, they would have featured blade twisting and binding moves aiming to control the opponent's  
30 weapon. In regions where fully-fledged swords made their appearance around this time, such as Britain and Ireland,  
31 the new weapon would have been used from the outset with the mature martial techniques that presumably  
32 accompanied its introduction.  
33

34 It is unfortunately impossible to chart the development of fighting styles in Final Bronze Age and Early Iron Age  
35 Italy (roughly contemporary to the British Wilburton, Ewart Park, and Llyn Fawr phases; fig. 23) due to the small  
36 number of swords examined in this study. Future research will doubtless clarify if the introduction of iron weapons  
37 and equestrian warfare brought about similar changes in this region as in Britain. We presume, however, that this  
38 should be the case, considering that British and Italian swords display similar wear marks and similar trends in  
39 trace patterning and clustering over time. The one notable exception is the tendency of Italian combat marks to be  
40 smaller than those on British swords. It is presently unclear why this should be so. Differences in alloy composition  
41 and work hardening might be a factor (Gutiérrez-Sáez and Martín-Lerma 2015), as well as – but this seems less  
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likely – differences in the amount of force applied by the combatants whilst fencing. This, too, is a problem for future research.

## 5. Conclusion

The article has discussed results of the experimental sword testing and wear analysis conducted by the authors from 2013-2018, as part of the *Bronze Age Combat Project*. The research has yielded original results that significantly contribute to our understanding of sanctioned violence and warfare in Middle and Late Bronze Age Europe, c. 1650-600 BC.

A first set of results concerns the approaches and methods utilised by these authors to researching prehistoric swordsmanship. Following the principles of experimental archaeology, we designed a wide array of controllable imitative experiments to generate and test hypotheses regarding the uses of swords and shields in Bronze Age combat practices (Mathieu 2002: 1). Unlike previous research on the subject, however, we grounded our experimentation in two sets of tests, which were guided by differing underlying principles and methods: Controlled Weapon Tests (CWTs), in which we separated fluid combat actions into their most elemental components (e.g. a single strike or parry), and Actualistic Weapon Tests (AWTs), in which HEMA fighters tested the capabilities of the weapons in experiential combat sequences grounded in historic specialist knowledge. Such a hybrid approach allowed us to break down the somewhat artificial barrier separating functional and phenomenological weapon studies (Dolfini and Collins 2018); enhanced the strengths of both types of experiment whilst minimising their weaknesses; and provided a reflexively generated dataset to interpret the combat marks visible on archaeological Bronze Age swords from Britain and Italy. Importantly, the replica weapons used in our experiments were built by skilled craftspeople, and their material properties and performance characteristics were assessed by scientific analysis. This has ensured consistency in the interpretation of experimental and archaeological wear marks. Overall, this interdisciplinary research strategy has allowed new knowledge to arise at the nexus between controlled experimentation, experiential weapon testing, and the validation of experimental results by metalwork wear analysis.

A second set of results concerns the new knowledge and understanding of prehistoric swordsmanship generated by the project. Firstly, the research has identified several types of diagnostic and undiagnostic combat marks on prehistoric bronze swords, and has interpreted them in light of the experimental tests. This has fulfilled, if perhaps partly, one of the project's main objectives, which was to link distinctive combat marks with specific uses of the weapons. Secondly, it has elucidated how Bronze Age swords may have been held and operated, and the degree of skill and training required in their proficient handling. Thirdly, it has overturned previous assumptions concerning the alternating attacking and defending stances that – it is often posited – would characterise prehistoric swordplay, while also disproving scholarly claims that early fencers would avoid blade-on-blade contact to preserve their weapons. On the contrary, the research has demonstrated that Bronze Age fighters would deliberately seek contact with their foes' swords in order to stifle and control them. Not only is this a significant advance in its own right; it also provides a convincing explanation for the plethora of wear marks found on archaeological swords, as well as much-needed analytical diagnostics for discriminating between combat and deliberate destruction marks (see also Knight 2019). Fourthly, the research has disproved suggestions that early sword fencers would intentionally bend the tips of their swords to hit their opponent's heart, and contributed new

1 knowledge about the body parts most often targeted by sword thrusts and cuts. This ties in with previous  
2 experimental research and osteological analysis (Canci et al. 2005; Downing and Fibiger 2017; Mödinger 2011a;  
3 2011b; Molloy 2006, 2007, 2008). Finally, it has provided a compelling narrative regarding the evolution of  
4 fighting styles in late 2<sup>nd</sup> and early 1<sup>st</sup> millennia BC Europe, which integrates, and elevates, other authors' insights  
5 (Molloy 2007, 2017).  
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8 Perhaps the most important result of the research is to have provided an innovative, methodologically sound  
9 blueprint for investigating early weapons and combat styles, which could be applied to other regions, periods, and  
10 weapon types in prehistoric Europe. The research has also highlighted two outstanding issues which future studies  
11 ought to address. Firstly, the extent to which the experimental and analytical results generated by different teams  
12 can be compared with one another. As the study of early weapons keeps growing in size and sophistication, this is  
13 emerging as a key issue hindering disciplinary progress. The strategy that these authors have adopted, which relies  
14 on a clearly defined wear mark terminology, explicit methods and protocols for testing replica weapons, and the  
15 complete publication of experimental and analytical results, offers a way out of the problem. A second issue  
16 concerns the relevance of early weapon and combat studies – a rather specialised research strand – for the broader  
17 field of European prehistory. Here, the answer comes from the many unexpected insights that the research has  
18 provided into burning issues in social archaeology including craftsmanship, apprenticeship, and skill (Kuijpers  
19 2018a, 2018b). Whilst their in-depth discussion lay outside the scope of this paper, the data and interpretations  
20 presented in these pages show clear potential for addressing these problems from a new angle. In this respect, too,  
21 the *Bronze Age Combat Project* has supplied a robust scaffold to which fresh research on prehistoric society could  
22 be anchored.  
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### 58 Supplementary material

59 **Appendix** The Appendix contains a database including all primary data obtained from metalwork wear analysis  
60 on 110 British and Italian Bronze Age swords and all micrographs. Each sword has been allocated its own Sword  
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1 ID. The micrograph for each individual mark can be located through 'Sword ID' and 'Picture reference' in the  
2 database. DOI: <http://doi.org/10.5281/zenodo.3511530>  
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#### 5 Conflict of Interest

6  
7 Author Raphael Hermann has received research funding from the Historical Metallurgy Society. The project has  
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9

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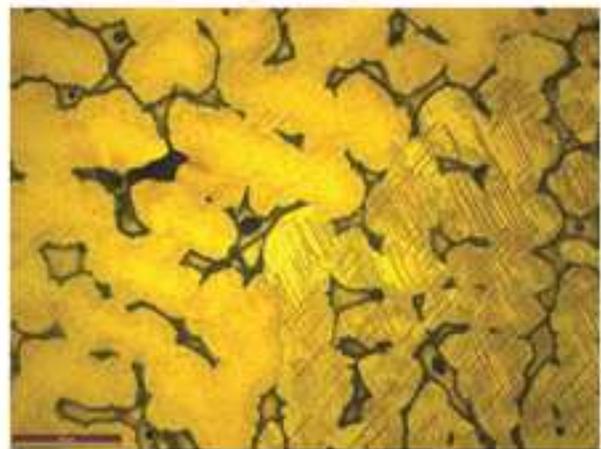
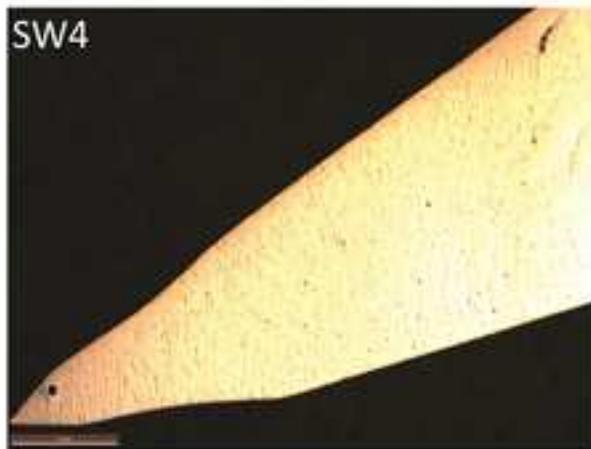
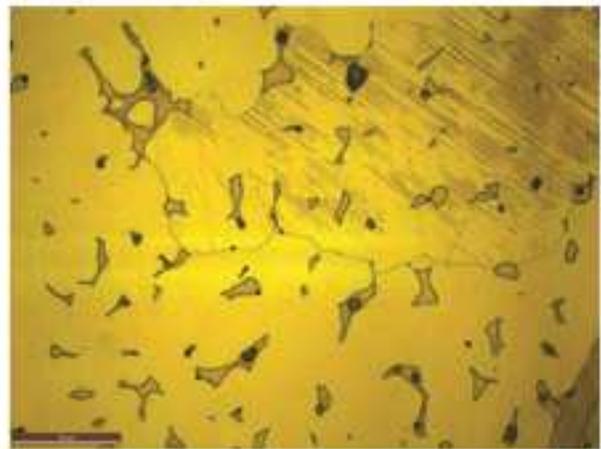
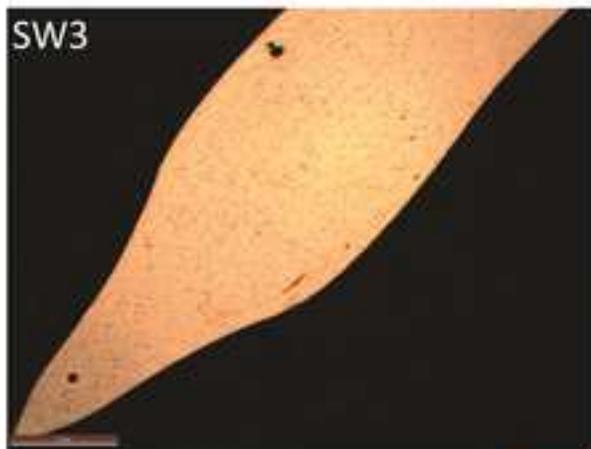
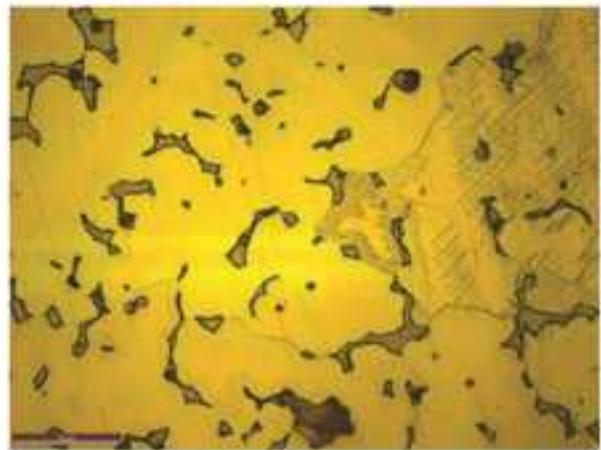
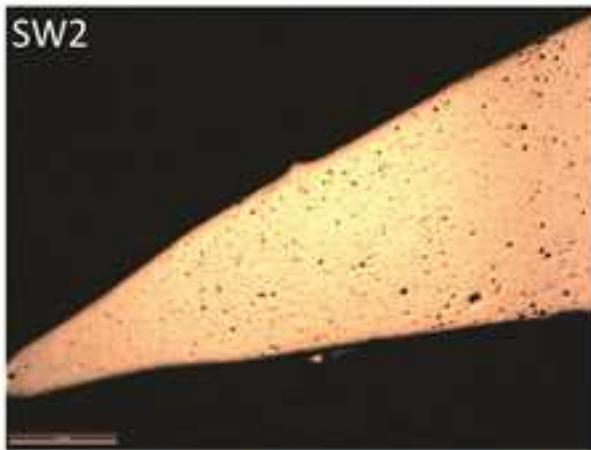
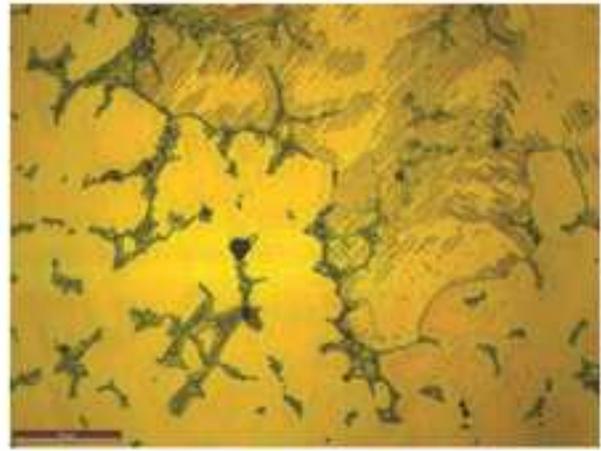
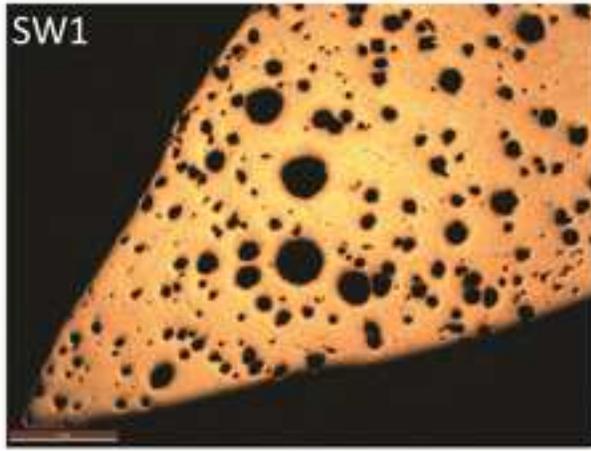
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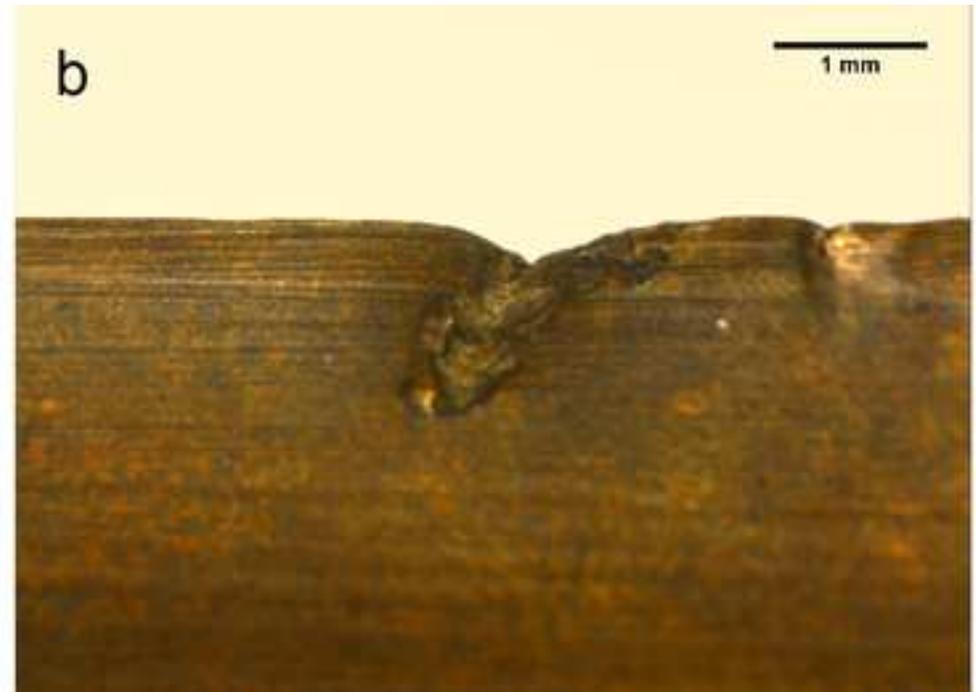
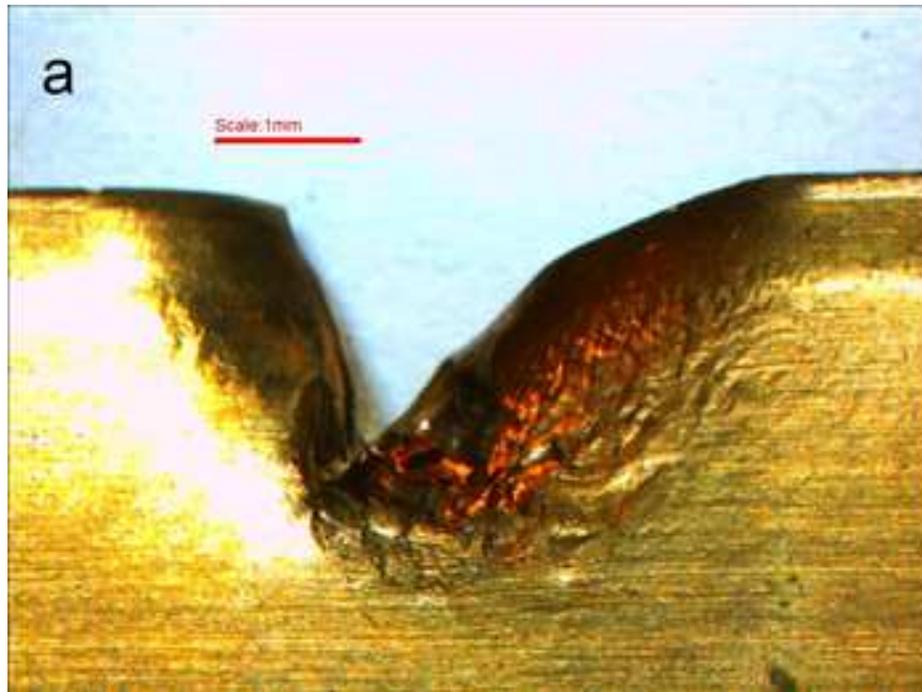
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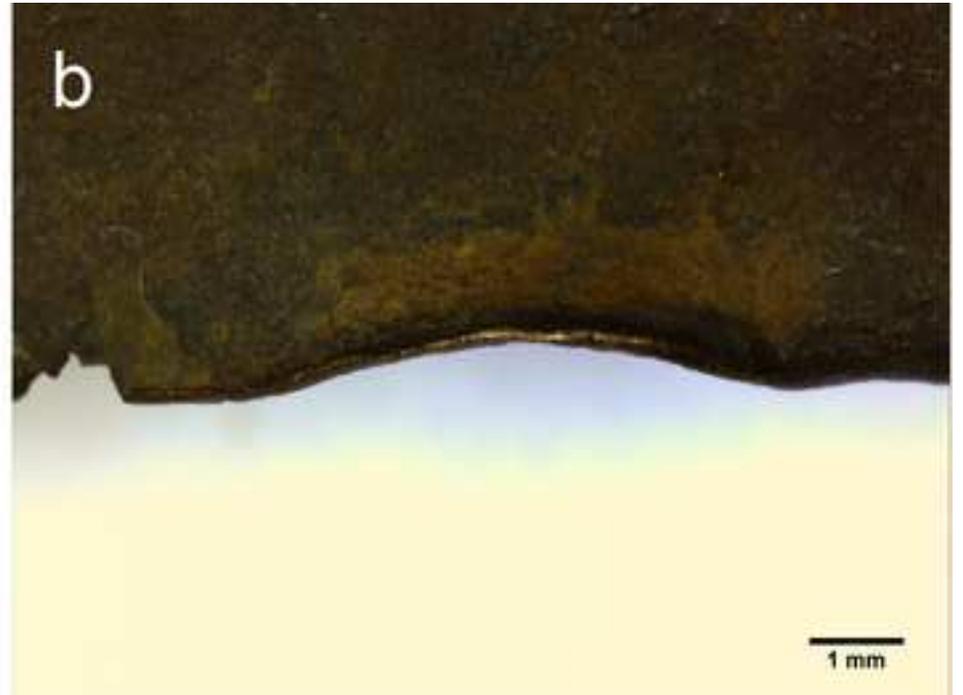
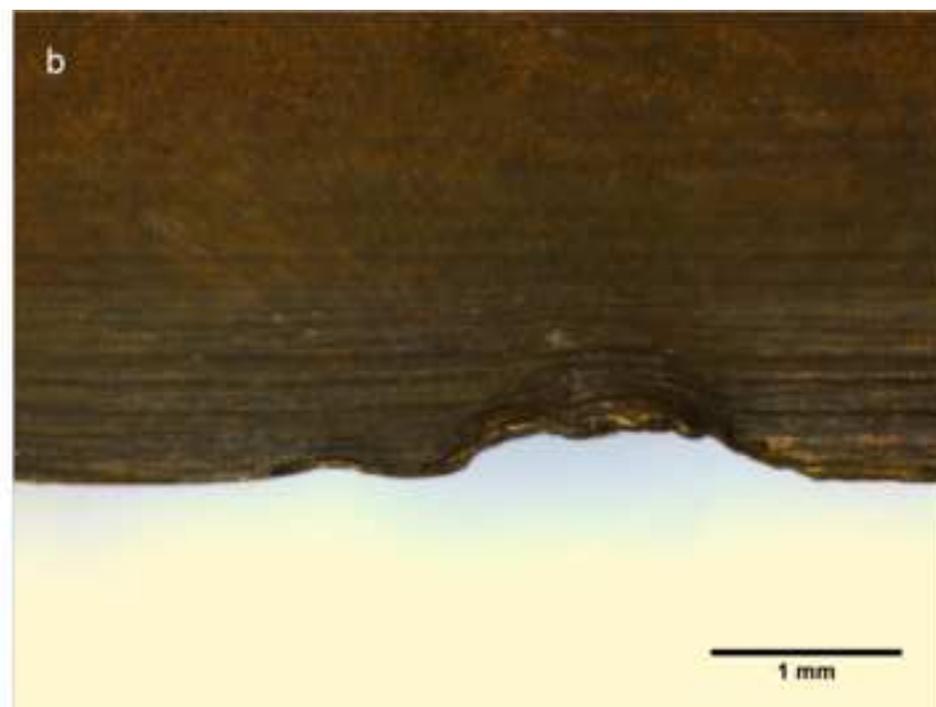
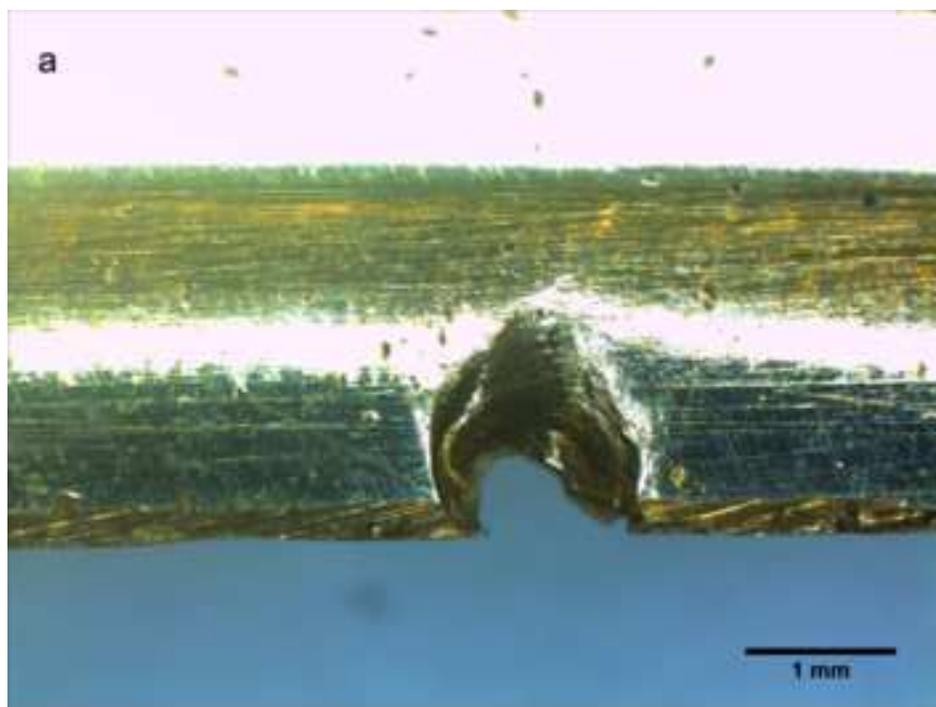


Figure 8

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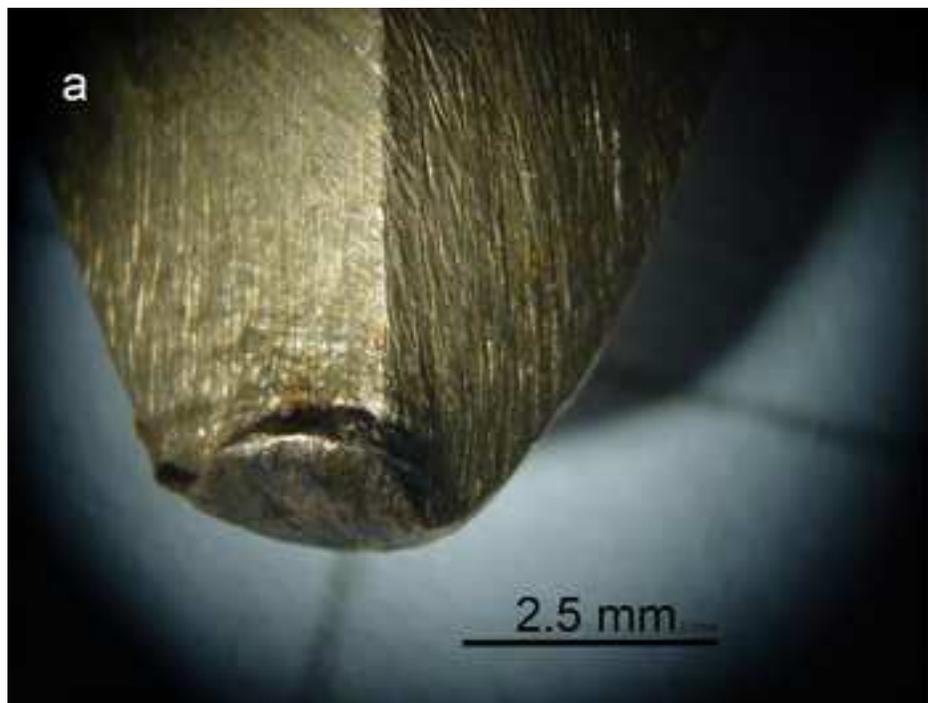
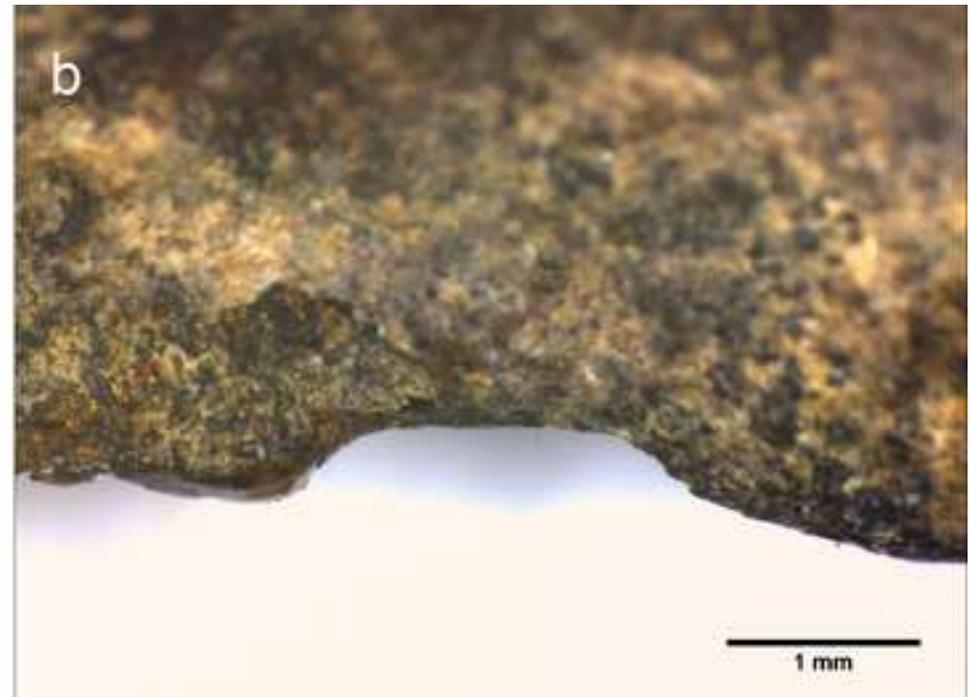
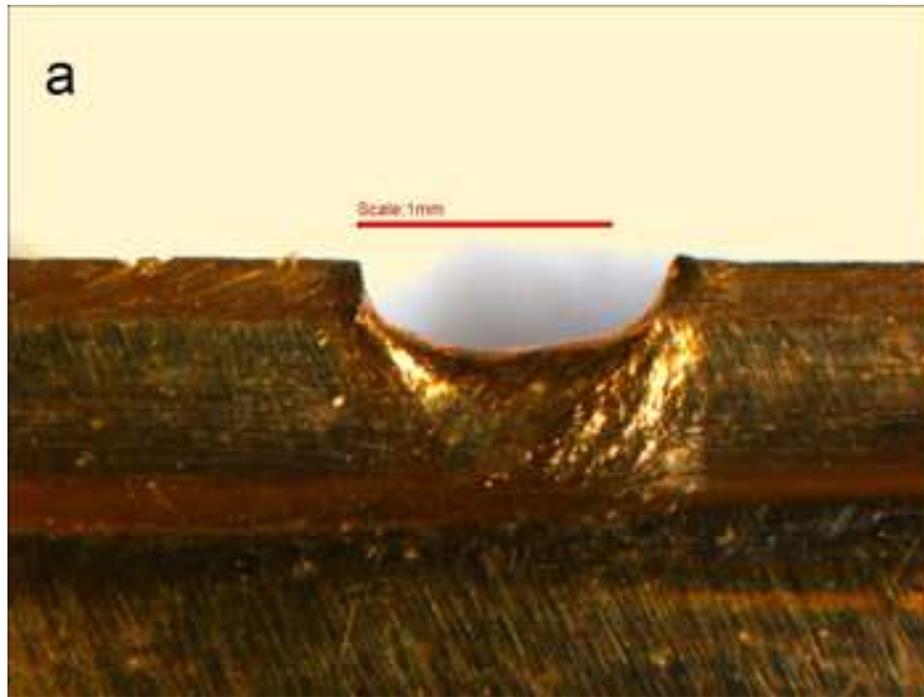
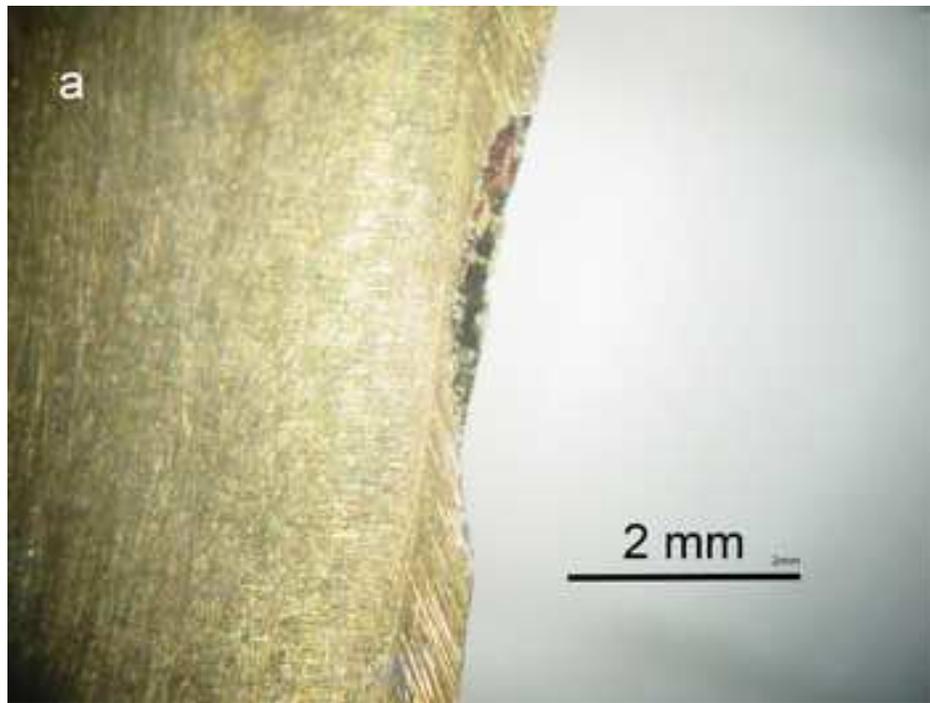




Figure 14



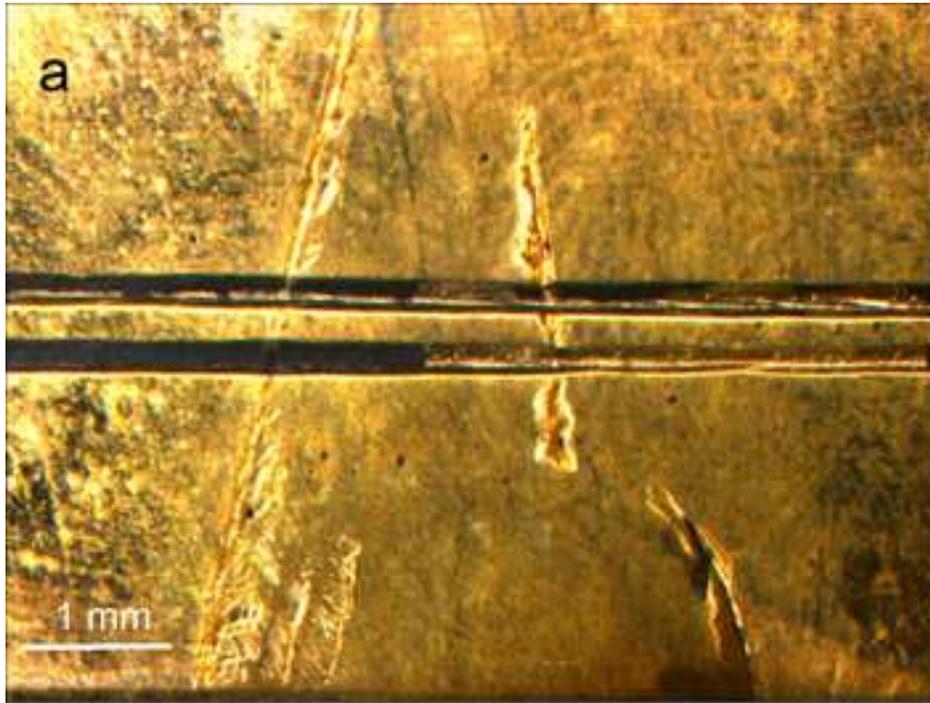




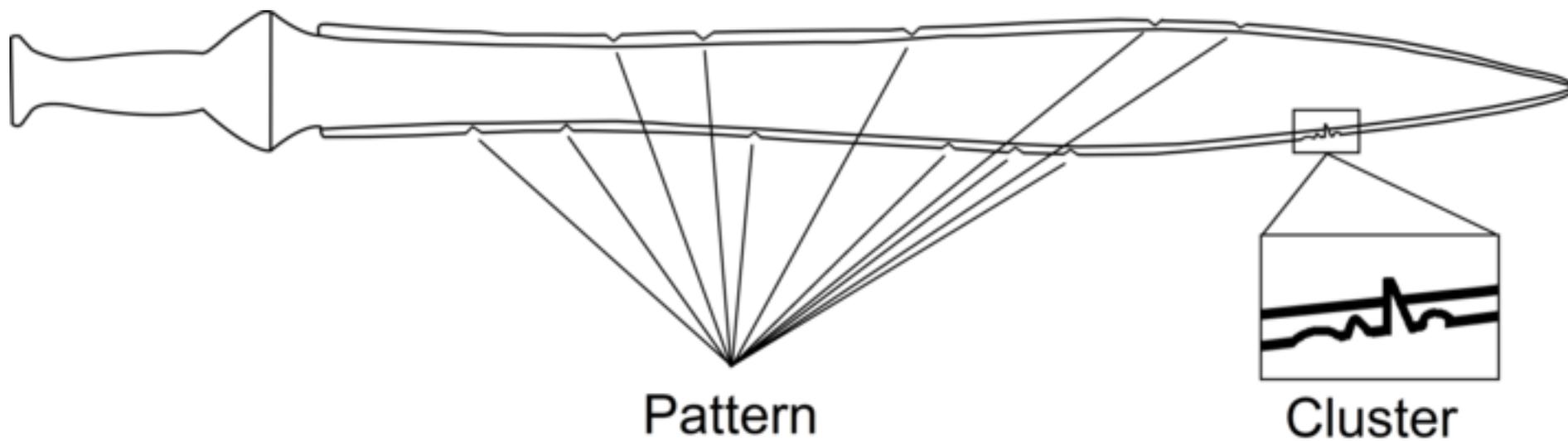


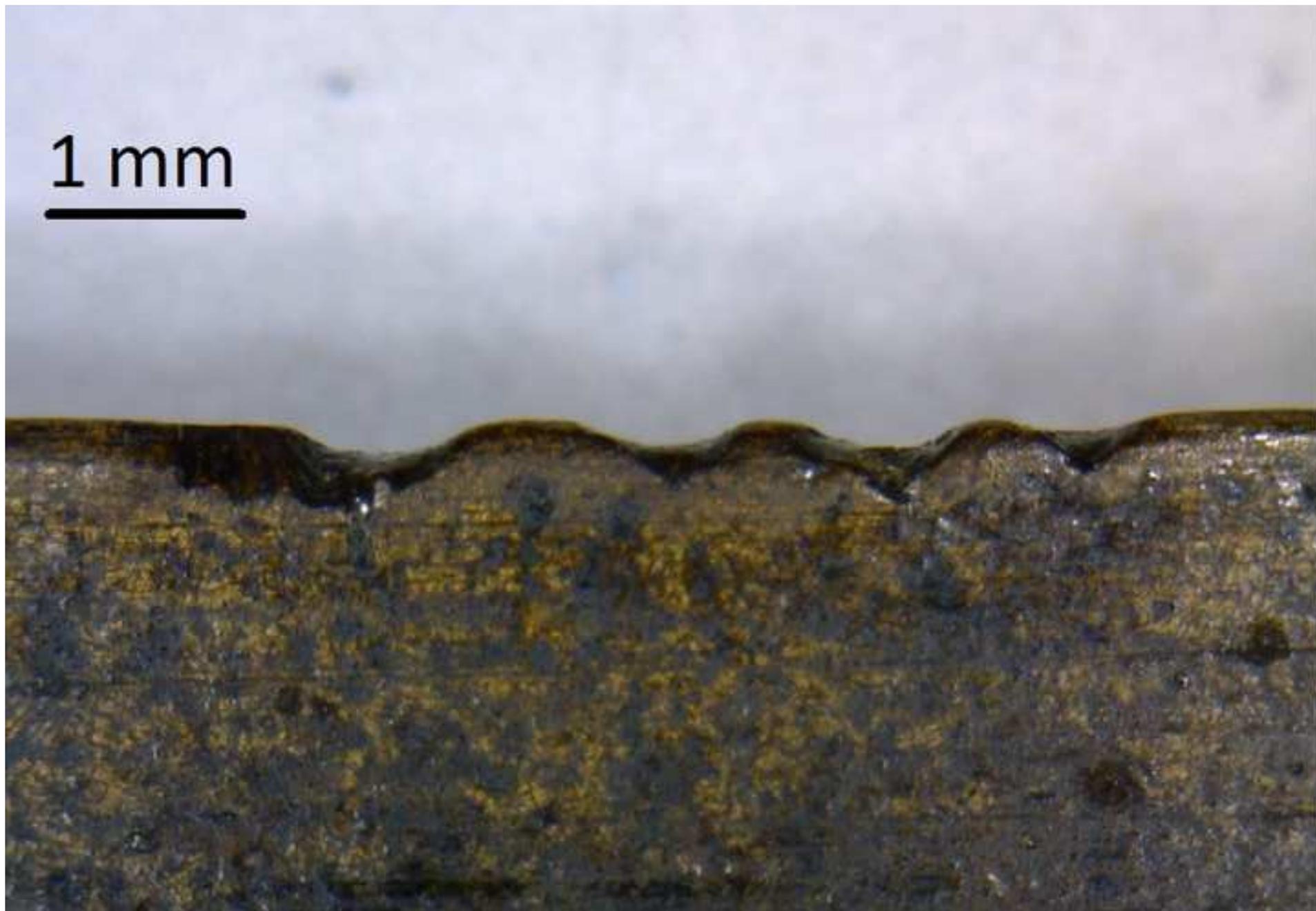












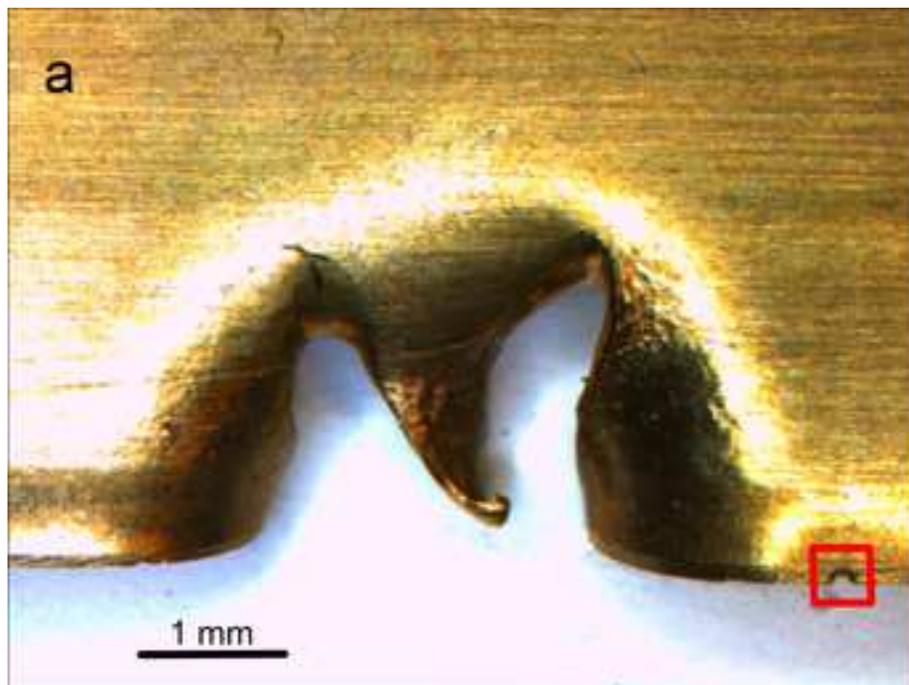
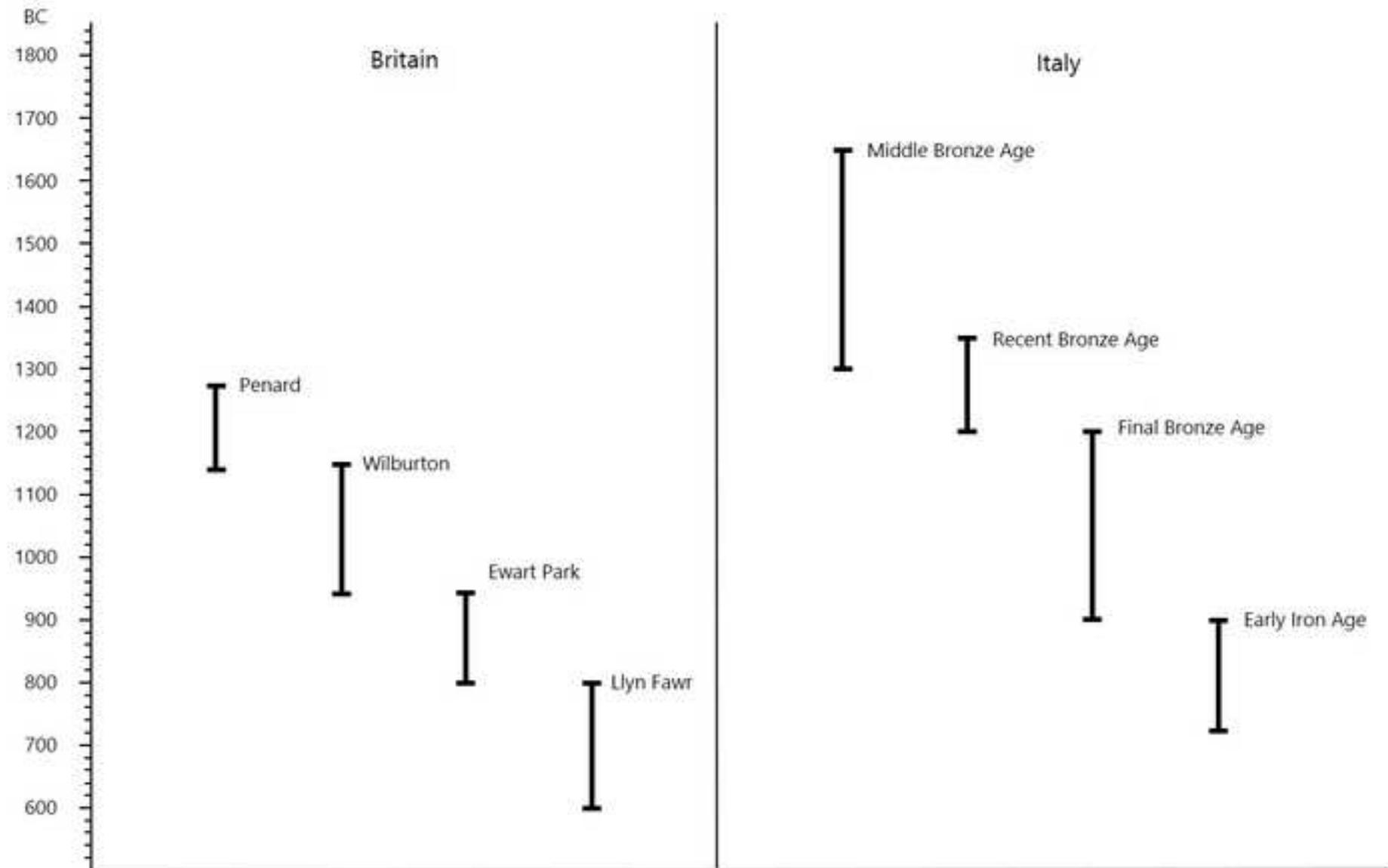
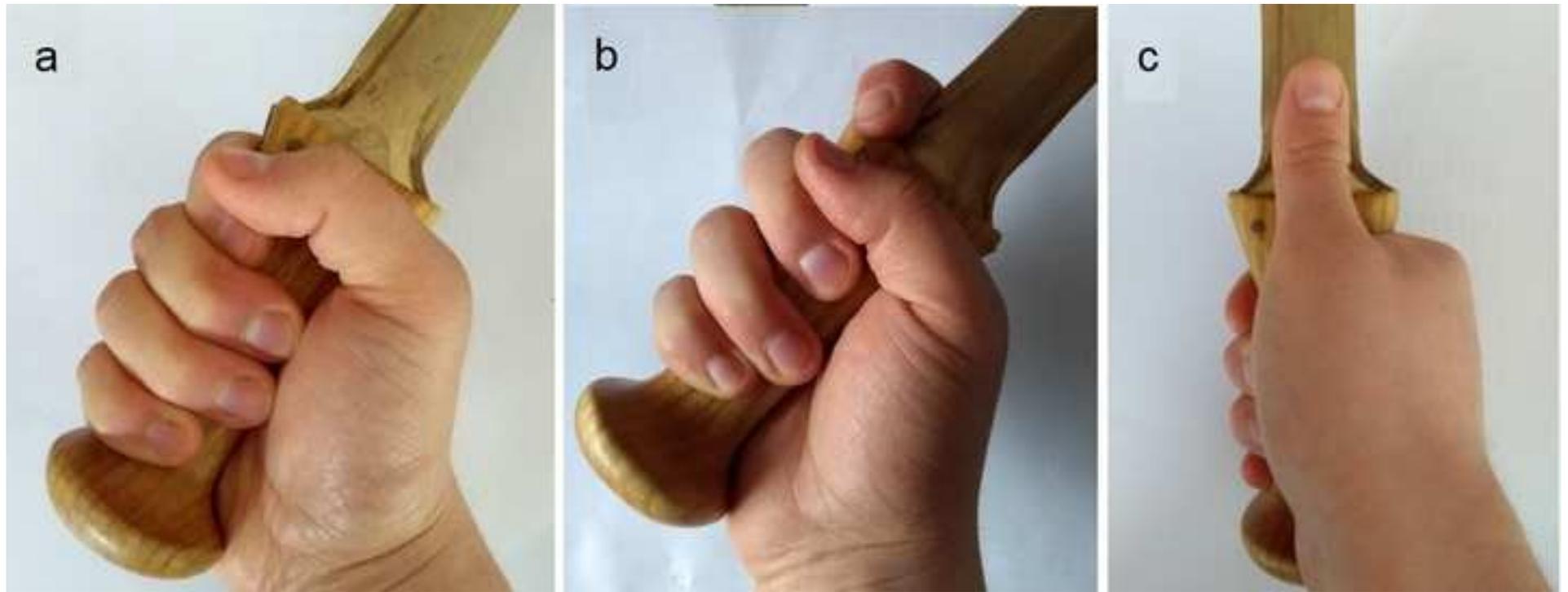


Figure 24









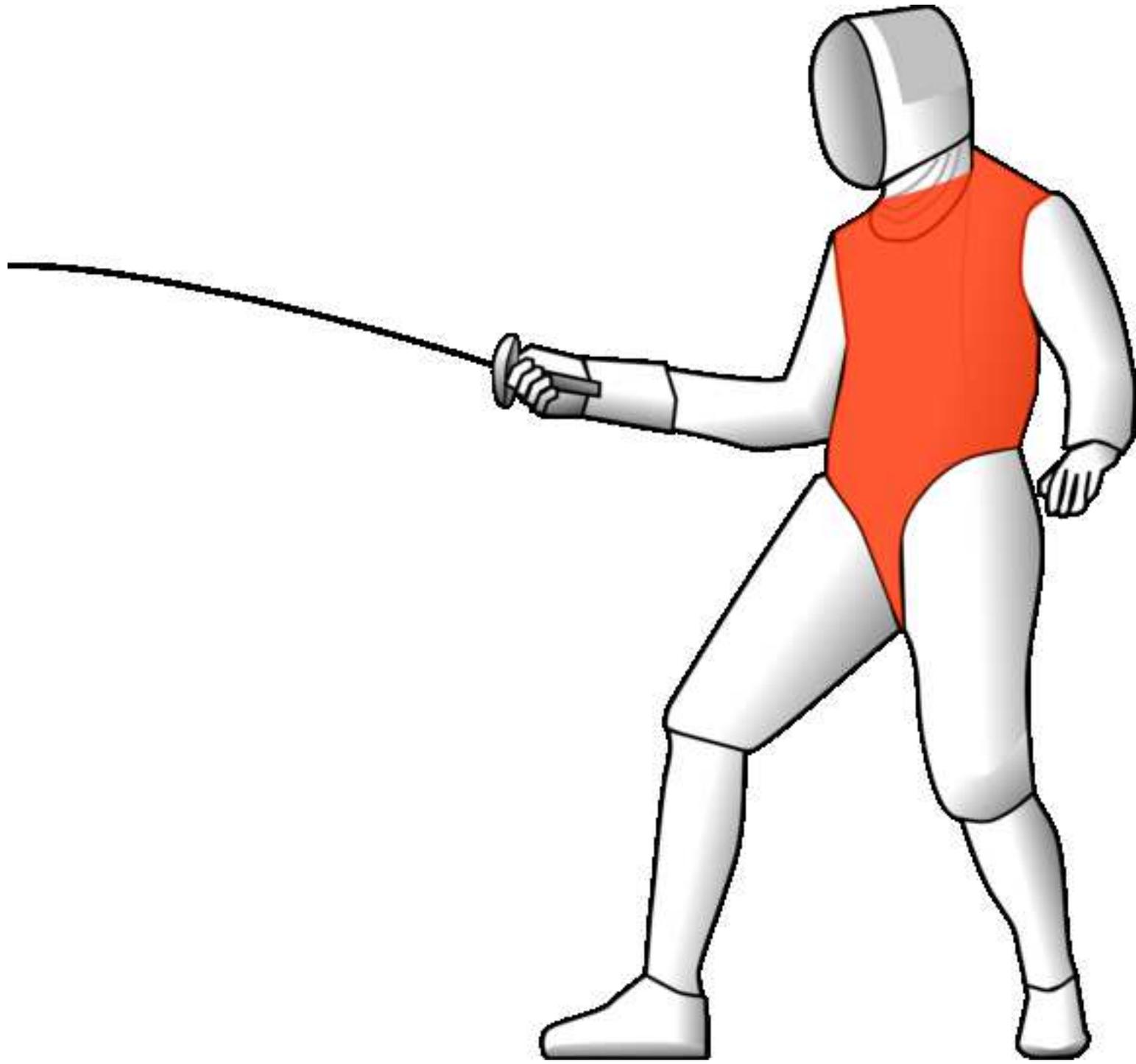
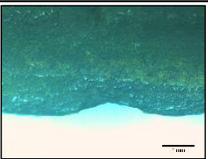
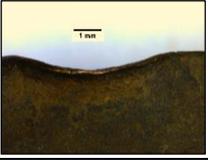
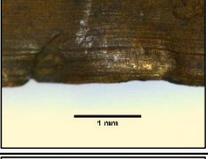
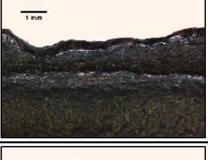
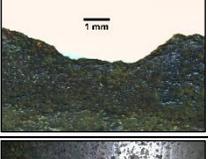
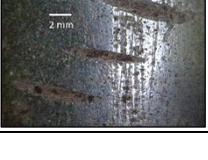
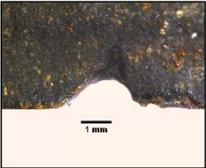
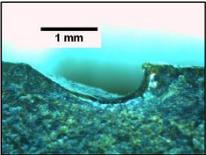
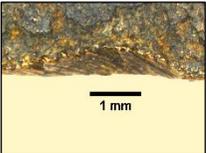
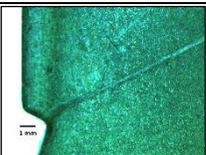
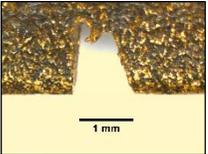
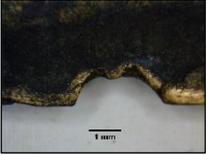
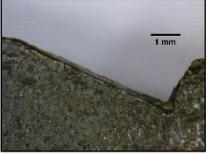
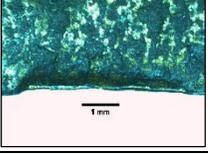
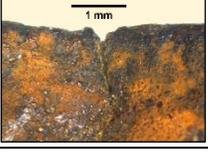




Image	Mark type	Archaeological sword	Controlled test	Actualistic test	Attack sword	Defence sword	Cause
	Wide-Angled Notch	✓	✓	✗	✗	✓	spear edge
	Indentation	✓	✓	✗	✓	✓	spear socket or shaft
	Bulge	✓	✗	✓	✓	✓	twist and bind
	Tip Pressure	✓	✓	✗	✓	✗	thrusts
	Irregular Graze	✓	✓	✗	✓	✗	glancing blow (wooden shield)
	Rectangular Indentation	✓	✓	✗	✓	✗	shoulder strike
	Blow Mark	✓	✓	✗	✓	✓	multiple causes

	Sharp Notch	✓	✓	✓	✓	✓	multiple causes
	Round Notch	✓	✓	✓	✓	✓	multiple causes
	Curved Graze	✓	✓	✓	✓	✓	multiple causes
	Flattening	✓	✓	✓	✓	✓	multiple causes, often by-product of other marks
	Micronotching	✓	✓	✓	✓	✓	multiple causes, often by-product of other marks
	Striation	✓	✓	✓	✓	✓	multiple causes
N/A	Bending	✓	✓	✓	✓	✓	multiple causes
N/A	Twisting	✓	✗	✗	✗	✗	unknown

	Toothed Notch	✓	✗	✗	✗	✗	unknown
	Double Notch	✓	✗	✗	✗	✗	unknown
	Straight Graze	✓	✗	✗	✗	✗	unknown
	Elongated Graze	✓	✗	✗	✗	✗	unknown
	Compression Curling	✓	✗	✗	✗	✗	unknown
	Rippling	✓	✗	✗	✗	✗	unknown
	Fissure	✓	✗	✗	✗	✗	unknown

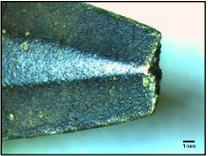
	Fracture	✓	✗	✗	✗	✗	unknown
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Table 5

**Hermann et al. tables**

Table 1

Sample	SW1	SW2	SW3	SW4	Sheet metal		
					As-cast	Annealed	Cold-worked
<b>mean HV</b>	<b>153</b>	<b>142</b>	<b>165</b>	<b>180</b>	<b>139</b>	<b>137</b>	<b>164</b>
<b>s.d.</b>	<b>20</b>	<b>10</b>	<b>27</b>	<b>42</b>	<b>8</b>	<b>9</b>	<b>7</b>
Point 1	160	147	193	198			
Point 2	138	130	177	180			
Point 3	140	135	129	185			
Point 4	185	141	145	122			
Point 5	142	155	180	217			

Table 2

<b>Strikes</b>	
Leg strike	The attacker swings the weapon with its tip facing downwards in a low-angled arc to strike the other weapon near the defender's legs, in the region of the knee area. The attack is parried with the defending sword pointing downwards at an angle.
Hip strike	The attacker swings the weapon horizontally in an arc to strike the defender's weapon near the hip. The defending sword is held almost vertically pointing upwards in front of the hip. To counter the height of the blow the defender has to crouch slightly.
Shoulder strike	The attacker swings the weapon in a diagonal arc from above to strike the defender's weapon near the shoulder or neck. The defender holds the weapon diagonally in front of the body, slightly raised towards the shoulder, with the tip pointing upwards towards the shoulder opposite the sword hand, to cover the upper body.
Head strike	An overhead strike, coming straight down onto the defender's weapon in the head area. The defending sword is held horizontally above the defender's head.
<b>Parries</b>	
Static edge parry	The defending weapon is held in place to block the attacker's strike with the cutting edge.
Static flat parry	The defending weapon is held in place to block the attacker's strike with the flat of the blade.
Kinetic edge parry	The defending weapon is moving away from the defender's body, forcefully meeting the incoming strike with the cutting edge.
Kinetic flat parry	The defending weapon is moving away from the defender's body, forcefully meeting the incoming strike with the flat of the blade.
Dynamic edge parry	A kinetic parry carried out with so much force and momentum that it catches the attacking blade on the cutting edge and knocks it off its course. This parry may be best described as a weapon attack met by another weapon attack.
Dynamic flat parry	As per above but the parry is executed with the flat of the blade.

Table 3

<b>Plays</b>	
Play 1	The first play with the buckler from the Oberhaw (over strike / strike from above). Mark when you drive the Oberhaw to the man: with the pommel go inwards, your sword close to the buckler and your thumb, and thrust in from beneath to his face. Wind against his sword and then go with a snap over and around.
Play 2	From the Underhaw (under strike / strike from below), when he strikes from above. Wind against him to your left side, [with his sword] against your shield. Thus you stand in two shields. So wind to the right side opening and strike in at the mouth. See if he deals with this by raising his shield, and if so then take the left leg. This works on both sides.
Play 3	From the buckler, from the Wechelhaw (changing strike), sweep from the left side. From your buckler sweep clearly above with your sword then cut into his head from the left side; wind [to the] opening and thrust into his mouth. If he lifts with the shield and with the sword and defends against this then cut with the long edge in at his right leg. This works on both sides.
Play 4	From the Mittelhaw (middle strike) make the Twer (cross strike) to both sides and the Schaitlär (skull strike) with the long edge, then make a thrust in underneath.
Play 5	From the Sturtzhaw (plunging strike) make as if to go to [his] left side over his shield with a thrust then with the point change under and thrust swiftly inside his shield. Wind immediately to your left side and if he defends against this then take his right leg with your long edge.
<b>Strikes</b>	
Oberhaw (over strike)	The attacker delivers a downwards strike to the opponent's head, shoulder, arm or hip from a raised position, e.g. from over the attacker's own shoulder or head.
Underhaw (under strike)	The opposite of an Oberhaw. This time, the attacker strikes in an upward motion from a low position, e.g. from the attacker's own hip.
Mittelhaw (middle strike)	Unlike the Oberhaw (striking from above) and the Underhaw (striking upwards), the Mittelhaw is a left-to-right horizontal or slightly diagonal side cut.
Wechelhaw (changing strike)	When the attacker's initial strike is parried/deflected, they suddenly change into a different cut directed against another unprotected area of the target.
Twer (cross strike)	The attacker strikes twice horizontally, once from each side. A Twer can also be used to displace downwards blows coming from above; this is then immediately followed by a counter-attack on the other side (Wechelhaw)
Schaitlär (skull strike)	The attacker executes a short, quick blow directly at the opponent's skull. This can be directed horizontally to strike the forehead or vertically to strike the crown of the head.
Sturtzhaw (plunging strike)	The attacker strikes at the opponent from a high position but with the back cutting edge; this results in the tip of the sword pointing at the target's face.
Versetzen (displacement)	Displacing and controlling of the opponent's weapon by deliberately searching contact between the two blades. Verstezen is often combined with twisting one's own weapon in order to set oneself up for the next attack while maintaining blade contact.

Table 4

Britain		
Museum	Chronological phase	Number of swords analysed
British Museum	Penard (c. 1275-1140 BC)	1
	Wilburton (c. 1150-950 BC)	2
	Ewart Park (c. 950-800 BC)	11
	Llyn Fawr (c. 800-600 BC)	6
Museum of London	Penard (c. 1275-1140 BC)	4
	Wilburton (c. 1150-950 BC)	8
	Ewart Park (c. 950-800 BC)	10
	Llyn Fawr (c. 800-600 BC)	3
Great North Museum: Hancock	Ewart Park (c. 950-800 BC)	6
	Llyn Fawr (c. 800-600 BC)	2
Yorkshire Museum of Archaeology	Penard (c. 1275-1140 BC)	3
	Wilburton (c. 1150-950 BC)	1
	Ewart Park (c. 950-800 BC)	3
	Llyn Fawr (c. 800-600 BC)	1
	Unknown	1
Alnwick Castle Museum	Ewart Park (c. 950-800 BC)	6
Preston Park Museum	Ewart Park (c. 950-800 BC)	2
Italy		
Soprintendenza Archeologica per il Veneto	Middle Bronze Age (c. 1650-1300 BC)	21
	Recent Bronze Age (c. 1300-1200 BC)	9
Museo Nazionale Preistorico Etnografico Luigi Pigorini	Middle Bronze Age (c. 1650-1300 BC)	2
	Recent Bronze Age (c. 1300-1200 BC)	6
	Final Bronze Age (c. 1200-900 BC)	1
	Early Iron Age (c. 900-725 BC)	1

Table 6

Marks per cluster	Sword ID (number of clusters per sword)
Cluster of 2 marks Total = 254	3 (4); 4 (1); 5 (7); 7 (1); 8 (2); 12 (4); 14 (3); 16 (14); 17 (3); 18 (8); 20 (1); 21 (9); 22 (1); 24 (3); 25 (10); 27 (2); 32 (3); 33 (2); 34 (2); 35 (1); 39 (3); 40 (6); 43 (1); 45 (4); 47 (3); 51 (3); 52 (1); 53 (2); 54 (2); 55 (2); 56 (12); 57 (8); 58 (2); 59 (1); 60 (2); 61 (1); 62 (2); 63 (2); 65 (9); 66 (3); 69 (1); 71 (2); 74 (3); 75 (5); 76 (7); 77 (1); 79 (6); 80 (5); 81 (4); 85 (3); 86 (12); 87 (2); 88 (7); 89 (8); 90 (2); 92 (3); 95 (9); 98 (4); 99 (1); 100 (8); 101 (3); 103 (6); 106 (1); 108 (1)
Cluster of 3 marks Total = 53	3 (1); 4 (1); 12 (4); 14 (1); 16 (10); 18 (3); 25 (1); 32 (1); 40 (4); 45 (2); 51 (3); 56 (2); 60 (1); 61 (1); 65 (2); 67 (1); 74 (2); 75 (1); 76 (1); 79 (4); 80 (1); 85 (2); 86 (3); 95 (1)
Cluster of 4 marks Total = 15	14 (1); 16 (4); 60 (1); 65 (2); 79 (1); 85 (2); 86 (3); 99 (1)
Cluster of 5 marks Total = 3	16 (2); 86 (1)

**Hermann et al. tables**

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